

WATERpak

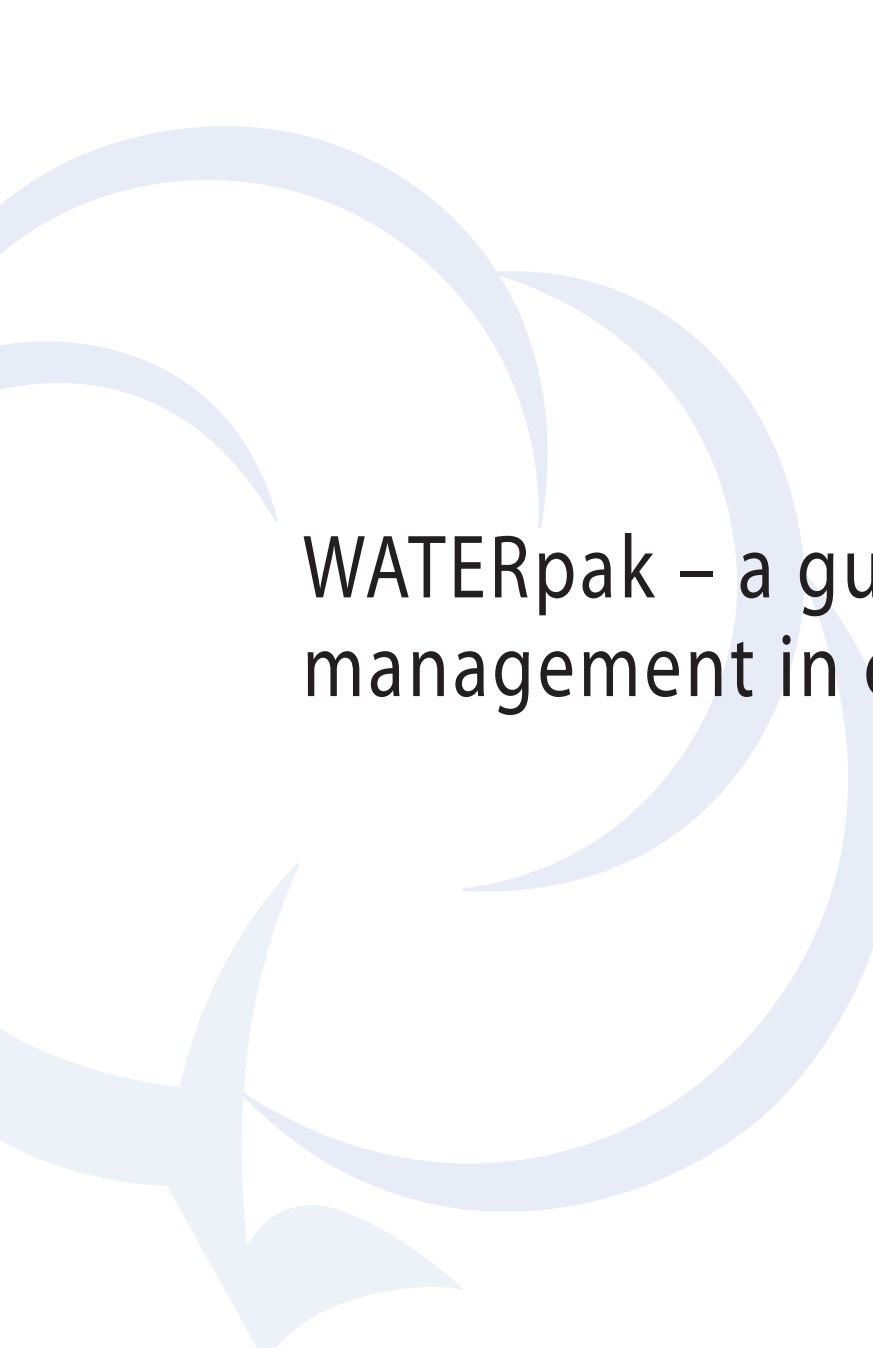
*a guide for
irrigation
management
in cotton*



Australian Cotton
Cooperative Research Centre



Australian Government
Cotton Research and
Development Corporation



WATERpak – a guide for irrigation management in cotton



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Cooperative Research Centre



Australian Government
Cotton Research and
Development Corporation

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Please contact the Cotton Research & Development Corporation with any feedback that can be incorporated in the next edition.

Disclaimer and warnings

The information in this publication is designed as an information source to improve the sustainable use of water on irrigation farms in eastern Australia growing cotton. The information has been prepared from research studies and grower trials with specialist input from researchers, extension staff and irrigators. While these authors provide comprehensive coverage of on-farm water-related issues, they do not purport to address every eventuality that may arise on irrigation farms.

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Foreword

Water resource management today presents as big a challenge as any ever faced by the cotton industry. Further, the challenge is both financial and environmental in nature. Reduced allocations, increased community scrutiny, rising costs and increased international competition all mean that cotton growers will need to continue to improve their water management – efficiently and responsibly.

Australia's cotton growers have a proud tradition of responding positively to challenges. Many times the response has involved a commitment to investing in and implementing the results of research directed at addressing the challenge.

WATERpak is one such response: it challenges cotton growers to improve their water management and, at the same time, provides them with the information to do it.

It is a comprehensive and detailed document that can help maximise production of cotton per megalitre, while at the same time further minimising the environmental impact of cotton growing. WATERpak continues the industry's tradition of timely, practical information based on good research.

The publication of WATERpak demonstrates that the Australian cotton industry is taking its responsibility to manage its water resource seriously. It has been designed to be the technical support for the water components of the cotton industry's Best Management Practice manual.

I recommend that you spend some time referring to, reading, and applying the knowledge within this publication.

James L Moore

Water Sub-committee,

Australian Cotton Growers Research Association



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About this publication

Water is the major limiting factor of cotton production in Australia and efficient water management is paramount for cotton growers to achieve high yields and profits. An unpredictable climate coupled with a range of soil types forces farmers to make management decisions in a complex and variable environment.

The challenge for irrigators is to find the balance between the higher costs of improved water use efficiency and environmental stewardship and the maintenance of farm profits.

WATERpak provides technical information and practical advice to help irrigators improve irrigation practices, minimise environmental impacts and increase farm profits from irrigated cotton crops.

For the first time, WATERpak brings together in one place the many years of irrigation research conducted by a variety of organisations in the Australian cotton industry.

The easiest gains to improve farm water use efficiency are within the field: minimisation of tailwater losses, drainage and the potential improvement in yield through the reduction of waterlogging effects.

Harder to achieve but very significant in terms of water use efficiency, gains exist in the control of evaporative and seepage losses from storages and channels. This is where most water is lost on cotton farms and it is essential that researchers and growers combine forces to address evaporative and drainage losses.

WATERpak and the cotton industry's Best Management Practices Program

The Cotton Industry's Best Management Practices Program prioritises issues for attention, provides a process of identifying the potential management risks and provides an outline on how to manage those risks.

WATERpak provides detailed technical and practical advice that growers maybe looking for when using the BMP Manual. Thus, the order of topics in WATERpak and the new BMP Land and Water module are similar.

This is aimed at minimising the time that cotton growers need to spend looking for information, and maximising the time spent implementing better solutions.

Another companion resource is *SOILpak for cotton growers*, generally referred to simply as SOILpak in this publication.

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Self-assessment checklist for irrigation efficiency

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Assess your enterprise with this self-assessment checklist to identify areas of potential improvement in water use efficiency.

(The questions in *italics* refer to pressurised systems such as drip, lateral or centre pivot: skip these if they are not relevant to your enterprise.)

Tick the relevant box for your enterprise:	Yes	No	Not sure	Relevant WATERpak topic(s)
Soil, and water use efficiency				
Have you mapped where the different soil types are on your farm?	☐	☐	☐	2.5, 2.10
Are soil types underneath channels and storages suitable to minimise seepage?	☐	☐	☐	2.5
Is your irrigation system designed to suit different soil types on your farm?	☐	☐	☐	4.3
Have you examined the active root zone for each of your crops using back hoe pits?	☐	☐	☐	2.10
Do you know the readily available water and soil water deficit for your soils?	☐	☐	☐	2.10
Designing for water use efficiency				
Do you have a current whole farm irrigation plan that optimises irrigation performance?	☐	☐	☐	1.1, 2.5
Do you revise your whole farm irrigation plan on a regular basis?	☐	☐	☐	1.1
Have you had professional help to design your irrigation system?	☐	☐	☐	2.5
Do you know where the main losses are in your irrigation system?	☐	☐	☐	2.1
Can you contain and recycle all normal tailwater and smaller storms on your farm?	☐	☐	☐	2.5
Have you normally got the capacity to store water on farm from unexpected storms?	☐	☐	☐	BMP
Is there a surge area on your farm to help you catch excess water?	☐	☐	☐	BMP

Tick the relevant box for your enterprise:

Yes

No

Not
sure

Relevant
WATERpak topic(s)

Can you release excess water out of the system through blowouts, to avoid excessive crop damage? (Blowouts are designed in large surface irrigation systems to get storm-generated flows away without damage.)

☐
☐
☐

BMP

Does your furrow irrigation take less than 10 hours for a change during a normal irrigation?

☐
☐
☐

2.3,2.4,2.9

Is the duration of the irrigation changes in all your fields about the same (7 to 10 hours)?

☐
☐
☐

2.9

Have your irrigation works been professionally installed and commissioned?

☐
☐
☐

4.3, 4.6

Ongoing systems maintenance

Do you laser level all of your fields regularly?

☐
☐
☐

4.2

Do you know if your pumps operate at their optimum level?

☐
☐
☐

9.3, 9.4

Do you regularly check sprinkler heads for wear, and drip lines for blockages?

☐
☐
☐

4.3, 4.6

Do you regularly check the differential pressure across any filtration systems?

☐
☐
☐

4.6

Do you regularly check your system's distribution uniformity?

☐
☐
☐

4.3, 4.6

Do you regularly check your system's operating pressures?

☐
☐
☐

4.3, 4.6

Do you regularly check and record your system's flow rates?

☐
☐
☐

2.2

Do you undertake seasonal and preventative maintenance to prevent algae, silt or mineral build-up in mainlines, submains and laterals?

☐
☐
☐

4.6

Water use efficient irrigation management

Have you got a long-term plan to improve your water use efficiency on farm?

☐
☐
☐

BMP Land & Water

Do you undertake a seasonal water balance or budgets with regular updates during the season?

☐
☐
☐

2.10

Do you know how much water is required by your crops for each irrigation event?

☐
☐
☐

2.10, 3.1

Are you confident that you are timing the last irrigation of the season accurately?

☐
☐
☐

2.10, 3.1

Do you have a stormwater management plan in place which includes specific roles for each of the relevant people on the farm?

☐
☐
☐

BMP Land & Water



Tick the relevant box for your enterprise:

Yes

No

Not
sure

Relevant
WATERpak topic(s)

Applying irrigations efficiently

Do you schedule irrigations to account for different crop needs/soil characteristics?	☐	☐	☐	2.10
Do you know your readily available water or soil moisture deficit for each of your soils?	☐	☐	☐	2.10
Do you monitor, record and interpret soil moisture levels at various depths for each crop?	☐	☐	☐	2.10
Do you schedule your irrigations with weather forecasts in mind?	☐	☐	☐	2.10
Do your irrigation staff understand how to irrigate efficiently?	☐	☐	☐	2.9, 4.2
Is the length of water applications (changes) to avoid tailwater or excessive deep drainage?	☐	☐	☐	4.2
Do you irrigate to get water on and off the field as quickly as possible?	☐	☐	☐	4.2
Are crops irrigated with minimum amounts of water required plus a leaching fraction?	☐	☐	☐	2.10
Do you irrigate your crops with the minimum amount of water required?	☐	☐	☐	2.10
<i>Is your system automated?</i>	☐	☐	☐	4.3, 4.6

Monitoring your water use

Do you measure how much water you are pumping (including storm and recycled water)?	☐	☐	☐	2.8
Do you keep track of the volume of water you have in storage?	☐	☐	☐	2.7, 2.8
Do you monitor farm storages for inflows, outflows, evaporative and seepage losses?	☐	☐	☐	2.7, 2.8
Do you know how much water your crops used during and at the end of season?	☐	☐	☐	2.10, 2.11, 2.12
Do you irrigate to avoid deep drainage (water lost beneath the active rootzone)?	☐	☐	☐	2.3, 2.4, 2.10
Are your water meters regularly checked and calibrated?	☐	☐	☐	2.8
Do you know how much water you apply to the individual fields during an irrigation?	☐	☐	☐	2.2, 2.9, 2.10
Is the water quality on your farm good enough to ensure long-term sustainability?	☐	☐	☐	5.4, 6.1
Do you know if your groundwater levels are rising or falling?	☐	☐	☐	2.3, 2.4

Tick the relevant box for your enterprise:

Yes

No

Not
sure

Relevant
WATERpak topic(s)

Evaluating the efficiency of your operation

Do you know how many bales of cotton you produce per megalitre of water applied?	☐	☐	☐	2.1,2.2
Do you know the water use efficiency of your other crops?	☐	☐	☐	2.1,2.2
Do you calculate the \$ returned per megalitre applied for your different crops?	☐	☐	☐	2.1,2.2
Do you undertake evaluation of in-field irrigation performance?	☐	☐	☐	2.9
Have you estimated or actually measured your total irrigation system efficiency?	☐	☐	☐	2.2
Do you know how the irrigation performance of your enterprise compares at a local and industry level?	☐	☐	☐	2.2

If you can tick 'yes' for all of these key checks for your enterprise, you are very efficient with your water use.

If you have indicated 'no' or 'not sure' for some questions, then these could be an area for improvement.

Contact your Cotton Industry Development Officer or state Irrigation Extension Staff for advice on being an efficient irrigator.

By aiming to achieve all of these key checks, your ability to save irrigation water is increased.



Section 1

Assessing the farm's resources

1.1 Farm planning for irrigated cotton production

1



1.1 Farm planning for irrigated cotton production

Allan Williams
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Introduction

Planning simply means thinking ahead, which is vital to the success of any farming operation. Planning helps you identify issues and potential challenges facing your business, allowing early intervention.

Good farm planning requires an understanding of the farm's resources, especially its soils, water and infrastructure. The initial planning step involves assessing and recording those resources. Once this has been done, you can then assess what risks or management issues are associated with irrigating the specific soil types using the existing infrastructure on your farm. You can then develop appropriate plans for how you carry out your irrigation operations as efficiently and responsibly as possible.

The Land and Water Management module of the *Best Management Practices Manual* will assist in this process by helping you identify potential risks that may be associated with a particular activity, and then providing suggested solutions to managing those risks. If the Land and Water Management module does not contain sufficient information, then consult the WATERpak and SOILpak.

For an irrigated cotton farm, the issues and challenges are likely to centre on how efficiently irrigation water is used, and the potential for off-site environmental impact. Both these issues are the focus of the planning processes currently in place for irrigated agriculture in New South Wales (Irrigation and Drainage Management Plans {IDMPs}) and being introduced in Queensland (Land and Water Management Plans {LWMPs}).

The new Land and Water module of the BMP Manual is being developed in light of the IDMP and LWMP requirements, and will cover all the issues highlighted in those planning processes. Anyone completing the BMP Manual process will satisfy the majority of the IDMP or LWMP requirements, without doubling-up their efforts.

Why plan?

Knowledge and understanding of many factors and processes are required to address on-farm water losses in the areas of seepage, evaporation, deep drainage and run-off. Good planning is essential to ensure that the wide range of potential issues and factors affecting an irrigated cotton

farm are taken into account. Many improvements in water use efficiency may be easily gained through simple changes to irrigation management practices which are independent of either extensive farm redevelopment or changes to systems of higher water use efficiency. Indeed, experience to date has shown that the installation of new and efficient irrigation systems technology is not the only answer to improving irrigation systems.

The easiest improvements in whole farm water use efficiency often come from minimising deep drainage and tailwater losses, and this can also improve yield by reducing waterlogging. These gains may only require a simple change in the management of irrigation water onto the crop, for example, by reducing the time water is run. Significant gains may also be able to be made in the control of evaporative and seepage losses from storages and channels.

A good plan should not only allow you to maximise water use efficiency and return per megalitre: it should mean that you achieve the standard of environmental management expected by both the industry and the community.



Section 2

Efficient Irrigation

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Storage and distribution efficiency

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2.7	Managing evaporation and seepage in storages and channels	61
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Application efficiency and irrigation scheduling

2.9	Assessing field-scale water use efficiency	79
2.10	Irrigation scheduling of cotton	89
2.11	Calibrating soil water monitoring devices	101
2.12	Evapotranspiration	107
2.13	Using automatic weather stations	113



2.1 Assessing whole farm water use efficiency

David Wigginton

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Sunil Tennakoon and James Neilsen

Cotton CRC, CSIRO, Narrabri

Key points

- Water use efficiency describes a relationship between system inputs and outputs.
- Relating production outputs (such as \$ or bales) to water input (ML) results in a water use index (WUI).
- Relating water output (ML) to water input (ML) results in a dimensionless (%) irrigation system efficiency.

It is important to understand the inputs and dimensions of indices and efficiency terms as well as the scale at which they are applied.

The key water use indices are:

Crop water use index (kg/ha/mm) =

$$\frac{\text{lint yield (kg/ha)}}{\text{seasonal evapotranspiration (mm)}}$$

Gross production water use index (b/ML) =

$$\frac{\text{total yield (bales)}}{\text{total water (ML)}}$$

Irrigation water use index (b/ML) =

$$\frac{\text{total yield (bales)}}{\text{irrigation water (ML)}}$$

The key irrigation efficiency terms are:

Application efficiency (%) =

$$\frac{\text{irrigation water available to crop}}{\text{water received at field inlet}}$$

Field canal/conduit efficiency (%) =

$$\frac{\text{water received at field inlet}}{\text{water received at the inlet to a block of fields (farm)}}$$

Farm efficiency (%) =

$$\frac{\text{irrigation water available to crop}}{\text{water received at a block of fields (farm)}}$$

Background

Water use efficiency (WUE) is a concept that has historically caused much confusion for scientists, water suppliers and end users alike. Much of this confusion has stemmed from the range of terms available to describe water use efficiency and a lack of understanding of what WUE represents. A framework has been developed (Barrett, Purcell and Associates 1999) to describe water use efficiency and standardise the array of terms and definitions used. The concepts and definitions employed in WATERpak reflect this framework.

Water use efficiency is itself a generic label for an array of performance indicators used to describe water use within a cropping system. These indicators, particularly in combination, reveal the water use efficiency of a system or system component.

The indicators used vary according to the intended measurement and have varying inputs, outputs and boundary conditions. Both spatial (area) and temporal (time) boundaries need to be specified. Area boundaries might include a field, farm or region, whilst time boundaries could be a single irrigation event, a month, the growing season or a year.

Due to the complexity of the system it is not practical to calculate all the water use efficiency indicators, nor is it necessary, as a meaningful picture of water use efficiency is obtained through calculation of the most pertinent indicators.

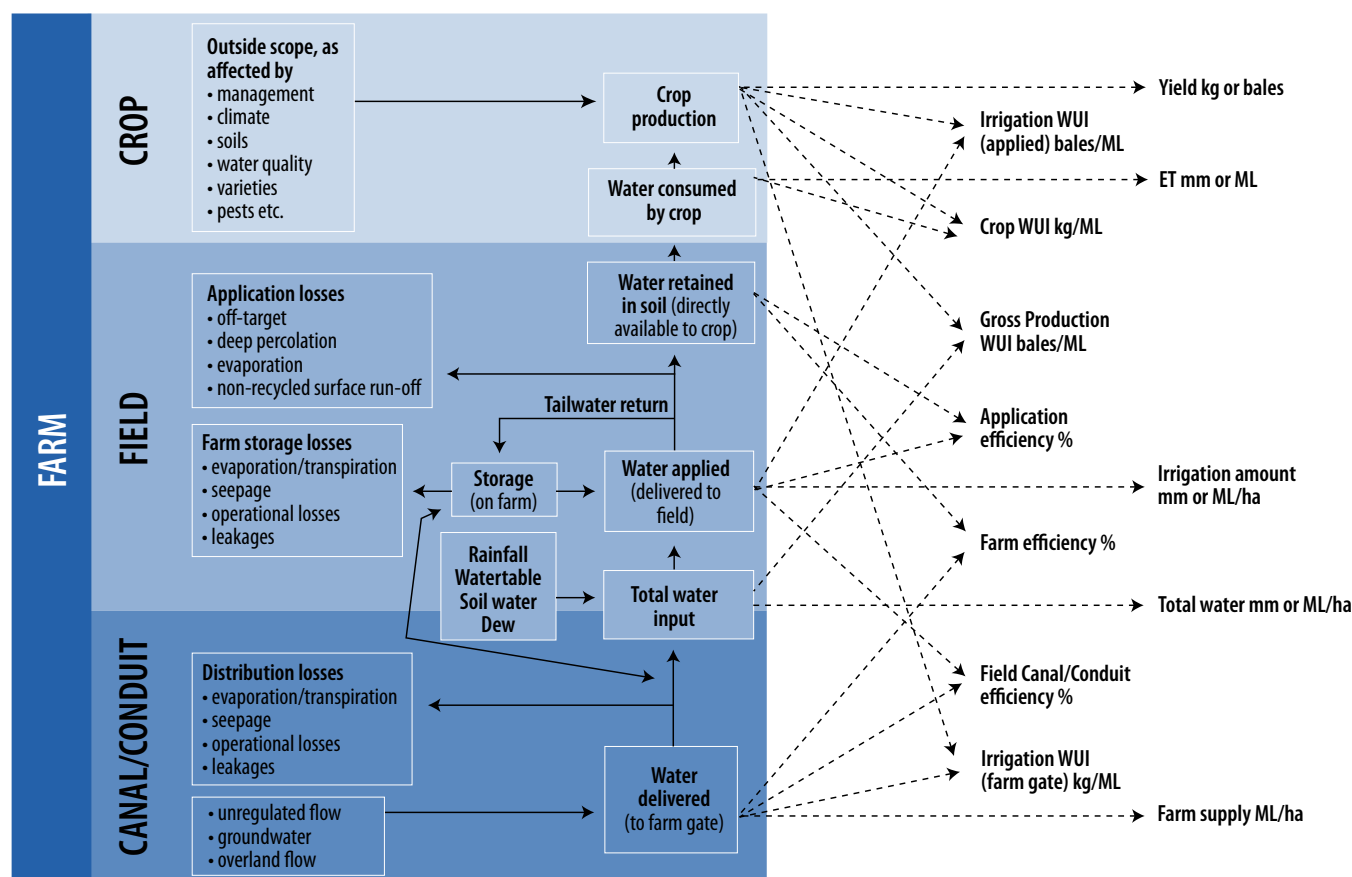
The concept of water use efficiency encompasses both water use indices (WUI) and irrigation system efficiencies. The difference between an index and an efficiency is as follows.

- **Water use indices** typically compare a production output (yield, return, gross margin) to a water input (such as irrigation water, total water, or evapotranspiration) at some level in the farm or production system. As such, they have defined units: kg/mm, bales/ML, \$/ML. Water use indices must be explicitly defined in terms of both the inputs used and the measurement units, but they are flexible and can be tailor-made to suit a particular use.

- **Irrigation system efficiencies** compare a water output to a water input at different points of the farm or irrigation system. Hence, efficiencies have the same units for both input and output, and are described as 'dimensionless' and expressed as a percentage.

The relationship between these indicators at different scales within an entire irrigation system is illustrated fully in the framework included at the end of this topic. A modified version, illustrating some of the most useful indicators within the farm scale, is illustrated in Figure 2.1.1.

Figure 2.1.1 Framework for on-farm water use efficiency



Source: modified from: Barrett, Purcell and Associates, 1999

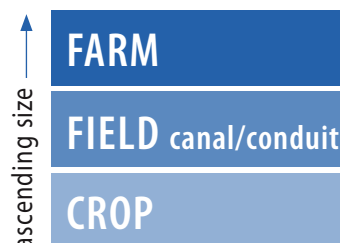
A note on spatial scales:

As previously discussed and as indicated in Figure 2.1.1, indices and efficiencies can be calculated over a range of spatial boundary conditions (scales). This concept is important for calculation of WUE indicators:

Indices: Indices are differentiated by the scale at which they are applied. For example, irrigation water use index (applied) and irrigation water use index (farm gate) both compare yield and irrigation water input, but are applied at different scales, the field and the farm respectively. Therefore, it is important to understand at which scale the inputs have been measured.

Efficiencies: As will be discussed later, efficiency terms at different spatial scales are all related, so that they may be multiplied together to gain an efficiency at the next greatest scale. This concept is termed a 'nested' approach.

The order of spatial scales is as follows:



Water use indices

Water use indices are generally defined in terms of the production output per unit of water input.

- Production can be defined in terms of lint yield (kg), total yield (bales), gross return (\$), gross margin (\$) or any other appropriate measure.
- Water inputs are usually defined in terms of actual water use (mm), irrigation water input (ML) or total water input (ML). Such water inputs across a whole farm can include water pumped from rivers and bores; the amount used from storage reservoirs; water harvested during the season; effective rainfall and soil moisture reserves depleted during the season.

Rainfall effectiveness

Rainfall is considered effective if it contributes to the water requirements of the crop. Effective rainfall includes:

- water intercepted by vegetation
- soil evaporation losses
- evapotranspiration losses
- a contribution to leaching requirement.

Ineffective rainfall includes:

- surface run-off
- deep drainage
- any remaining soil moisture that is not used for subsequent crops.

Calculating effective rainfall is very difficult, as it is affected by many variables such as rainfall intensity and initial soil moisture. (Rain falling on a full soil profile has little effectiveness.)

In the simplest of terms, accounting for the major losses, effective rainfall is approximated by:

Effective rainfall =

total rainfall – run-off – deep drainage

(This definition is only an approximation and does not account for the additional variables listed.)

Effective rainfall can be estimated using:

- HydroLOGIC (see Topic 3.5). This model accounts only for losses due to run-off.
- The change in soil moisture due to rainfall. This method relies on the accuracy of the measurement equipment (most soil moisture probes give only approximate values) and does not indicate the volume of water lost through the profile.
- A guess of the effective proportion: it is usually taken that 75% of the rainfall for the season is effective.

It is important to note that all of these methods include some substantial assumptions, particularly the soil moisture measurement and 75% methods.

As discussed previously, many water use indices can be applied at different spatial scales within the farming system. This concept is very useful, as it allows for comparison of production and water use at very specific locations (crop scale) and within individual management units (field scale), or for assessing the performance of the whole farm. By calculating WUIs at these different scales, appropriate management options can be formulated to try to improve the effectiveness of water use.

Crop water use index

Crop water use index (CWUI) is an indicator that describes plant–water interactions at the crop scale and is represented as the lint yield (kg) produced per millimetre of water evapotranspired from a cotton field during the growing season.

(Calculating evapotranspiration is explained in Topic 2.12.)

In essence, CWUI represents the ability of the plant to produce lint (rather than vegetative growth) for the given water use. This indicator is influenced by many factors such as nutrition, pests, disease, and climate.

In addition, the management of irrigation applications can affect the amount of energy that is being expended into crop reproduction, thus influencing CWUI (see Topic 3.2 ‘Managing irrigated cotton agronomy’ for crop response to irrigation).

CWUI can also be expressed in bales per megalitre.

$$\text{CWUI (kg/ha/mm)} = \frac{\text{lint yield (kg/ha)}}{\text{seasonal evapotranspiration (mm)}}$$

For example: A cotton field with 2000 kg/ha of lint yield and 750 mm of seasonal evapotranspiration:

$$\text{CWUI} = (2000 \div 750) = 2.67 \text{ kg/ha/mm}$$

This figure can be converted into bales per megalitre by dividing by 227 (kg ÷ bale) and multiplying by 100 (mm ÷ ML):

$$\text{CWUI} = (2.67 \div 227) \times 100 = 1.17 \text{ bales/ML}$$

Gross production water use index

Gross production water use index (GPWUI) is the gross amount of lint produced per unit volume of total water input. The total water input includes irrigation, rainfall and total soil moisture used where the rainfall component can comprise either total rainfall or effective rainfall.

It is suggested that the effective rainfall term is both more typical and more useful, but the type of rainfall component used must be specified.

The use of total or effective rainfall in this measure is discussed further in Topic 2.9. The gross production water use index can be applied to multiple spatial scales, typically to the field or farm.

Field scale:

$$\text{Gross production water use index (applied) (b/ML)} = \frac{\text{total yield (bales)}}{\text{total water applied (ML)}}$$

Farm scale:

$$\text{Gross production water use index (farm) (b/ML)} = \frac{\text{total yield (bales)}}{\text{total water used on farm (ML)}}$$

Case study: GPWUI

A cotton field has a yield of 80 bales, and used 100 ML of total water (irrigation, effective rainfall and used soil moisture).

$$\text{Gross production water use index (effective) (applied)} = (80 \div 100) = 0.8 \text{ bales per megalitre}$$

Across the whole farm, 450 bales were produced, using 490 ML of total water (irrigation, effective rainfall and used soil moisture).

$$\text{Net production water use index (effective) (farm)} = (450 \div 490) = 0.92 \text{ bales per megalitre}$$

Therefore, this field was unable to produce as much yield as the whole farm average for each ML of total water input. (Note that the use of effective rainfall has been made explicit.)

Irrigation water use index

Irrigation water use index (IWUI) is similar to the gross production water use index discussed above, except that it relates production only to the amount of irrigation water used, rather than to the total water inputs. Again, the IWUI can be applied to either the field or the farm scale.

Field scale:

$$\text{Irrigation water use index (applied) (\%)} = \frac{\text{total yield (bales)}}{\text{irrigation water applied (ML)}}$$

Farm scale:

$$\text{Irrigation water use index (farm) (\%)} = \frac{\text{total yield (bales)}}{\text{irrigation water supplied to farm gate (ML)}}$$

Case study (cont.): IWUI

Using the same case study: the amount of irrigation water applied to the field during a season was 50 ML, whilst the yield from this field was 80 bales. Hence the irrigation water use index is:

$$\text{IWUI (applied)} = (80 \div 50) = 1.6 \text{ bales per megalitre}$$

Across the whole farm, 450 bales of cotton were produced using 350 ML of irrigation water.

$$\text{IWUI (farm)} = 450 \div 350 = 1.3 \text{ bales per megalitre}$$



This would indicate that this particular field was able to produce more lint per ML of irrigation water: this may be due to irrigation and rainfall timing, disease, pests, nutrition, and other factors.

The GPWUI calculations above indicated that the field yielded less than the rest of the farm using the total water inputs. In this particular case, this is because the field ran short of irrigation water. The yield this field produced had less irrigation water input compared with the total water input than the whole farm average.

Take care when using water use indices for comparison purposes, particularly when comparing across regions or seasons. The irrigation water use index will be influenced by other water inputs (such as rainfall) as the irrigation component is increased or decreased. Therefore, both IWUI and GWUI should be used for comparisons. In this way, the total water input is accounted for, and variations in IWUI can indicate differences in irrigation system performance or management.

Economic indices

Economic indices can be calculated by applying an economic production measure to any of the indices described above. This measure could be gross return, gross margin, marginal return, or any other appropriate economic measure. The economic calculation is typically achieved by multiplying the economic measure and the appropriate WUI to achieve a \$/ML result.

Case study (cont.): GPWUI

Previously we calculated a gross production water use index (effective) (applied) of 0.8 bales/ML. If the cotton price is \$500 per bale, we can calculate a gross return per megalitre of total water applied.

Gross production economic water use index (effective) (applied) = $(0.8 \times 500) = \$400$ per megalitre

Other indices

Other indices can be constructed as required, provided the inputs and dimensions are specified. For example:

Marginal irrigation water use index (applied) (b/ML) =
$$\frac{\text{marginal production due to irrigation (bales)}}{\text{irrigation water applied (ML)}}$$

Crop economic water use index (\$/mm) =
$$\frac{\text{gross production (\$)}}{\text{evapotranspiration (mm)}}$$

Irrigation system efficiency

Calculating irrigation system efficiencies allows a purely volumetric analysis of a particular system or part of a system. In essence, an irrigation efficiency represents the proportion of water that is available from an irrigation system component compared with the total water supplied to that component. An example would be the proportion of water that is extracted from a head ditch compared with the proportion of water that is delivered to that head ditch at the pump or scheme inlet.

Three main efficiency terms are used widely in the irrigation industry and are applicable within the farming system:

Application efficiency (E_a)

Field canal/conduit efficiency (E_b)

Farm efficiency (E_f)

Note: The use of both 'canal' and 'conduit' indicates that this efficiency term is used for any type of distribution system (that is, it is equally applicable to channels and pipes).

Application efficiency (E_a)

Application efficiency relates the amount of water supplied to the amount of water available to the crop.

It is calculated using the formula:

$$E_a = \frac{\text{irrigation water directly available to the crop for use}}{\text{water received at field inlet}}$$

Calculation of application efficiency is particularly useful as it can indicate the potential for water savings within the field and the associated production benefits. Application efficiency is discussed further in Topic 2.9.

Field canal/conduit efficiency (E_b)

The field canal/conduit efficiency effectively covers the on-farm distribution system. The terminology 'distribution efficiency' is not used because it is typically reserved to describe the efficiency of the whole distribution system, from the headworks to the field (that is, it includes scheme, natural and on-farm distribution systems).

Field canal/conduit efficiency relates the water received at the field inlet to the water received at the farm gate; hence, it is usually able to account for the efficiency of on-farm storages.

$$E_b = \frac{\text{water received at field inlet}}{\text{water received at the inlet to a block of fields (farm)}}$$

Calculating the efficiency of the individual components of field canal/conduit efficiency (such as storages and channels) is discussed further in Topic 2.6.

Farm efficiency (E_f)

The use of the application efficiency (E_a) and field canal/conduit efficiency (E_b) terms allows a 'nested' approach for calculation of the farm efficiency (E_f). In other words, the farm efficiency is the product of the other efficiency terms:

$$E_f = E_a \times E_b$$

$$E_f = \frac{\text{irrigation water available to crop}}{\text{water received at field inlet}} \times \frac{\text{water received at field inlet}}{\text{water received at a block of fields (farm)}}$$

So:

$$E_f = \frac{\text{irrigation water available to crop}}{\text{water received at a block of fields (farm)}}$$

Calculating farm efficiency is useful for determining the potential for water savings, but it is not possible to establish where these savings can be made. Determining efficiency at the field scale is more useful for assessing the potential management or infrastructure changes that should be made. The nested approach for calculating efficiencies also means that once any two of the efficiency terms (E_a, E_b or E_f) are known, the other can be deduced.

It is vital to remember when calculating whole farm efficiency that tailwater recycling must be accounted for. Tailwater recycling effectively improves field application efficiency, and therefore the volumetric efficiency of the tailwater return system should be included when calculating field application efficiencies. This is discussed in Topic 2.9.

Other efficiency terms

The terms discussed above allow for the calculation of the efficiency of irrigation water use at any scale within a system, and should be the only efficiency terms required solely for irrigation water use.

There can be a need for alternative efficiency terms when additional water inputs need to be accounted for. One example is an efficiency term that accounts for rainfall inputs. For example, at the field scale:

$$\text{total water application efficiency} = \frac{\text{irrigation water available to crop}}{\text{total water applied (irrigation + rain)}}$$

(The rainfall term may be **total** or **effective** rain as discussed earlier in this topic.)



Note that these terms still follow the same structure as the main efficiency terms outlined.

When using non-standard terms such as these, it is vital to clearly define the name of the measure and the inputs required. Remember too that the result must be dimensionless (that is, it is a percentage: ML/ML or mm/mm).

Estimating farm irrigation efficiency

We can estimate the farm irrigation efficiency through the process of water accounting. Water accounting is a process of tracking irrigation water and estimating the proportion of this water that is actually used by the crop across the entire farm. The result gives a benchmark of farm management, indicates the performance of water, and identifies the potential for water savings and maximisation of economic returns. This process accounts for rainfall and evaporative demand and results in an estimation of the farm irrigation efficiency, which can be used to compare between properties, regions or seasons.

The reason we need to **estimate** the farm irrigation efficiency is that calculating an irrigation system efficiency at the farm scale can be very difficult. Let's revisit the formula for farm efficiency:

$$E_f = \frac{\text{irrigation water available to crop}}{\text{water received at a block of fields (farm)}}$$

The difficulty arises in determining the irrigation water available to the crop at the farm scale. At the field scale, as discussed in Topic 2.9 'Assessing field-scale water use efficiency', the irrigation water

available to the crop is typically equal to the soil deficit prior to irrigation. This means that, once the deficit is filled, additional irrigation water input is generally lost as run-off or drainage through the root zone. Applying this approach at the farm scale requires recording and summing the deficits for each irrigation on every field across the farm, an obvious impracticality.

Alternatively, the farm efficiency can be estimated using the proportion of irrigation water actually used by the crop (ET, see Topic 2.12) relative to the total irrigation water inputs at farm level over the same period, usually a season. One of the reasons that this method is only an estimate of farm efficiency is because a purely volumetric efficiency accounts for irrigation water available to the crop rather than the amount of irrigation water actually used by the crop, which is influenced by many other factors such as disease, variety, and pests.

Working out the proportion of irrigation water used by the crop involves starting with the crop's total water use (ET), subtracting the effective rainfall (RE), and accounting for the difference between the soil moisture at planting and the soil moisture at harvest (ΔSM). In this way, we have subtracted that water which was not supplied by irrigation from the crop's total water use.

irrigation water available to crop =

$$ET - RE - \Delta SM$$

Working out the amount of irrigation water supplied is somewhat easier and involves accounting for water from all sources:

- river
- bore
- scheme
- on-farm harvesting (not recycling)
- stored water used (ΔSW).

water received at a block or fields (farm) =

$$\text{river} + \text{bore} + \text{scheme} + \text{harvested} + \Delta SW$$

Practical problems may arise in estimating the volume of any of the water brought onto the farm, particularly river, bore and harvested water that is not metered. It may be possible to estimate these volumes by measuring the water level in the on-farm storage before and after pumping.

Subsequently, the estimate of farm efficiency (E_f) is:

$$E_f = \frac{ET - RE - \Delta SM}{\text{river} + \text{bore} + \text{scheme} + \text{harvested} + \Delta SW}$$

Table 2.1.1 illustrates the water account for an irrigated farm over two seasons. The water inputs from different sources, crop water use and some important water use indices are presented in the example.

Table 2.1.1 Water account for an irrigated farm over 2 seasons

Season	1996/97	1997/98
Production details		
Area grown (ha)	3064	3173
Total production (bales)	19234	25495
Average yield (bales/ha)	6.3	8
Water supply		
Total water pumped (bore)	0	1445
Total water pumped (river)	7447	12100
Total water pumped (ML)	7447	13545
On farm storage at planting (ML)	6250	6500
On farm storage at harvesting (ML)	3975	4473
Used from farm storage (ML)	2275	2027
On farm harvested (ML)	3710	1402
Water used on other crops (ML)	2300	2800
Total irrigation applied on cotton (ML) = total pumped + used storage + harvested – other crops	11132	14174
Rainfall		
In season rainfall (mm)	518	459
Run-off (mm)	171	159
Effective rainfall estimate (mm) = (rainfall – run-off)	347	300
Estimated effective rainfall for farm (ML) = (Effective rainfall (mm) ÷ 100) × area (ha)	10632	9519
Rainfall efficiency (%) = effective rainfall ÷ total rainfall	67	65
Soil water		
Used soil reserve (mm) average of all fields (soil moisture at sowing – soil moisture at harvest)	119	133
Used soil reserve ML = (Used soil reserve (mm) ÷ 100) × area (ha)	3646	4220
Total seasonal water usage (ML) = total irrigation + effective rainfall + harvested water + used soil reserve	25410	27913
Water use summary		
ML/ha pumped	2.42	4.03
ML/ha effective rainfall	3.47	3
ML/ha harvested	1.21	0.44
ML/ha used soil reserve	1.19	1.33
ML/ha total water usage	8.3	8.79
Total seasonal crop water use (ET) mm	690	772



Water use indices

Crop water use index (kg/mm/ha)	2.06	2.36
Crop water use index (bales/ML) = yield ÷ ET	0.91	1.04
Production WUI (farm) (bales/ML) = yield ÷ total water (with effective rain)	0.76	0.91
Irrigation WUI (farm) (bales/ML) = yield ÷ irrigation water	1.73	1.8

Farm irrigation efficiency

Irrigation water used in ET (mm) = ET – effective rainfall – Δsoil moisture	226	343
Irrigation water used in ET (ML) = (mm) × area (ha) ÷ 100	6924	10883
Whole farm irrigation efficiency (%) = irrigation water used in ET ÷ total irrigation water	62	77

Certain components such as run-off and rainfall efficiency can be estimated by HydroLOGIC (see Topic 3.5).

Software packages for on-farm WUE assessment

A user-friendly software tool has been developed by the Cotton CRC and CSIRO Plant Industry for cotton farmers to assess on-farm water use. The HydroLOGIC irrigation management tool can be used to determine key WUE indices on a field level following harvest (see Topic 3.5).

In the future it is hoped that HydroLOGIC will provide a user-friendly platform for whole farm water accounting and estimation of farm efficiency.

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2.2 Water use efficiency in the Australian cotton industry

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Key points

- The industry average whole farm irrigation efficiency was 59% but all studies have observed a large variability in efficiency between farms.
- The greatest losses identified were likely to be from farm storages, via evaporation losses, and seepage from unlined distribution channels.
- The industry average crop water use index was 2.79 kg/mm/ha.
- Water movement and amounts need to be documented. Producers at the lower end of the ranges have significant scope to increase the efficiency with which they use water.
- Improving whole farm irrigation efficiency by just 1% could produce an additional \$6,500 per hectare per 1000 ML allocation, when the price is at \$500 per bale.

More than 98% of the water absorbed by the roots of any crop, including cotton, is transpired as water vapour during the course of plant growth. Most of this water is lost through stomata, which are specialised pores on leaf surfaces that allow water vapour to exit the leaf while carbon dioxide enters. This exchange process is necessary for photosynthesis and to maintain canopy temperature. Therefore, any measures to reduce water loss through the leaves (reduce transpiration) also reduce photosynthesis and overall crop yields.

It is difficult to provide the exact amount of water required by the crop via irrigation systems due to losses and design limitations. The crop uses only a portion of the water applied from rainfall and irrigation during the growing season. Generally, 50% efficiency is used in designing surface irrigation systems or estimating irrigation water requirements. The proportion of irrigation water actually used by the crop can be maximised by better irrigation management and improved designs. These improvements in efficiency are important to save irrigation water, as well as to protect the environment.

An assessment of water use efficiency should also consider how efficiently a cotton crop

converts water into lint yield. Every millimetre of water used by the crop as evapotranspiration or depleted from the farm should produce yield. Therefore, crop management decisions on aspects such as fertiliser, pest management, variety, tillage, and farming systems can affect water use efficiencies.

WUE assessment studies

The water use efficiency of the Australian cotton industry has been assessed several times in the past 15 years. One of the more comprehensive studies of water use efficiency assessment of irrigated cotton was by Cameron Agriculture and AB Hearn (1997). They collected regional data from Australian Bureau of Statistics (ABS), NSW Department of Land and Water Conservation, and the Department of Natural Resources in Queensland. Farm level and field level data were collected from eleven farms in the Macquarie, Namoi, Gwydir and Macintyre valleys.

In this analysis, the total in-season rainfall was counted as effective and on-farm harvested water was not included in the analysis. This means that, in estimating WUE, only the water input to the farm from irrigation and rainfall, and not the soil moisture reserves used by the crop, were considered.

Tennakoon and Milroy (2003) collected historical water management data at field and farm level from 25 farms in major cotton-growing valleys for the 1996-97, 1997-98 and 1998-99 seasons. Water use efficiency indices were estimated at the farm level for the growing season: between the date of sowing and the date of harvest.

In this analysis, total water input included water pumped from rivers and bores, the amount used from storage, water harvested during the season, rainfall contribution and soil water reserves depleted during the season. Soil water reserves could be from pre-season rainfall, pre-irrigation or moisture stored during the fallow or previous crop. Water used for other crops in the farm was subtracted from the water input to the farm in calculating GPWUI (farm) and IWUI (farm) specifically for cotton. The whole farm irrigation efficiency (WFIE) was calculated as the percentage of irrigation water used in crop evapotranspiration, including soil moisture reserves, relative to the total irrigation water input at the farm level.

The Queensland Rural Water Use Efficiency Initiative (RWUEI) was a state government funded project from 1999 to 2003, operating in five major Queensland irrigation regions, principally St George, Border Rivers, Darling Downs, Dawson/Callide and Emerald/Mackenzie. The key focus of the program was monitoring water use, on-farm storage and distribution, as well as considering application methods and in-field management. Up to twenty-nine demonstration (benchmarking) sites were established each season, with water use efficiency indices calculated.

On-farm irrigation efficiency benchmarking was conducted by Dalton, Raine and Broadfoot (2001) from the National Centre for Engineering in Agriculture (NCEA), University of Southern Queensland, over the 1998–2000 cotton seasons. This research study had an engineering focus and surveyed eight farms within the Queensland-New South Wales Border Rivers catchment.

Indices of WUE collected

A range of water use efficiency indices were calculated in each study:

Gross production water use index
(total water at farm level – pumped + rain)

$$\text{GPWUI (farm) (bales/ML)} = \frac{\text{lint yield}}{\text{total water input}}$$

Irrigation water use index
(farm level – applied water only)

$$\text{IWUI (farm) (bales/ML)} = \frac{\text{lint yield}}{\text{irrigation water input}}$$

Crop water use index

$$\text{CWUI (kg/mm/ha)} = \text{yield} \div \text{ET}$$

where seasonal ET was estimated using neutron probe data and simulated values

Whole farm irrigation efficiency (farm level)

$$\text{WFIE} = \frac{\text{ET} - \text{RE} - \Delta \text{SM}}{\text{Total water pumped from rivers and bores} + \text{harvest water used}}$$

where

ET seasonal ET

RE in-season rainfall contribution

ΔSM change in soil moisture from sowing to harvest

The Australian industry in summary

A summary of water use efficiencies reported from these projects is given in Table 2.2.1. Overall, the on-farm seasonal total water (including rain) input averaged 10.7 ML/ha and there was a large variability between properties (8.5 ML/ha to 17.2 ML/ha). The average applied irrigation water at farm level was 6.8 ML/ha. It is important to note that there have been subtle differences in definitions and methodologies used in estimating water use efficiencies within these projects and the results represent a range of growing seasons from 1998–99 to 2002–03.

At the farm level, Tennakoon and Milroy found GPWUI-farm averaged 0.79 bales per megalitre across the industry, but ranged from 0.38 to 1.27 bales per megalitre (Table 3). When based on irrigation water, IWUI-farm averaged 1.26 bales per megalitre and the range was greater, varying from 0.43 to 3.28 bales per megalitre between farms.



Table 2.2.1 Water use efficiencies, estimated by different projects within the Australian cotton industry over the last 15 years

Project	Seasons	Region	No of farms	Irrigation ML/ha	Total water ML/ha	Seasonal ET mm	Yield kg/ha	IWUI (farm) bales/ML	GPWUI (farm) bales/ML	CWUI kg/mm/ha	WFIE %
Cameron & Hearn	1988–89 to 1994–95	NSW & Qld	11	5.37			6.73	1.48	0.82	3.05	63
CSIRO Plant Industry	1996–97 to 1998–99	NSW & Qld	25	6.96	12.1	735	8.13	1.32	0.79	2.52	57
RWUEI Project	2000–01 to 2002–03	Qld	29	7.51	9.36	721	8.73	1.16	0.93	2.79	58
NCEA	1998–99 to 1999–2000	Qld	7	7.50							
Industry average				6.84	10.73	728	7.86	1.32	0.85	2.79	59

Note: The calculations used in each survey differ slightly, represent only a small number of growers in the industry, and cover 12 years of production. Cameron and Hearn found only three surveyed farms were able to provide information to allow the calculation of CWUI.

Table 2.2.2 Average GPWUI-farm and IWUI-farm, surveyed production areas

Region	GPWUI-farm (bales/ML)	IWUI-farm (bales/ML)
Macquarie Valley	0.93	1.23
Namoi Valley	0.81	1.53
Gwydir Valley	0.47	0.65
Macintyre Valley	0.77	1.36
Darling Downs	0.92	1.71
Emerald	0.81	1.59
Industry average	0.79	1.32

The overall industry whole farm irrigation efficiency (WFIE) average was 59%, but all the studies have observed a large variation between farms. The greater range found in WFIE on a farm basis, compared with CWUI, suggests that this variable has the greatest scope for improvement. Constraints of location, farm design and soil type may prevent some producers from achieving higher WFIE without significant capital investment. However, if very low WFIEs are indicated, there are clearly grounds for further investigation using more detailed measurements.

When examined on the individual irrigation level, as in the NCEA study, the proportion of the whole farm water used by the cotton crop in an individual irrigation event ranged from 21% to 65% (or between 28% to 68% with complete tailwater recycling). The most significant sources of water loss in both cases, that is, no recycling and with

recycling, included evaporation from storages (14% and 39% respectively), and in-field deep drainage (11% and 13% respectively).

It is noteworthy that the benchmark proposed by Cameron and Hearn of 75% is still to be achieved on an industry-wide basis. However, improving the current industry average of 60% to 75% will save a significant amount of irrigation water and provide substantial financial incentives to irrigators. For example, improving WFIE by 15% in a farm with 1000 ML of irrigation water use will save 150 ML of irrigation water. On an average, one ML of irrigation water can produce 1.3 bales. Assuming a price of \$500/bale, the additional income for the farm would be $(150 \times 1.3 \times 500) = \$97,500$.

Measurements made in the NCEA study indicate that the greatest losses reflected in the WFIE component are likely to be from farm storages. Evaporation losses can be as high as 10 millimetres per day, resulting in losses of up to 50% over twelve months. Seepage from unlined distribution channels varies with soil type and has been recorded between 1 and 23 millimetres per day.

Storage and conveyancing losses are likely to be lower for bore supplies, although, if bore capacity is limited, water would be pumped into storages before irrigation and could be lost.

The other important aspect in improving WFIE highlighted by these surveys is application efficiency. The application efficiency of the furrow systems that were benchmarked indicated many systems can be improved by manipulating lengths and slope of furrows with appropriate flow rates and

cut off times (refer to WATERpak Topic 6.3). A three-year study of furrow irrigation systems by NSW Agriculture in the Macquarie Valley found furrow conditions and variable siphons flow rates had considerable impact on the effectiveness of an irrigation event. While field lengths varied from 450 to 1300 m, the time to cut-off ranged from 3.5 to 26.0 hours and the total volume delivered to each furrow ranged from 0.01 to 0.30 ML. Within a single siphon set, flow rates were found to vary from less than 0.5 L/sec to 2.8 L/sec.

Crop water use index (CWUI) within the Australian cotton industry averaged 2.79 kg/mm/ha, which compares favourably with other cotton-producing countries. A summary by Grismer (2002) of recent cotton water use studies around the world found crop water use indices ranging from 1.12 kg/mm/ha in California to 3.87 kg/mm/ha in Argentina. Cameron and Hearn proposed that Australian cotton producers should aim towards 3.0 kg/mm/ha.

The wide variation in WFIE, CWUI, GPWUI-farm and IWUE-farm found within each production region suggests that while better producers compare very well internationally, there is significant scope for producers at the lower end of the ranges to increase the efficiency with which they use water. Collecting water management data at the field and farm level provides important information for the diagnostic analysis of water use efficiency. Coupled with the Australian cotton industry's move toward the implementation of best management practice procedures, this should allow accurate assessments of water use efficiency at the farm level in the future.

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2.3 Water balance and deep drainage under irrigated cotton

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Key points

- Deep drainage below the root zone causes rising watertables and salinity and can be significant even in heavy clays.
- Drainage occurs when more rain or irrigation is added to soil than there is empty storage capacity to hold it.
- Drainage risk can be reduced by maintaining sufficient empty storage (soil water deficit) as a buffer.

What is deep drainage?

When water in the soil moves below the root zone it is irretrievably lost to plants and is referred to as **deep drainage**. It is usually a small yet significant component of the soil water balance.

The soil water balance can be compared to the financial balance sheet of a company that balances funds credited to and debited from an account. The credits in the water balance are rainfall, run-on from upslope, and irrigation. On the debit side are evapotranspiration, run-off and deep drainage. The net profit or loss – the difference between the total credits and total debits – is analogous to the change in soil water storage. The water balance can be represented mathematically as:

$$\text{Rainfall} + \text{run-on} + \text{irrigation} = \\ \text{evapotranspiration} + \text{run-off} + \text{deep drainage} \\ + \text{increase in soil water}$$

However, there are important differences between a financial balance and the water balance. Net profit can accumulate over time and a bank balance can increase indefinitely. (Net losses can also accumulate indefinitely, so long as

funds can be borrowed.) In the soil water balance, soil water storage is finite. It cannot be overdrawn, and the maximum storage is limited by the total porosity of the soil. This means that once the storage is full or empty, one of the other components on the right-hand side of the equation has to change. Another difference is that, while a bank account does not limit the rate at which funds are added to or withdrawn from it, the soil does limit the rate at which water enters or leaves it. If water is added too fast, run-off increases. Similarly, the rate at which water can move in the soil may limit evapotranspiration.

The water balance can be calculated over different time periods. Over short periods (days, months or seasons), the change in soil water can be an important component of the balance (see below), but over longer periods the change becomes negligible, because of the fixed amount of storage available.

The components of the water balance are usually quoted in units of depth per unit time, for example, mm/yr, or volume per unit area per unit time, for example ML/ha/yr. (Note that 1 ML/ha is equivalent to 100 mm.)

Why is drainage important?

In much of inland Australia, shortage of water is a major limitation to plant growth. Native ecosystems have adapted to this by ensuring they use most of the water entering the soil. As a result, deep drainage under native vegetation is usually close to zero. Crops and pastures generally use less water over the long term, resulting in increased run-off and deep drainage. However, deep drainage is generally a very small proportion of the total water balance (Table 2.3.1).

Table 2.3.1 Components of the water balance for various land use systems on vertosols (cracking clays) at Gunnedah, NSW

Mean annual rainfall is 631 mm/yr. Results are means from simulations for 40 years (1958–98) of historical weather data for 10 different vertosols found in the district.

	Run-off mm/yr	Evapotranspiration mm/yr	Deep drainage mm/yr
Long fallow wheat and sorghum	19	562	50
Opportunity cropped wheat and sorghum	15	600	16
Continuous sorghum	20	593	18
Continuous wheat	14	554	63
Improved pasture	11	619	1
Woodland	13	618	0

Source: from Ringrose-Voase et al. 2003

In dryland and especially in irrigated agriculture, drainage is a waste of a valuable resource and can remove nutrients from the root zone. Although it is only a small fraction of the water balance (<10% mean annual rainfall in Table 2.3.1), it disrupts the hydrologic cycle of the landscape, which has long-term consequences in the broader landscape.

There are few values for drainage under irrigated cotton in the northern Murray-Darling Basin. McHugh (2003) reported drainage values for two cotton seasons in the Emerald Irrigation Area, varying from 0 mm under the best subsurface drip irrigation systems to 118 mm under furrow irrigation. While the best treatments always gave low values, drainage under other treatments was much more variable from season to season.

In many cases, the assumption has been that drainage in heavy clays is negligible because of their low hydraulic conductivity (for example, Tennakoon and Milroy 2003). Tim Weaver (pers. comm.), however, found in-season values of between 14 and 90 mm for various sites around Narrabri, NSW for the 2000–01 season. He also found winter drainage values in 2001 of between 11 and 39 mm. Determining long-term drainage under irrigated cotton systems in the northern Murray-Darling Basin is the subject of current research, but it seems unlikely that the assumption of negligible drainage is justifiable.

In many inland regions of Australia, large amounts of salt have built up over geological time deep in the soil. In part this has happened because of the efficiency of native vegetation in using available water, which has prevented the tiny quantities of salt in rainfall from being leached from the soil. Instead, salts concentrate at the bottom of the root zone over thousands of years. In other situations, salt produced by the weathering of rock has built up due to the same lack of leaching. In yet other areas, groundwater occupies sedimentary rocks of marine origin.

When native vegetation is cleared, drainage generally increases, with two effects:

- Drainage can mobilise salt stored in the soil.
- Drainage can increase recharge to groundwater, causing a rise in groundwater levels if the groundwater cannot move fast enough to accommodate the extra recharge.

The rise in groundwater causes waterlogging in lower parts of the landscape. Where the groundwater contains either pre-existing salt or salt mobilised by extra drainage, salinity occurs as this salt is brought into the root zone. Waterlogging and salinity can occur at the site of increased drainage, but often occur elsewhere in the landscape. Therefore salinity has to be tackled at the landscape scale and requires cooperation between land managers in areas where salinity is occurring with those where drainage has increased.



How does drainage happen?

Principles of soil water storage and movement

Before discussing the mechanisms leading to drainage, it is worth describing the principles of water storage and movement in soil. Water is stored in and moves through pores in the soil. There are two basic principles that govern how pores hold and transmit water.

- The strength with which pores hold water – the ‘suction’ they can exert – is inversely proportional to their diameters. If the diameter is doubled, the suction is halved.
- The rate at which water moves through pores is proportional to the fourth power of their diameters (that is, diameter raised to the power of 4). If the diameter is doubled, the rate of water movement is increased 16 times.

The amount of water that the soil holds at saturation is determined by the porosity of the soil (although soil rarely saturates completely because of trapped bubbles of air). However, only a portion of the porosity can store water in a form available to plants. On the one hand, pores larger than about 0.03 mm in diameter cannot hold water against the influence of gravity and will eventually drain. They can only store water temporarily. The volume of such pores is referred to as the **drainable porosity**. On the other hand, pores with diameters less than about 0.00002 mm exert such a high suction that plants are unable to extract it. Water stored in such pores

is generally considered ‘unavailable’. Pores between these extremes hold water sufficiently strongly that it does not drain but not so strongly that it cannot be extracted by plants. The maximum volume of water that can be held in these pores is the **plant available water capacity** (PAWC).

Because small pores exert greater suction than larger ones, water is stored in small pores more readily than in larger ones. In a wet soil only the largest pores are empty and the suction exerted by the soil as a whole is less than in a dry soil, in which small pores are also empty. Therefore a layer of dry soil tends to suck water from a wetter layer even against the influence of gravity.

Water moves through the soil under the influence of both gravity and ‘suction’. However, water moves much faster through large pores than through small ones. Thus the ability of wet soil to transmit water – its ‘hydraulic conductivity’ – is much greater than that of dry soil. Once the drainable porosity has emptied, the rate of water movement drops considerably.

Water balance basics

During rain or irrigation a portion of the water runs off, depending on the surface properties and slope. (This is called **infiltration-excess** run-off, as it is water in excess of the infiltration capacity of the soil surface.) The remainder infiltrates the soil and fills empty pore space.

In general, water fills the soil from the top down. As the surface layer fills, water moves to deeper layers under the influence of gravity. If the deeper layers are drier, the greater suction of those layers also assists water movement.

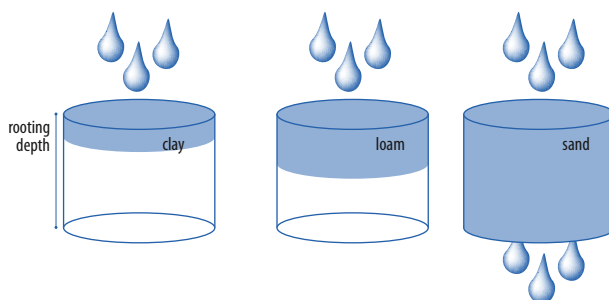
If the rate of water movement to deeper layers is insufficient to accommodate the infiltrating water, water backs up and extra run-off is generated: this is referred to as **saturation-excess** run-off. This can happen in texture-contrast soils in which a relatively porous topsoil sits above a relatively impermeable, clay subsoil. Water only moves into the subsoil slowly, so, once the topsoil has filled, extra run-off is generated if rain or irrigation continues.

A rare exception to the soil filling from the top down occurs when water flows down large macropores to the subsoil, bypassing the bulk (‘matrix’) of the topsoil as it does so. For example, in vertosols (cracking clay soils) the soil matrix has relatively small pores so it can only fill up slowly. During heavy rain, the matrix is unable to fill up fast enough, so water flows down cracks and other large pores directly to the subsoil.

In contrast to water input to the soil, which tends to occur in discrete rainfall or irrigation events, removal of water by evapotranspiration is a more continuous process. When the surface soil is wet, evaporation from the soil surface is determined by the evaporative demand of the atmosphere (radiation, temperature, relative humidity, wind, and other factors). However, once the surface has dried, its hydraulic conductivity drops rapidly and evaporation is limited by the rate at which water is able to move to the surface. Transpiration by plants is also controlled by evaporative demand, but they are able to extract water from wherever it is available within their root zone.

Water storage in the soil root zone can be viewed as a water tank that fills from the top down. The depth of the tank represents the depth of the root zone. The width of the tank can vary with depth and represents the way water-holding capacity can change with depth as soil texture, structure or bulk density change. Water added to the top of the tank represents the water that infiltrates after rainfall, irrigation or run-on. With every rainfall or irrigation event, the depth of water in the tank increases by the amount of water that infiltrates. Between rainfall events, evaporation or transpiration by plants removes water and the depth decreases. The pattern over time is for the depth of stored water to fluctuate, with relatively rapid increases followed by periods of slower decline. Clearly, so long as the decline in depth between fillings creates sufficient empty storage to accommodate the next filling, the tank never completely fills and the depth fluctuates about an average. However, if the rate of emptying over a particular period is insufficient to match all the amounts added during the same period, water accumulates and eventually reaches the bottom of the tank. Any additional water results in leakage from the bottom of the tank, which represents deep drainage beyond the root zone.

Figure 2.3.1 The effect of soil texture on drainage



Factors affecting drainage

Drainage occurs when the input of water from a rainfall or irrigation event is greater than the spare storage capacity of the soil. This spare capacity is referred to as the **soil water deficit** and equals the PAWC minus the amount of available water actually stored in the root zone.

Drainage does not occur continuously, but in episodes. On the one hand, small events only cause drainage if the deficit is already small. This might be because the PAWC is small or because the soil is already wet and nearly full. On the other hand, larger events are able to cause drainage even when the deficit is larger. The probability of a drainage event occurring is determined by:

- the size of rainfall or irrigation events
- the intensity of rain or irrigation relative to the infiltration properties of the soil
- the soil water deficit.

Size of the rainfall or irrigation event

The effects of the size of individual inputs of rain or irrigation on filling the water storage are self-evident. The size of rainfall events at a particular time of year is out of the control of the land manager, but additions of water by irrigation can certainly be adjusted to maximise water use efficiency and minimise drainage.

The other two factors affecting drainage are more complicated, and require further discussion.

Infiltration properties

How much of any rainfall or irrigation event actually enters the soil is controlled by:

- slope. The steeper the slope, the less water infiltrates.
- soil surface properties. Surfaces with unstable structure crust easily, which decreases infiltration. This may be caused by silty texture, dispersive (sodic) clays or lack of organic matter. Compaction of the surface by machinery or animals can also decrease infiltration.

- cover by crop residues. Greater cover protects the soil surface from raindrop impact and improves infiltration.
- subsurface constrictions to water movement. These constrictions prevent water moving into the subsoil, causing surface layers to saturate more quickly and any additional rain or irrigation to run-off.

The role of infiltration properties in drainage is complicated. On the one hand, greater infiltration increases the probability of filling the available storage and causing drainage. On the other, infiltration needs to be maximised for plant production and to reduce the risk of soil erosion. In fact, poor infiltration can sometimes *increase* drainage, as when crops fail, leaving the land fallow and reducing the soil water deficit.

In general, land management should seek to maximise infiltration where possible. This can be achieved by:

- ensuring good cover through retention of crop residues, or sowing of sacrificial cereal crops;
- ensuring structural stability through maintenance of soil organic matter;
- avoiding surface or subsurface compaction by traffic.

Soil water deficit

To prevent deep drainage, the soil water deficit at a particular time of year needs to be large enough to accommodate the largest likely addition of water at that time of year. Otherwise, a large addition of water may fill the root zone beyond its PAWC and cause drainage.

The deficit acts as a buffer against rainfall and irrigation events. The larger the deficit, the greater the ability of the soil to absorb additions of rainfall or irrigation without drainage occurring. The deficit is controlled by:

- the water storage capacity of the soil
- the rate of accumulation of water over various time periods.

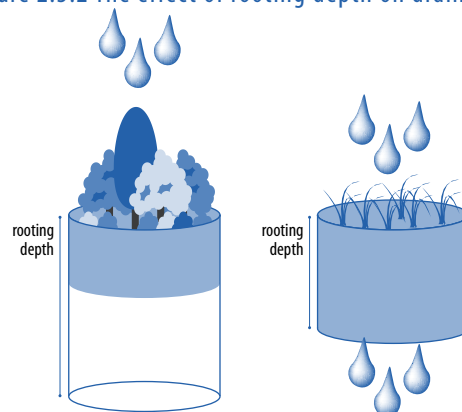
Soil water storage capacity: The storage capacity – the size of the ‘tank’ – is a function of the inherent water-holding capacity of each soil layer and the rooting depth – the width and depth of the tank, respectively. The main factors controlling these are as follows:

- Factors controlling the inherent water-holding capacity of each soil layer (see Figure 2.3.1):
 - soil texture – in general clay soils hold more water than sandy soil.
 - soil structure – compaction by traffic tends to reduce water-holding capacity

- Factors controlling the rooting depth (Figure 2.3.2):
 - vegetation species – trees and other perennial vegetation have greater rooting depths than annual species.
 - soil depth – rooting depth is limited by shallow soil or hostile soil conditions, such as alkaline or saline layers.
 - impeding layers – root growth is impeded by hostile layers due to soil texture, alkalinity or shallow saline watertables.
 - soil structure – compaction by traffic or depletion of organic matter can limit rooting depth, especially of annuals.

Water-holding capacity determines the maximum deficit size. For example, on a vertosol (cracking clay) it might be possible to completely buffer against drainage using pasture with relatively shallow roots, because the water-holding capacity of clay is so high. In contrast, deep-rooting tree species might be necessary on a lighter textured soil. The former situation is comparable to a wide, shallow tank and the latter to a thin, deep one.

Figure 2.3.2 The effect of rooting depth on drainage



Rate of water accumulation: The size of the soil water deficit at a particular time of year or point in a crop rotation depends on the rate of accumulation of water in the soil profile. Over periods when inputs are roughly equal to losses by evapotranspiration, the deficit fluctuates about a mean (see Figure 2.3.3).

If this mean is large enough, drainage is unlikely, though not impossible if larger than average events occur close together. However, over periods when inputs are larger than losses (over-irrigation, for example), the deficit still fluctuates but gradually diminishes (Figure 2.3.4), with the likelihood of drainage increasing as it does so.

The factors controlling the accumulation of water are:

- climate
- crop vegetation management
- irrigation management.

Climate has a major control over the accumulation rate at different times of year. Total annual rainfall obviously affects the total input of water to the system. Within a region of broadly similar climate, wetter areas with greater rainfall and smaller potential evapotranspiration – for example, hills – tend to have a greater risk of drainage.

The distributions of rainfall and evapotranspiration through the year are also of great importance. There are two aspects: first is the evenness of rainfall through the year. Climates with more peaked rainfall distributions have greater

drainage risk than those in which the monthly rainfall is more equal. Less water accumulates with an even distribution because there is more time between events to empty the storage.

The second aspect is the monthly distribution of rainfall relative to evapotranspiration. In southern parts of Australia, monthly rainfall and monthly potential evapotranspiration are out of phase, with the most rain occurring in winter when there is the least evapotranspiration. Accumulation of water in the soil is therefore greater than in climates where the two are in phase, such as northern NSW. Differences in drainage risk due to differences in distribution are more noticeable between regions than within a region.

Figure 2.3.3 Zero accumulation rate

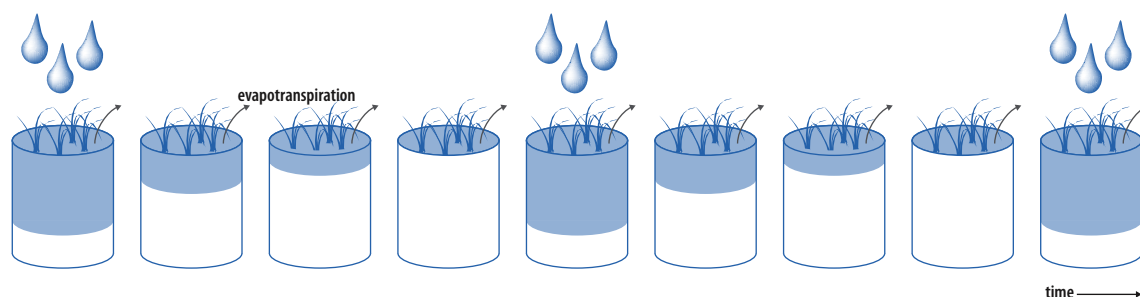
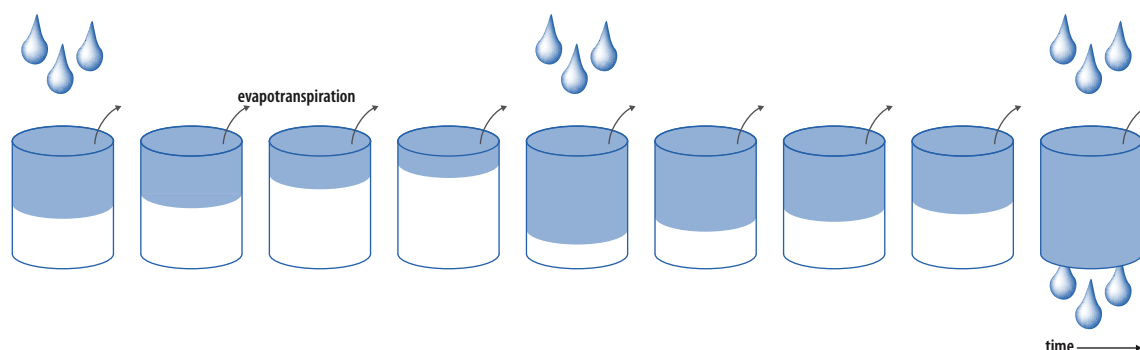


Figure 2.3.4 Positive accumulation rate



Crop vegetation management affects the conversion of evaporative demand into actual evapotranspiration. When the soil surface is bare, the conversion is inefficient except when the surface is wet, and therefore water tends to accumulate during fallow periods, especially if these occur at times of peak rainfall. Vegetation converts potential to actual evapotranspiration much more efficiently because it can extract water from the whole root zone and is not limited by the rate at which water can move to the surface.

Irrigation management affects accumulation in several ways. First, it increases the total addition of water to the soil during the year – comparable to increasing mean annual rainfall – and this increases the risk of drainage. Second, within the growing season, over-irrigation causes drainage, because additions through irrigation are larger than losses. Correct scheduling ensures the amount of water added by each irrigation equals losses by evapotranspiration over the period between irrigations.

In summary, water tends to accumulate in three main situations:

- during winter when evaporative demand is low and, in some regions, when rainfall is greatest;
- during fallow periods when there is no extraction by plants and evaporation from the surface is limited once it has dried;
- when more irrigation water is applied than plants can extract.

Control of drainage

Of the many factors affecting drainage, only a limited number can be influenced by land management, and these can be grouped under four activities:

- improving subsoil structure
- using deep-rooted species
- maintaining an adequate soil water deficit
- managing irrigation in irrigated systems.

Improving subsoil structure

Removing barriers allows roots to exploit a greater depth of soil, especially useful in annual cropping (when the time available for root growth is limited). Methods include deep tillage to remove compaction, and controlled traffic and permanent beds to maintain good structure. These methods usually only lead to minor improvements in PAWC, because rooting depth is still limited by the species. Their chief benefit is in improving crop production.

Using deep-rooted species

Much greater increases in PAWC can be achieved by changing to deep-rooted species such as lucerne or trees. Deep-rooted species dry the soil to much greater depths, thereby creating much greater deficits (Figure 2.3.5) which provide greater buffering against drainage. This option usually involves changing to perennial vegetation, because annual species simply don't have the time to exploit a greater depth of soil.

Perennial species can either be used in permanent plantings or in sequence with crops.

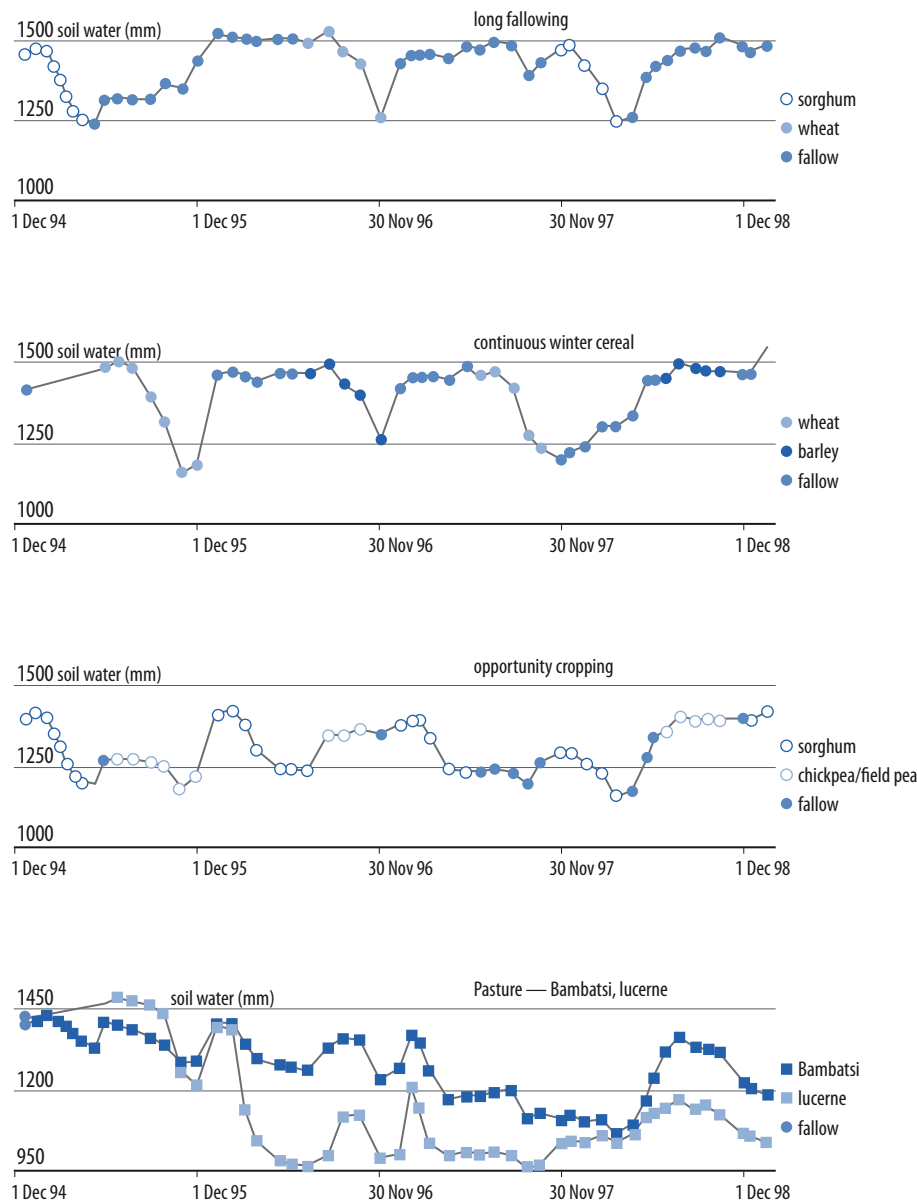
Permanent plantings reduce the proportion of the landscape prone to drainage, and if located strategically can use excess water from elsewhere in the landscape that could otherwise recharge groundwater. Whilst they can be economically productive, they are usually less so than cropping, but, in addition to reducing excess water in the landscape, they can provide benefits by forming windbreaks and by increasing biodiversity.

When perennials are used as part of a cropping sequence, the aim is to produce an additional temporary buffer of dry soil below the rooting depth of the crop species. The most common perennial species used is lucerne. The lucerne phase, which lasts for several years, dries the soil to a depth of two or more metres. During the subsequent cropping phase, drainage below the root zone of the crop is stored in the dry zone created by the lucerne. This temporary store gradually fills up until it is emptied again by the next lucerne phase.

The success of this system depends on changing phases at the correct time (Ridley et al. 2001). If cropping is continued for too many seasons, the temporary storage fills and drainage occurs. Conversely, if cropping phases are too short, profitability will suffer.

Improving subsoil structure and using deep-rooted species effectively increases the rooting depth and thus the PAWC and maximum possible soil water deficit. In soils with low water-holding capacity per unit depth – that is, those with narrow 'storage tanks' – increasing rooting depth may be the only way of having a large enough deficit to prevent drainage.

Figure 2.3.5 Total profile water (0.1–3.1 m depth) under various cropping or pasture systems measured by neutron moisture meter at a site in the Liverpool Plains



The soil is a Black Vertosol, and the mean annual rainfall is 684 mm/yr.

Source: Ringrose-Voase et al. 2003

Maintaining an adequate soil water deficit

Maintenance of an adequate soil water deficit provides a buffer against drainage. During periods of net accumulation of water, the deficit decreases until it is too small to accommodate the next rain or irrigation event.

The main ways to maintain an adequate soil water deficit are as follows:

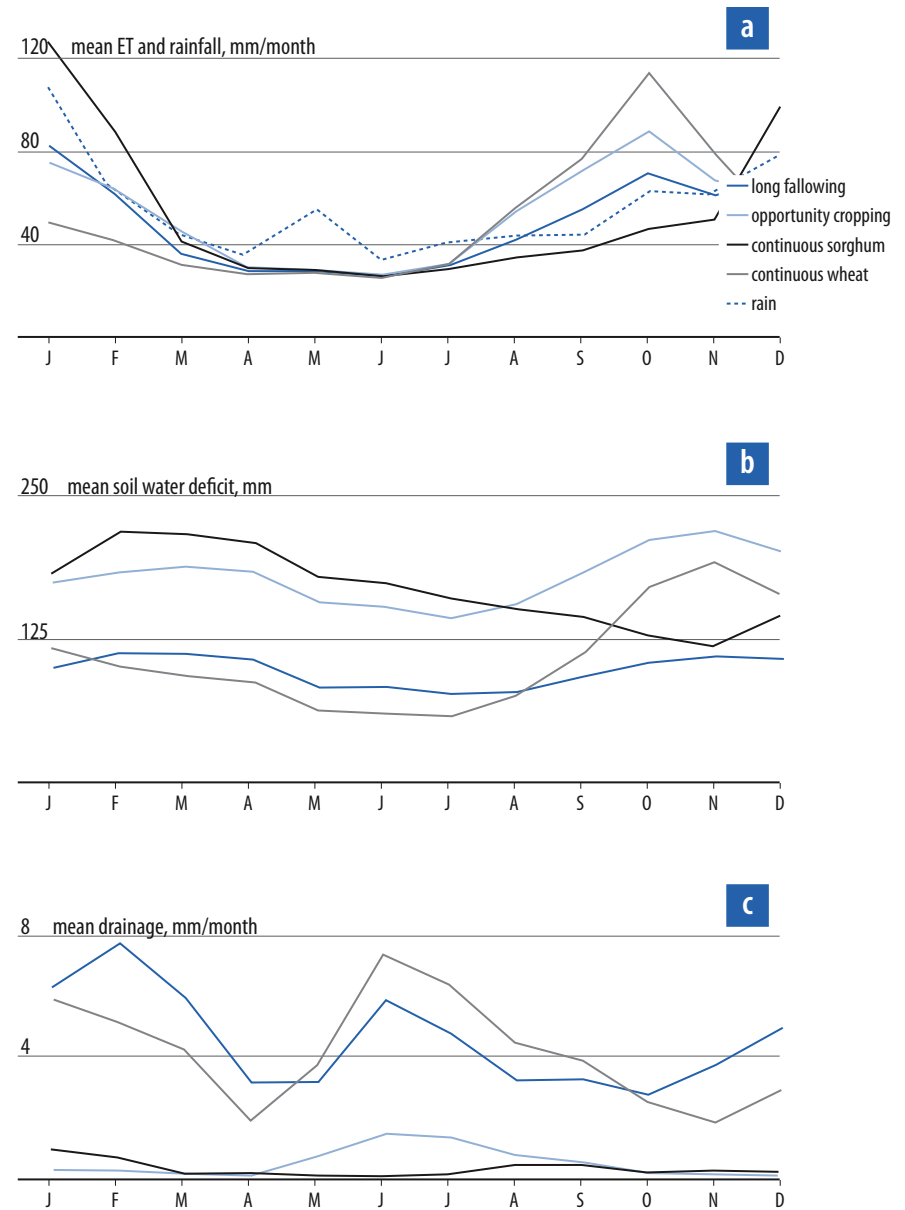
Decreasing the length of fallows between crops: When soil is left fallow it accumulates water (as long as weed growth is controlled). This provides extra water to the subsequent crop to supplement in-season rainfall, especially in soils with high water-holding capacity, such as vertosols. The fallow also increases the risk of drainage, because the deficit reduces as the fallow progresses. A compromise is clearly necessary that reduces the dependence of crops on in-season rainfall and minimises the risk of drainage.

For example, in the northern grains regions of New South Wales, a popular cropping system on vertosols is made up of one wheat and one sorghum crop every three years, separated by long fallows of about 12 months. The system has been popular because it provides reasonable yields even in seasons with lower than average rainfall. However, monitoring soil water under such a system has shown that this length of time is rarely required to refill the soil profile between crops, and that the deficit is dangerously small during much of the fallow period (Figure 2.3.5).

Long fallowing can be successfully replaced by response or opportunity cropping in which a decision is made during each spring and autumn sowing window on whether to sow a crop based on the amount of stored water. Wheat is sown in the autumn window only if there is sufficient depth of wet soil measured with a push probe, and similarly for sorghum in the spring window. Common rules for opportunity cropping in northern NSW are 70 cm of wet soil for wheat and 90 cm for sorghum. In this system, the fallow period is tailored to the weather conditions so that water is only allowed to accumulate up to a fixed amount.

For the climate and soil involved in Figure 2.3.6[b], the deficit under long fallowing declines to a minimum of about 75 mm in July, while the minimum under opportunity cropping is 135 mm, providing 60 mm of extra buffering against rainfall events. In this example, average yield per crop under opportunity cropping (3.9 t/ha/crop) is less than under long fallowing (5.0 t/ha/crop). However, average production per year is greater (4.5 t/ha/yr versus 3.1 t/ha/yr, respectively) because more crops are grown – 1.15 crops per year instead of 0.63. Average long-term gross margins are also greater (\$340/ha/yr versus \$240/ha/yr, respectively).

Figure 2.3.6. Predicted (a) mean monthly rainfall and evapotranspiration, (b) soil water deficit, and (c) drainage under various cropping systems



Same site as Figure 2.3.5, over 40 years (1958–98)

Generating the maximum possible deficit before a prolonged period of accumulation: Sometimes periods of prolonged accumulation cannot be avoided because of the climate. In winter periods, evaporative demand is small, so any rain accumulates in the soil. However, the deficit before such periods can be maximised by better matching the peak water demand of the crop to the climate. In northern NSW rainfall is greatest in summer (Figure 2.3.6a), and the summer is long enough to allow summer cropping. In this region, peak water use by wheat is in spring before the summer peak in rainfall (Figure 2.3.6a). Thus under continuous wheat the deficit is maximum (average 185 mm) in November (Figure 2.3.6b). This deficit is diminished by rain during both the subsequent summer and winter and reaches a minimum of about 60 mm in winter. This is often insufficient to buffer against drainage (Figure 2.3.6c). In contrast, peak water use by sorghum is in summer, coinciding with peak rainfall. Sorghum not only uses summer rain shortly after it falls – preventing its accumulation in the soil – but uses stored water as well. By March the deficit under continuous sorghum exceeds 200 mm. This is usually sufficiently large to store rain during the subsequent winter. In this example, both systems have the same cropping frequency, but quite different drainage outcomes.

Using permanent vegetation: The use of deep-rooted perennials to increase PAWC has already been discussed. An additional advantage of perennials and other permanent cover – such as permanent pasture – is that they have no fallow periods. Hence, the vegetation maximises the translation of evaporative demand at the surface into water removal from the soil (Figure 2.3.5).

Irrigation management

Irrigation increases the risk of drainage simply because it increases the input of water into the system, in the same way that drainage risk increases with mean annual rainfall (see above). However, unlike the climate, irrigation can be managed to ensure that all water added during the growing season is used to meet the dual aims of crop production and drainage minimisation.

- As the crop uses water, it increases the soil water deficit. Correct irrigation scheduling to meet the plant water requirements ensures that the amount of water added is equal to the soil water deficit. Over-irrigation occurs when the amount of water added is greater than the soil water deficit, and it directly causes drainage. It can be avoided by accurate irrigation scheduling and effective soil water monitoring. In addition, wetting front detectors can be buried in the soil at particular depths and used to show when infiltrating water has wet the soil to those depths (Stirzaker

2003). These devices have a role in teaching irrigators how much water is required to fill the root zone in different conditions. By placing them at different depths in the soil profile, irrigators can learn when over-irrigation is occurring.

- Enough time should be left at the end of an irrigated crop for the crop to dry the profile before harvest. This ensures the soil deficit is maximised before the fallow period, which is especially important when the fallow is during winter. Winter rainfall can cause drainage because low evaporative demand means water accumulates in the soil. This occurs even in regions where summer rainfall dominates, such as northern NSW.

Unfortunately, several factors make it difficult not to have drainage under irrigated paddocks.

- Standard irrigation practice requires a leaching fraction – a proportion of the irrigation water that is drained from the root zone – to prevent salts in irrigation water from building up in the root zone. The leaching fraction required increases as the quality of irrigation water declines. The leaching fraction directly adds to the total deep drainage. However, the large deep drainage values estimated for many irrigation systems probably meet the leaching fraction requirement, without specifically adding a leaching fraction.



- In many irrigation systems, the economic penalty of under-irrigation far outweighs the economic savings achieved by very accurate scheduling – that is, it is better to slightly over-irrigate since the extra cost of water is much less than the value of lost production if the crop is water stressed. This strategy increases the amount of drainage.
- The unpredictability of rainfall during the growing season makes it difficult, if not impossible, to prevent drainage when rain falls on recently irrigated soil.

Summary

While there are many factors affecting deep drainage, only some can be controlled by the farmer. Their relative magnitudes also vary. In a particular location, the degree of manipulation required to minimise drainage depends on those factors out of the farmer's control – soil and climate. Where soil and climate factors combine to give a high risk of drainage, greater manipulation of management factors is necessary.

The dryland management factors discussed above can be *approximately* ranked in order of increasing ability to control drainage. Note that improvements to irrigated systems, such as better soil water monitoring to improve irrigation scheduling, could potentially have a large effect on deep drainage because drainage tends to be larger under irrigated systems than under dryland ones.

However, the magnitude of drainage reductions achievable relative to the list below is unclear and requires further research.

Level 1. Improving soil management – for example, by removing compacted layers – has a moderate effect on increasing the depth of the rooting zone.

Level 2. Increasing crop frequency shortens the length of fallows during which water accumulation occurs – for example, switching from long fallowing to short fallow wheat.

Level 3. In regions with summer-dominant rainfall, changing to summer crops whose maximum demand for water matches peak rainfall prevents summer rainfall accumulating by using the water shortly after it falls.

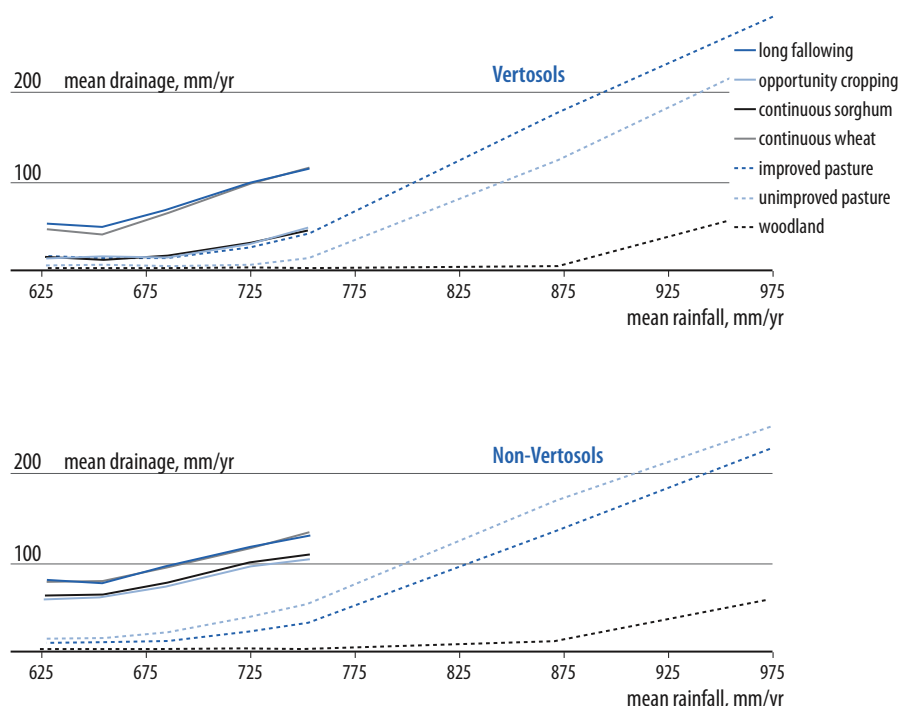
Level 4. Converting to cropping systems that are responsive to climate – for example, opportunity cropping – ensures that water accumulation is tailored to the needs of crops and does not lead to prolonged periods of low deficit.

Level 5. Changing to perennial pasture removes fallow periods altogether and ensures maximum translation of potential evapotranspiration into actual evapotranspiration.

Level 6. Changing to deep-rooted perennial species – for example, trees or lucerne – removes fallow periods, as above, but also increases the depth of the root zone, thereby increasing the maximum possible deficit.

The degree of intervention required for a particular climate–soil combination is difficult to determine. Computer simulation of the land use system using long-term historical weather data is one way of comparing the potential leakiness of different systems. For example, in Figure 2.3.7, computer simulation has been used to predict the drainage under a range of land uses on vertosols in the Liverpool Plains. At locations where mean annual rainfall is less than 700 mm/yr, the large PAWC of these soils means only quite mild intervention is required to reduce drainage to near natural levels (say level 3 and above in the list). There are a wide range of land use options available that are well buffered against drainage, including some profitable cropping options. In areas where rainfall is greater than about 700 mm/yr, even the less leaky cropping options are no longer able to completely buffer against drainage and well-managed pasture or woodland (levels 5 and 6) are the only simulated options able to prevent drainage. These options provide buffering with mean annual rainfalls up to about 800 and 900 mm/yr respectively.

Figure 2.3.7 Predicted average annual drainage under different land uses at different locations in the southern Liverpool Plains of NSW



From a computer simulation using climatic data over 40 years, and characteristics of Liverpool Plains soils.

Figure 2.3.7 also shows the predicted drainage under the same land uses but on non-vertosols found in the Liverpool Plains. Because these soils have far lower PAWC than the vertosols, more drastic intervention is required to lower the risk of drainage. On these soils, none of the cropping systems perform well in terms of drainage and even well-managed pasture only provides a degree of buffering up to 700 mm/yr rainfall. In the areas with greater rainfall than this, the only option giving low drainage is woodland.

Whilst the generic principles outlined above can be used to reduce the risk of drainage, strategies for particular regions are the topic of much current research. Without data on local soil and climate and computer simulation of long-term performance, specific recommendations cannot be made reliably.

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2.4 Deep drainage under irrigated cotton in Australia: a review

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Key points

(for furrow-irrigated fields)

- Deep drainage varies considerably depending on soil properties and irrigation management, and is not necessarily 'very small'
- Drainage of 100–200 mm/yr (1–2 ML/ha) is typical, although 3 to 900 mm/yr (0.03 to 9 ML/ha) has been observed.
- Soils used for irrigated cotton have much more diverse properties and management requirements than the simple description 'clay soil' suggests.
- Some drainage is needed to avoid salt build-up in the soil profile.
- The consequences of deep drainage are distinctly different where underlying groundwater can be used for pumping (fresh water, high flow rate) and where it cannot (saline water or low flow rate).
- Increased stream salinity is a threat to the irrigated industry.

Deep drainage describes movement of water below the root zone of crops. It is of concern, as it leads to:

- farming systems that are less water-efficient
- leaching of chemicals (for example, nitrogen), which may be a loss to the farming system and contribute to poorer off-site water quality, and
- raising of water levels in shallow groundwater systems. If groundwater levels rise to within or close to the crop root zone, production is adversely affected and control costs increase. (This has already occurred in large areas of irrigated agriculture in southern Australia.) The increased leaching by deep drainage of salts previously stored in the soil and regolith contributes to increased salinity in groundwater and surface water. (Regolith is the unconsolidated geological material above the base rock and includes the soil profile.)

It has been assumed that these problems will not occur in the northern inland areas used for irrigation, including the northern Murray-Darling Basin and central Queensland, roughly Dubbo to Clermont. This is because these areas have heavy clay soils and the pattern of water inputs (rainfall and irrigation) matches crop water use and climatic demand more closely than in the south. As we will see, both of these assumptions are now being questioned.

The cost of 'getting it wrong', however, is large. It takes a reasonably long time for groundwater systems to respond to increased drainage, with time scales in the order of decades. This means that the response to improved management is also slow – once you get a problem, it can take a long time to fix.

Shallow groundwater systems under the alluvial plains, at least in some places, are known to have a reasonable depth to the watertable (Free et al. 2001, Ian Heiner, NRM&E pers. comm.). There is a threat, but also an opportunity – time to do something to avoid potential problems, to investigate their extent, and to learn how to manage them.

Past research on the water balance of irrigated cotton in Australia, reviewed by Hearn (1998), dealt with some areas in detail, particularly crop water requirements, responses and allowable water deficits, waterlogging and soil structural degradation. Other topics have only recently begun to receive attention, for example, water use efficiency at a variety of scales (see Hearn 1998), and elements of the water balance such as run-off and deep drainage. Run-off and related soil erosion was reviewed by Silburn et al. (1997, 1998).

Hearn states a widely held view that saturated hydraulic conductivity (K_{sat}) is very low for soils used for irrigated cotton (clay soils or vertosols), with the consequence that deep drainage through the profile is 'very small'. By contrast, Shaw and Yule (1978) noted significant drainage and substantial leaching of chloride on a range of soils under irrigation in the Emerald area.

Actual measurements of deep drainage on irrigated cotton soils began in the late 1990s and results are now becoming available. Results from some of these studies are reviewed here. A number of studies have been conducted since (up to 2003) (for example, P Dalton, J McHugh, R Zischke, T Weaver, pers. comm.), and generally confirm the results presented here. They generally indicate that deep drainage varies considerably depending on soil properties and irrigation management, and is not necessarily 'very small'. In essence, therefore, we attempt to explain how soils of low K_{sat} can still give considerable deep drainage under irrigation.

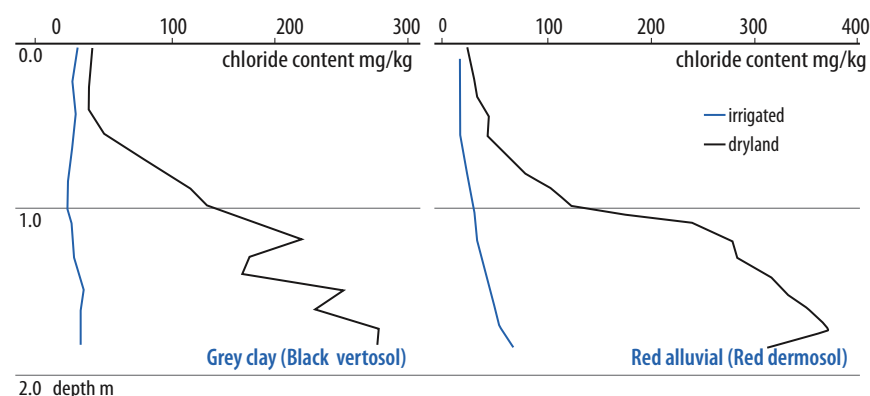
Remember that some level of deep drainage or 'leaching fraction' is needed under irrigation to avoid excess build-up of salts in the soil profile. The required leaching fraction is low for good quality irrigation water and increases as the salinity of irrigation water increases. The rate of deep drainage that is acceptable at any site depends on the characteristics of the receiving groundwater systems, particularly their discharge and pumping rates (if any).

Recent deep drainage studies

Soil properties and solutes studies

Chloride (Cl) concentrations in the soil profile provide an insight into past drainage through a soil. This is because chloride, which occurs naturally in rain, soil and streamflow, is soluble and mobile in soils, and in the long term moves where the water moves. Under native vegetation, pasture and dryland cropping, chloride concentrations typically increase with soil depth (a 'chloride bulge') due to storage of historic chloride from rainfall (Figure 2.4.1). Irrigated fields in the Gwydir Valley (Figure 2.4.1) have lower Cl concentrations in the soil profile than adjacent dryland sites, indicating that chloride has been leached downwards, and drainage is greater than under dryland cropping.

Figure 2.4.1 Soil chloride profiles in irrigated and nearby dryland cropping fields, on two soils in the Gwydir Valley, NSW



Source: J. Montgomery

Willis and Black (1996) also found lower soil chloride for irrigated sites compared with non-irrigated sites in the Macquarie Valley for 4 soils (generally 'lighter textured' soils, although one was a grey vertosol). They used measured changes in soil chloride profiles and transient chloride mass balance to calculate long-term changes in deep drainage associated with flood irrigation. Their results (Table 2.4.1) indicate a wide range in the increase in deep drainage under irrigation, with a larger increase for the lightest textured soils. Partly because of their greater drainage, the lightest textured soils received more irrigation water, thus further contributing to greater drainage.

Table 2.4.1 Increase in drainage below the root zone under irrigation compared with non-irrigated sites, calculated using soil sampling and transient chloride mass balance

Soil		Clay content (%)		Irrigation water applied (mm/yr)	Increased deep drainage under irrigation	
Local name		A horizon	B horizon		(mm/yr)	LF* (%)
Mullah	Grey vertosol	51	53	491†	17	3
Mitchell poorly drained	Uniform silty loam	16	46	400	45	11
Wilga non calcic	Duplex	19	35	811	206	25
Macquarie	Duplex	39	38	860	131	15

* Leaching fraction – increased deep drainage as a proportion of irrigation water input. † 100 mm = 1 ML/ha.

Source: Willis and Black 1996

The increase in drainage was lower on higher clay soils (Mullah and Mitchell), due to their higher water-holding capacity, leading to less frequent irrigation, lower drainable porosity and (presumably) lower subsoil permeability. The low drainage for the grey vertosol (assuming the increased drainage is close to total drainage) is roughly equivalent to the drainage estimated for sodic grey vertosols in the Namoi Valley, discussed below (Table 2.4.2).

Thorburn et al. (1990) analysed soil chloride (Cl) profiles for 42 irrigated sites in Queensland (central Queensland and the Lockyer Valley) and determined deep drainage from transient Cl mass balance. Non-irrigated Cl profiles were assumed to represent the soil prior to irrigation.

- Soils were mainly black and grey vertosols and a range of other soils: for example, clay content ranged from 17% to 70%, and exchangeable sodium percentage (ESP) 1–40.

- Drainage was 0–100 mm/yr for about half the sites, 100–300 mm/yr for 18 sites and 500–1200 mm/yr for 3 sites. On one soil with a drainage rate of ~0 mm/yr, the chloride data indicated the presence of a high watertable preventing drainage and contributing chloride.
- Time to establish a new soil chloride equilibrium under irrigation mostly ranged from 3 to 40 years, depending on the drainage rate and irrigation water salinity, but was as short as 1 year with very high drainage and 50–100+ years for soils with low drainage rates. The new equilibrium under irrigation involved cases of both increased soil chloride (salinisation) and decreased soil chloride.

Zischke (NRM&E, pers. comm.) used measured soil properties (Moss et al. 2001) and the SaLF model (Shaw and Thorburn 1985) to estimate deep drainage for non-irrigated and irrigated soils in cotton regions (Table 2.4.2). SaLF is an equation that estimates steady state drainage (or

leaching fraction) under irrigation from rainfall, irrigation applied and soil properties.

- Irrigated sites had a much higher drainage than dryland sites.
- Under irrigation, a wide range of drainage occurred, depending on soil properties. Generally, under irrigation, Macquarie soils (lighter textured, greater irrigation used) had high drainage potential; Darling Downs soils intermediate but still considerable drainage potential (200–300 mm/yr); and Namoi soils (sodic grey vertosols), low (but not insignificant) drainage.

Only a few soils in each region were considered. A range of soils and drainage potentials occur within each region, as illustrated by Thorburn et al. (1990) and Willis and Black (1996). The Namoi soils considered were grey vertosols, with very high subsoil sodium (ESP) and lower salt levels: both of these factors contribute to lower permeability.

Table 2.4.2 Deep drainage below the root zone estimated using paired site soil sampling (dryland non-irrigated and irrigated) and the SaLF model

Location	Number of soils	Under rainfall/ non-irrigated		Irrigated	
		Leaching (%)	Drainage (mm)	Leaching (%)	Drainage (mm)
Average	22	1.2	8	30	210
Darling Downs	7	0.3	2	24	266
Namoi (grey clays ^A)	5	0.2	1	2	27
Macquarie	6	3	19	52	754 ^B

^A soils with very high subsoil ESP (sodium) and lower salt levels.

^B lighter textured soils and higher irrigation, thus more drainage.

Source: R Zischke, NRM&E, based on Zischke and Gordon 2000, Moss et al. 2001

Where irrigation water contains high levels of salts (for example, bore water of marginal water quality), salinisation of soil profiles has occurred. See, for example, some soils in the Lockyer and Dee valleys (Thorburn et al. 1990) and the Condamine alluvial plains (Ian Gordon NRM&E, pers. comm.). Sodium content of irrigation water is also important, as accumulation of the salt sodium (sodicity) can occur, and this has adverse effects on soil properties and manageability. Increased salinity in streams, a major source of fresh irrigation water, is a threat to the irrigation industry.

Lysimeter study, Darling Downs

Moss et al. (2001) measured deep drainage directly, using lysimeters with a considerable area (3 m x 1.5 m). These lysimeters are basically large trays under 2 m of undisturbed soil which collect drainage by applying suction to the soil. They have the advantage of collecting all drainage, whereas other methods (for example, measured water balance) may miss some periods of drainage and often depend on imprecise soil moisture measurements.

Lysimeters were installed under nearby fields irrigated by furrow and subsurface 'drip' (T-tape). (Often referred to as subsurface 'drip' irrigation, it actually involves water applied at a positive pressure, meaning the soil is saturated and likely to drain.)

- Under furrow irrigation, annual deep drainage (over 3 years) was 150–180 mm, about 20% of the total rainfall plus irrigation (Table 2.4.3).

- Deep drainage under subsurface irrigation was more variable (95 and 305 mm/yr) than under furrow, and was quite high, considering about half the amount of irrigation water was applied compared with furrow.
- Drainage occurred under both systems within a day of irrigation. Rainfall events following soon after irrigation caused significant drainage. In 1998–99, a large amount of drainage occurred (809 mm) when rainfall/floodwater was ponded over the subsurface irrigation lysimeter for an extended period (a natural occurrence on floodplains).

The data illustrate that **under saturated conditions there is significant drainage through this heavy clay soil** (Moss et al. 2001). Soil moisture data indicated soil at 1.75 m depth (that is, below the root zone) was continuously moist (at or above 'field capacity'). Significant quantities of nitrate N (a loss to production), chloride (which may contribute to salinity of groundwater) and traces of pesticides were measured in the drainage water.



Table 2.4.3 Deep drainage (below 2 m) measured using lysimeters near Macalister, 50 km NW of Dalby, for adjoining fields under furrow and subsurface drip irrigation

Data are annual total (June–June). Soil is a grey vertosol (clay 75–80%, ESP 10–30 below 30 cm).

Field	Year	Irrigation (I) (mm)	Rainfall (R) (mm)	Total (mm)	Drainage (mm)	Drainage (% of I+R)
Furrow irrigation	1996–97	327	478	805	182	23
	1997–98	343	667	1010	162	16
	1998–Jan 1999	337	579	916	152	17
Subsurface irrigation	1996–97	150	478	628	305	49
	1997–98	142	667	809	95	12
Flood over lysimeter	1998–99	0	739	Unknown	857	n.d.

Source: Moss et al. 2001

Measured water balances studies (Janelle Montgomery)

This study determined deep drainage below the root zone for an irrigation season (or part of a season) on three soils under furrow irrigation, using the ‘measured water balance method’.

Measurements were made of soil moisture contents before and after each irrigation (ΔS), and irrigation (I), rainfall (P), run-off (R) and evapotranspiration (ET) amounts.

Deep drainage was calculated as

$$DD = (P+I) - (ET+R+\Delta S)$$

for the period between soil moisture sampling. Average drainage per irrigation (Table 2.4.4) was

- 40 mm for the grey vertosol (Gwydir)
- 8.8 mm on the red alluvial (Gwydir)
- 1.5 mm for the grey vertosol (Namoi).

Rainfall during one irrigation period contributed to greater drainage on the Gwydir grey vertosols, although 45% of rain plus irrigation ran off, but drainage was still 23–40 mm per irrigation during other irrigations. Total measured deep drainage for the irrigations monitored was 158 mm and 53 mm for Gwydir grey and red soils, and about 9 mm (assuming 1.5 mm $\times$ 6 irrigations) for the Namoi grey vertosol. Total drainage for the season may be greater than these amounts, if drainage continued between the measurement periods or if other irrigations or larger rainfall events occurred.

Table 2.4.4 Water balance components measured under furrow irrigated cotton, each for part or all of one irrigation season, where deep drainage = (I+P)–(R+ET+ΔS) for the period between soil moisture measurements before and after irrigation.

Date	Irrigation (I) (mm)	Rainfall (P) (mm)	Run-off (R) (mm)	ET (mm)	ΔS (mm)	Drainage (mm)
Grey vertosols, Gwydir (4 irrigations)						
19/12–24/12	96.8	0	12.5	24.0	26.1	34.2
6/1–8/1	115.1	0	7.8	13.1	54.2	40.0
21/1–26/1	89.6	157.8	110.2	39.2	36.9	61.2
1/3–4/3	86.9	3.6	8.0	22.3	37.8	22.5
Total	397	161	139			158
% of I+P			24			28
mm/irr			34.6			39.5
Red alluvial, Gwydir (6 irrigations, totals)						
Total	372	19	34			53
% of I+P			11%			14%
mm/irr			5.6			8.8
Grey vertosols, Namoi (2 irrigations, totals)						
Total	176	0	8.8			3
% of I+P			5%			1.7%
mm/irr			4.4			1.5



Measured and modelled water balance, Emerald

Connolly et al. (1998, 1999) used measured water balance (rain, irrigation, run-off and soil moisture) and agronomy from furrow-irrigated cotton fields in the Emerald Irrigation Area (EIA) (Carroll et al. 1995, Simpson et al. 1998) to calibrate a daily water balance model (GLEAMS). While the intention was to model run-off rather than drainage, the model accounts for all the water balance components and calibration generally forces a reasonable representation of each component.

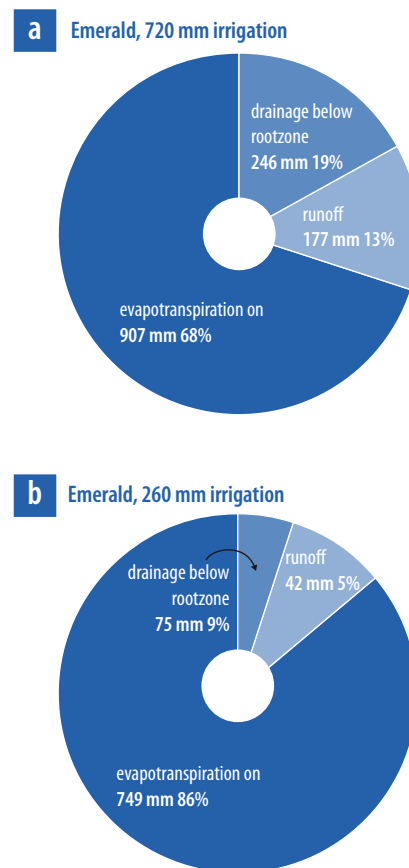
The results (Figure 2.4.2a) indicate considerable deep drainage is likely when irrigation of 7.2 ML/ha/yr is applied (720 mm/yr), that is, about the average used for cotton crops (Hearn 1998). Drainage (246 mm) and leaching fraction (19%) are similar to those from the furrow-irrigated lysimeter study ($LF \approx 20\%$) (Table 2.4.3) and SaLF model results for Darling Downs soils (Table 2.4.2). Average annual run-off is similar to the average measured over 12 years in the EIA (174 mm) (Silburn et al. 1997, 1998). Total annual ET (907 mm) is above that estimated for a typical growing season (700–750 mm) (S Milroy, Cotton CRC, pers. comm.), as it also included soil evaporation during the non-crop season.

What the model is telling us is that if you put 720 mm of irrigation and 600 mm of rain per year on a cotton field, it has to go somewhere – unless ET is considerably larger than estimated here, about 250 mm must have been lost as deep drainage.

When considerably less irrigation is used (average 260 mm/yr, 2.6 ML/ha/yr), mimicking a system with ‘perfect’ irrigation, that is, only just refilling the soil water deficit to field capacity, considerably less drainage is predicted (75 mm or 9% of water input) (Figure 2.4.2b). This drainage is due to rainfall occurring during the season and is greater than for dryland cotton, due to rain falling on soil wet by irrigation. This provides a leaching fraction for maintaining the soil salt balance, even though irrigation is not causing drainage.

With no irrigation (dryland cotton), drainage was 6 mm (1%), run-off 16 mm (3%) and ET 589 mm (96% of rainfall).

Figure 2.4.2 Average annual water balance (deep drainage, run-off and evapotranspiration) calculated using the calibrated GLEAMS model (Connolly et al. 1998, 1999) for an Emerald black vertosol, EIA, (a) furrow-irrigated cotton, with typical irrigation, and (b) with reduced irrigation amount.



Observed groundwater responses

An obvious question is, if there has been considerable drainage under some areas of irrigated cotton, why haven't we seen rising groundwater levels? Right now, the answer is not entirely clear, mostly because there is limited monitoring of groundwater levels, particularly in shallow groundwater systems, response times are long and the answer varies from place to place. Groundwater levels are rising in some locations and falling in other areas (Willis and Black 1996, Gordon 2000, Free et al. 2001).

These and other issues relating to the groundwater situation in southern and central Queensland are summarised (by NRM&E salinity and groundwater staff) in Table 2.4.5:

Table 2.4.5 Summary of issues affecting groundwater response to possible deep drainage under irrigation

Data available

Historically, drilling focused on finding good quality water, and monitoring has focused mainly on sustainable water use from these pumped groundwater areas.

Data are limited outside pumped areas, and data from within these areas is often from pumped aquifers. Data are very limited for shallow aquifers, particularly as drilling for water production would typically exclude shallow, low yielding or poor quality layers, such as salty layers.

Groundwater trends

Groundwater levels have a mixture of rising, falling and steady trends in most regions, with local influences often overriding regional trends.

- Groundwater levels are mostly falling in the Callide, the Upper Condamine Irrigation Areas and the Lower Namoi, due to groundwater pumping.
- Hot spots of rising groundwater occur around the Darling Downs, Border Rivers, St. George, Theodore and Emerald irrigation areas – that is, there is some coincidence with irrigated, non-pumped areas. Free et al. (2001) found groundwater closer to the surface near irrigation than in non-irrigated areas in the Border Rivers.

Response time

An increase in drainage below the root zone is not immediately transmitted to the watertable. Walker et al. (1985) found that, in the western Murray Basin, increased drainage due to clearing of mallee takes 50 to 500 years to increase the recharge of watertables >30 m deep, depending on drainage rate and soil type.

Response time is shorter where drainage rate is higher, depth to watertable is shallower and non-water filled porosity is lower. To illustrate this:

- If moisture storage capacity is 10% (0.1 v/v), the material holds 100 mm of 'new' water per metre depth. (v/v is a unit of water storage capacity, i.e. volume of water storage capacity per unit of total volume).
- With drainage of 10 mm/yr, the new wetting front advances at 0.1 m/yr, reaching a watertable 10 m down in 100 years.
- If drainage rate is 100 mm/yr, the wetting front advances at 1 m/yr, taking 10 years to reach a 10 m deep watertable.



Lateral flow

Some draining water may flow laterally and not reach the watertable directly below where it started. This would require a lateral gradient, and for water to be perched on a less permeable layer between the bottom of the root zone and the watertable.

Recharge refers to drainage that actually reaches the watertable.

Groundwater discharge and pumping

Water is lost from groundwater as discharge (leakage to other groundwater systems or surface streams) or pumping or both.

If the aquifer is losing water faster than the input from recharge then the watertable will fall rather than rise.

Some areas of irrigated cotton coincide with pumped groundwater systems and have falling trends, while other areas of irrigated cotton production and dryland cropping are in areas of little or no groundwater pumping (Gordon 2000), for example the Border Rivers and Lower Balonne.

Multiple aquifer layers

Groundwater systems and their responses to increased recharge are further complicated by the fact that below the root zone there will be layers of varying hydraulic conductivity, porosity, geology and states of decomposition and fracturing.

Saturated layers (aquifers) can occur at various depths. Excessive deep drainage can be causing a watertable to rise in a shallow layer, while pumping is causing depletion of a deeper layer, and all of these layers can be receiving or discharging water laterally.

Proportion of area irrigated

Only a small proportion of any catchment is irrigated, for example less than 1% of the Condamine-Balonne, and not all areas developed for irrigation are irrigated in any one year.

However, in a particular subcatchment or groundwater system (e.g. alluvial valleys), the proportion of area irrigated can be larger. Also, if the drainage rate under irrigation is large compared to other land uses, the contribution from irrigation can be large even though the area is small (Vervoort et al. 2003).

Recent drilling in non-production areas (Free et al. 2001; Ed Power, NRM&E, pers. comm.) indicate significant areas of alluvial plains in the QMDB have watertables at depths of, for example, 10 to 20 m, with high to very high salinity (14,000 to 45,000 EC units). No trend data are available as yet.

How can deep drainage be 100–200 mm/yr?

The review of deep drainage studies indicates that drainage ranges from 3 to 900 mm/yr (0.03 to 9 ML/ha) and is often 100 to 200 mm/yr (1–2 ML/ha). This is surprisingly high considering the long-held view, described in the introduction, that 'clay soils don't drain'. Here three factors that might limit drainage are considered: soil infiltration rate (or hydraulic conductivity), soil drainable porosity and the balance of water supply relative to evapotranspiration.

Simple drainage estimate 1: low infiltration rates

Say the final infiltration rate under irrigation is 1 mm/hr (that is, 24 mm/day). This is about the upper limit for long-term infiltration rates, that is, with 3 to 7 days of ponding, of Shaw and Yule (1978) and Gardiner and Coughlan (1982), but is generally below the infiltration rates measured after 5 hours of ponding, by which time soil water deficits were replenished.

- With this infiltration rate through wet soil, only 8 days that have a wet profile are needed for drainage of 200 mm/yr. That is, $1 \text{ mm/hr} \times 24 \text{ hrs} \times 8 \text{ days}$ (say 6 irrigations and 2 large rainfall events) = ~200 mm/yr.
- Conclusion: 1 mm/hr is not that low – drainage of 200 mm/yr is quite likely.

If drainage is 1 mm/day, which is at the low end of the range of long-term infiltration rates of Shaw and Yule (1978) and Gardiner and Coughlan (1982), for example, a soil with a sodic subsoil (ESP >25) (Shaw 1995):

- If drainage occurs for 3 days after each of 6 irrigations and 2 rainfalls, drainage = 1 mm/day × 3 days × 8 events = 24 mm/yr. This is consistent with drainage data from sodic grey clays, presented above.
- However, if the subsoil below the root zone is saturated after each irrigation, and drains for, say, a total of 100 days, drainage is 100 mm/yr. Data presented below (Figure 2.4.3) indicates that the subsoil can be near saturated through the entire irrigation season.
- Thus, even 1 mm/day drainage rate will result in considerable drainage if there are many days of drainage.

Simple drainage estimate 2: drainable porosity

Drainable porosity is the volume of water that can be stored in the volume of soil and which is able to drain after each wetting event. Gardiner (1988) showed that, for clay soil profiles, drainable porosity is 0.03 to 0.07 v/v.

If we take 0.03 v/v × 1000 mm soil depth = 30 mm of drainable water per wetting; for 7 wetting events = 210 mm that drains eventually, if it is not used in ET before it can drain. Thus the low drainable porosity of clay soils will not prevent drainage at the annual rates observed.

Simple drainage estimate 3: approximate water balance

Drainage is limited if evapotranspiration (ET) uses the rainfall and irrigation water. A water balance (Table 2.4.6) based on available data indicates that typical rainfall and irrigation is sufficient to allow drainage of 200 mm/yr. Various factors can be adjusted up or down by, say 50 mm, but water in excess of ET must go somewhere.

Table 2.4.6 A simple average water balance for a cotton crop season

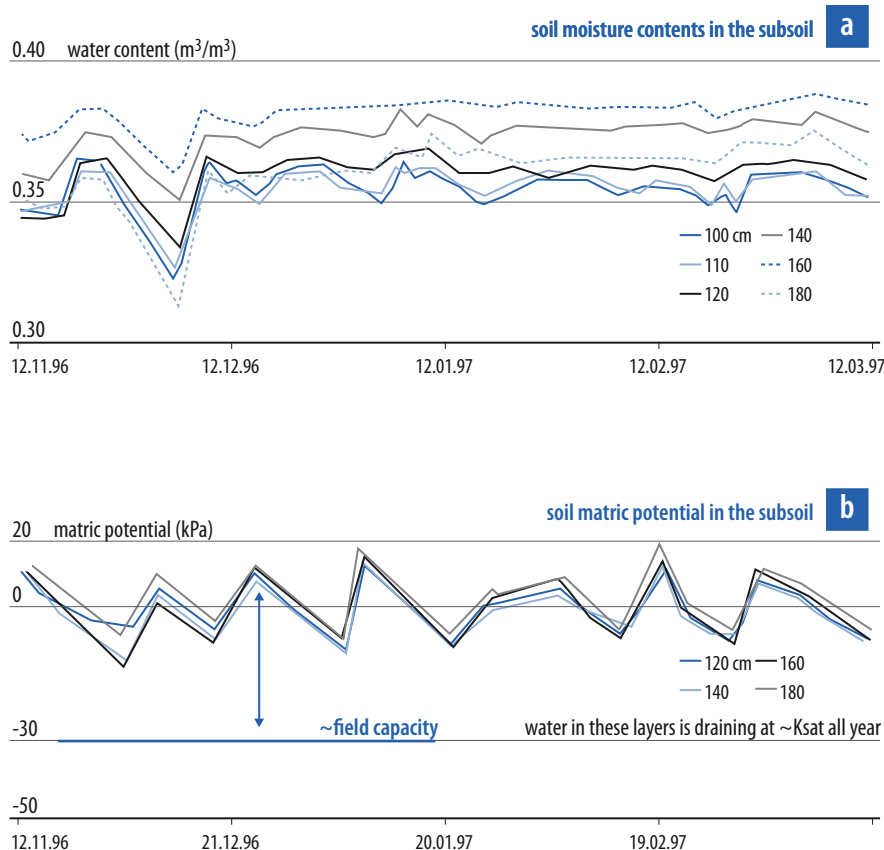
Component		Water (mm)	Source
Water inputs	Rain	400	2/3 of a 600 mm annual rainfall
	ΔSW	50	25% storage of 200 mm winter rain
	Irrigation	700	7 ML/ha, Hearn (1998)
	Total	1150	
Water outputs	ET	–800	Steve Milroy, ACRI; Hearn (1998)
	Excess	350	
	Run-off	–150	Silburn et al. (1997, 1998)
	Drainage	200	by difference



Don't get fooled by constant subsoil moisture contents!

In the past, emphasis has been put on constant subsoil moisture content as evidence of no drainage. Figure 2.4.3a is an example of such data from a grey vertosol in the Gwydir valley.

Figure 2.4.3 (a) Soil moisture in subsoil layers of a grey vertosol (Gwydir) through the irrigation season (b) Soil matric potential in the same layers, indicating near saturation (zero matric potential) throughout.



All layers from 100 to 180 cm show fairly constant moisture contents in the range 0.35–0.38 v/v which would seem like a somewhat moderate water content. However, with a bulk density (BD) of 1.59 g/cc, total porosity (TP) is 0.40 v/v (with a BD of 1.7, TP=0.36), so a water content of 0.38 v/v is in fact near saturation. We expect drained upper limit (DUL or field capacity) to be about 0.05 v/v below TP (typical air content in clay subsoils at drained upper limit, Gardner 1988), that is, DUL=0.35 v/v.

Thus, the measured subsoil moisture contents are likely to be between drained upper limit and saturation, and some soil water is drainable. This is confirmed by tensiometer data (soil matric potential) from the subsoil (Figure 2.4.3 b), which indicates that all layers between 120 and 180 cm were at or near saturation throughout the irrigation season. (Roots appear to have penetrated to about 100 cm.) Thus, water was probably **draining through the subsoil** throughout the season. Water balance measurements at the site indicated that 158 mm drained below 180 cm during the four irrigation periods monitored (Table 2.4.4).

Conclusions

Studies (up until about mid-2001) of drainage below the root zone (deep drainage) in irrigated cotton fields in the Northern Murray–Darling Basin and central Queensland were reviewed. These studies indicate that, for furrow irrigated fields:

1. Deep drainage varies considerably depending on soil properties and irrigation management, and is not necessarily 'very small', as believed in the past.
2. Deep drainage of 100 to 200 mm/yr (1–2 ML/ha) is typical, although rates of 3 to 900 mm/yr (0.03 to 9 ML/ha) were observed.
3. These drainage rates are compatible with clay soil infiltration rates, drainable porosity and with water balance (water applied, run-off and ET).
4. Some drainage, or leaching fraction, is needed to avoid salt build-up in the soil profile, although this should largely be provided by rainfall except where irrigation water quality is poor (for example, some bore waters).
5. Increased salinity in the water used for irrigation (from streams and groundwater) is a threat to the irrigated industry.
6. Soils used for irrigated cotton are more diverse than 'clay soils', with a wide variety of properties and management requirements.
7. The consequences of deep drainage are distinctly different where underlying groundwater can be used for pumping (fresh water, high flow rate) and where it cannot (saline water or low flow rate); significant areas of irrigation occur on groundwater areas of both classes.

Acknowledgments

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2.5 Developing a surface irrigation system

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Key points

- what to consider when selecting an irrigation system
- what is involved in upgrading a surface irrigation system
- soil types for storages and canals
- the 'perfect' layout for an irrigation system

This topic is aimed at those wishing to develop a new surface irrigation system or expand or upgrade an existing system. It is designed to help prevent the farmer making the same mistakes that others have made over the last twenty years. It combines experience with commonsense and some detailed technical advice.

The development of a large-scale surface irrigation system can be quite complex and good advice is essential. It is often found that good advice is paid for one way or the other and it is cheaper before construction starts.

Why consider surface irrigation? Because less than 2% of the Australian cotton crop is irrigated by drip and less than 2% is irrigated by sprinkler.

Questions for developments

A farmer looking to develop or upgrade any irrigation system needs to be able to answer all of these questions:

- Is the terrain irrigable?
- Are the soils fertile and suitable?
- Is the climate suitable for the crop?
- Is there a reliable, good quality water supply?
- How much area can be developed?
- How much will it cost?
- Will it make money?
- Do I have the required licences in place?

An irrigator must know the answer to all these questions before any construction proceeds.

What is irrigation?

Before looking at development in any detail it is worth reflecting on the basics. Irrigation is the process of artificially providing water to the soil in the crop root zone to enable a crop to prosper and yield well.

The process, then, includes the crop, the soil and the irrigation system.

These three aspects must work well together for a successful outcome. Poor performance from any one of these will lead to a poor result.

Matching irrigation system to soil

Lengthy and meaningful debates can be had on whether surface, sprinkler, or drip is the best form of irrigation. Of particular interest, however, is not which system may be preferred but **which system is best suited to a particular situation and crop.**

The single most important consideration in deciding which irrigation system is best suited to a particular situation is the **soil.**

The soil is the medium which takes in and stores the irrigation water for the crop to use. As stated above, the irrigation system, the soil and the crop must work well together to achieve a good crop yield.

Sandy soils: No matter how much a farmer may like surface irrigation, it is not possible to irrigate a field crop in a very sandy soil with surface irrigation because the water would infiltrate into the top part of the field mainly, and the tail end would get very little water. There are also real difficulties irrigating a crop in a sandy soil with subsurface drip because the water cannot sub up to the seed after planting. A sandy soil is well suited to efficient sprinkler irrigation.

Clays: A heavy clay can be poorly suited to sprinkler irrigation because these soils have a low infiltration rate. Water from sprinklers can quickly exceed this rate, causing surface run-off. Clay soils, however, are well suited to surface irrigation because the soil infiltration rates quickly slow to very low, allowing the water at the top of the field to flow over the wet soil and supply the dry soil further down the field.

Loams: A medium loam soil has more options, being basically suitable for each type of irrigation.

Matching the irrigation system type to the soil is a very important consideration which is sometimes overlooked. It is much easier to change an irrigation system than basic soil characteristics. Table 2.5.1 summarises the major considerations when selecting the most suitable type of irrigation.

Table 2.5.1. What type of irrigation suits me?

Irrigation type:	Surface	Mechanical sprinkler	Drip
Capital cost	L	M	H
Operation and maintenance	M	H	M–H
Labour requirements	H	M	L
Management	M–L	M	H
Water use	M–H	L–M	L
Yield potential	H	H	H
Surface drainage needs	H (regular laser levelling required)	M (for stormwater only)	M (for stormwater only)
Soil infiltration needs	M–H (high initial infiltration followed by moderate sealing for best distribution uniformity)	H (high infiltration rate required)	L.
Soils best suited	Heavy soils	Medium to light soils	Medium soils
Soils less suited	Sand (risk of deep drainage)	Heavy clays (infiltration problems)	Heavy (hard to pre-irrigate) Light (hard to sub up)
Lifestyle and personal	Your choice: some like dirt – some like gadgets.		

Note: L = low, M = medium, H = high



Answers for developments

A straightforward and systematic procedure has been developed to ensure that the correct answers are available at the outset and that nothing is missed. The following information must be obtained:

- preliminary inspection and selection of the potential area
- feasibility topographic (levels) survey of the whole potential area
- water quality analysis
- available water volume and reliability
- water supply delivery capacity
- determination of crop water requirements
- assessment of required irrigation water supply capacity
- agricultural soil suitability (samples and test pits – what's under the surface). See SOILpak B9 'Soil survey for development or re-development'.
- engineering soil properties for canals and embankment construction.

From this information it is possible to complete:

- a whole farm layout,
- a preliminary design and costing, and
- a preliminary economic analysis.

If the preliminary assessment is satisfactory, then it is possible to complete:

- a detailed survey and design,
- a final costing,
- a final economic analysis, and
- construction.

A thorough investigation is essential to ensure that any potential problems are foreseen and overcome before one clod of earth is turned. Development can stop at any of the above stages if serious problems are encountered. Once construction begins, it is very expensive to change, while it is easy and cheap to rub out and shift some lines on drawings. Shift things on paper, not in the field!

Using a consultant

As with all things, there are many who offer advice and are keen to help with irrigation development. There are those who 'know it all', although they have no formal training and little experience. There are those that know only a little but offer the lot. Be very careful. An irrigation consultant has a large impact on the development and it is vital that he/she is qualified and trained in the correct field, and is experienced. Ask if your consultant is qualified and what experience they have. Ask around and find out how they went with other projects.

Who can provide a complete answer to your development questions? A qualified engineer with detailed irrigation experience is a good option, as is a qualified surveyor with additional training in irrigation engineering. The important requirement is that an irrigation consultant must have the necessary training and experience in irrigation engineering to add value to an irrigator's own experience.

Any consultant may choose to use others qualified in specialised areas, such as soil science, but the consultant should know what has to be done and why, and should coordinate the project.

Development layouts

The first and most important part of the design process is to start with the whole farm layout. Worry about the detail such as sizes and so on after the whole farm is fitted together. Try a few alternatives and work with the designer and have your say (or at least review the preliminary layout before the detailed design is started).

A good layout requires:

- uniform runs of reasonable length
- regular field shapes
- a minimum number of control structures and crossings, and
- good access.

In particular, it means attention to detail and design. It should ensure that no unforeseen 'bugs' occur after implementation which reduce the efficiency of the operation.

It is vital that the layout is right before proceeding to the next steps. Any changes to the farm layout will mean changes throughout the whole system. It is quite expensive, for example, to decide later to merge two fields into one larger one, if land levelling has already put a pronounced step between the fields. If unable to afford required changes, a farmer may be stuck with an inbuilt inefficiency.

A good layout does not guarantee success, but at least it makes it possible.

A 'good' layout in fact could probably be defined as one that allows farmers to optimise their operations. This means that all of the elements that make up the system coordinate and function properly. Water is applied at the right time and in the right amount and uniformly, irrigation tailwater and stormwater run-off are removed quickly, cultural operations and access are enhanced, and labour is minimised.

Avoid having the supply and tailwater systems crossing. The best option is to have the supply system on one side of the development and the tailwater system on the other. Position the tailwater drain on the outside of the development to allow for easy overflow or blow-out of large stormwater events.

A staged development

Only a very few farmers can afford not to stage a development. Most tread the fine line of developing only enough to match finances but making this large enough to be an economic unit. As Stage I makes money, Stage II proceeds, and so on.

Any work done in Stage I must be readily adaptable for Stage II, III, and so on. Do not build temporary works for Stage I, rebuild for Stage II, and then build the final works for Stage III. For instance, build full-size canals and structures for Stage I, even though they are too big for the first area developed. If you need two pumps for the complete job, build the full pumping station and only install one pump for Stage I.

Design elements for development

Individual elements of the system must be selected and sized to be cost effective and efficient, and to fit into the overall system. There are many solutions to each design task, and several can be tested 'on paper' before the best is selected. Again, it is always cheaper to try pumps, shift earth and build canals on paper than in the field.

Do not forget to take stormwater and flooding into account when designing your system. In many cases it can be just as important to get the water off your fields during floods as it is to apply it.

Pumping station

The pump station is the workhorse of the irrigation system. Very large volumes of water are handled in an irrigation system, and the operation and energy costs makes it worthwhile optimising the pump and motor selection and the station layout.

Pump performance: When evaluating alternatives, consider operation and maintenance as well as capital cost. The cheapest pump to buy may not be the cheapest overall. Choose a pump which is efficient not just at the normal or most common flow and lift, but also over the full range of duties proposed (that is, normal river as well as low and high river). Allow a margin in the pump duties of up to 20% above the manufacturers' performance figures: the pump performance can be below the predicted performance by this margin because of pump wear and adjustment and a difference between laboratory and field conditions.

Check several models and make to find one which most closely matches the required duty. No one pump is going to be the best for all jobs.

Which motor?: Determine the input power required to the pump. This power must be made available from the motor continuously. The choice between diesel and electric motors can be made by considering capital, operation and maintenance costs together as a total cost. Other factors such as reliability of electricity supply and ease of operation must also be considered.

If diesel is selected, then the continuous power rating of the motor must be checked. The performance figures published by the engine manufacturers should comply with recognised standards. Unfortunately there are currently at least five recognised standards (ISO 3046, AS 4594, BS 5514, DIN 6270 and SAE J 816). The international (ISO) standard should be used if available.

De-ratings must be applied to this continuous power to allow for non-standard conditions, including altitude, air temperature, humidity and allowance for extras such as fans, alternators, and transmissions. As well as these specified de-ratings, allow a safety factor of 20%.

Final selection of the suitable motor will depend on the operating speed and power flexibility over the duty range. The most efficient motor is the one which operates closest to its point of minimum specific fuel consumption.

In the case of an electric motor, the continuous rating must be adequate to cover the pump duty plus a 15% safety factor.



Station layout and dimensions: The most common reason for poor pump performance is a lack of adequate submergence of the pump inlet. A lack of sufficient submergence can result in poor performance and damage to the pump. In using an inclined river bank installation, one of the problems is finding a pool of sufficient depth. Depth should always be measured, and not taken from hearsay.

With vertical installations, the pump suction bell has to be located with the correct clearances from the walls and floor of the pumping station to ensure an evenly distributed inflow of water to the pump inlet. Uneven distribution and high velocities can favour the formation of vortices, introducing air into the pump and reducing capacity. The sump dimensions have to be sized to suit the pump capacity: don't use a rule of thumb.

The correct size of rising main or discharge pipe will be the lowest cost alternative when capital costs and operating costs are summed over the life of the pipe, using a suitable discount rate.

Consider head loss through the outlet when choosing between an overflow bubbler type and a flap gate:

- When pumping into a storage, an overflow type outlet may result in significant energy cost increases, unless a low level outlet is also provided.
- Be very careful with flap gates on pipelines as they can cause massive pressure surges in the pipeline from water hammer and can also cause damage to the pumping station structure when slamming shut.

Storages

An on-farm storage or ring tank can be used to harvest supplementary (off-allocation) stream flows and on-farm and overland flow (if appropriate). It also allows the easier management of regulated flows, as irrigation can start or finish before or after regulated flows arrive at the farm.

Storages should also be incorporated in the tailwater return system, allowing re-circulation of irrigation tailwater and capture of first flush stormwater, which may contain nutrients or pesticides.

Sometimes a 'surge reservoir' or 'buffer storage' is constructed to store stormwater run-off by gravity inflow for later pumping to the ring tank storage.

Siting: In planning the storage, consider using natural depressions for additional storage or using natural ridges for banks (where nature has constructed part of the embankment). Incorporating billabongs and gullies, however, is often of little advantage in many cases, as these features often store only a relatively small amount of water and are often subject to licence restrictions and environmental complications.

Sizing: Determining the best size of storage for a particular farm is difficult and should be done by simulating the storage behaviour under the anticipated crop demands, taking into account past stream flows. A computer program is available to do this laborious task.

The optimum depth to store this water is a balance between the cost of the embankment, the value of the land inundated, and the value of the water lost due to evaporation.

- For a given volume of water, a large shallow storage requires less earthworks but inundates a larger area and loses more water from evaporation.
- Increasing storage depth reduces land and evaporation losses, but the larger quantities of earth, longer construction hauls and the more rigorous construction requirements of higher banks rapidly increase costs.

A circular ring tank requires the least earthworks for a given surface area and can be used where suitable. More often a square or rectangular shape as close to square as possible is used to fit in with property and field boundaries.

Reducing evaporation: Evaporation losses can be reduced by constructing internal dividing walls to form cells. One cell is completely emptied at a time. Generally the value of the water saved cannot justify the cost of more than one dividing wall (two cells) with the appropriate connecting pipe work and gates. Celled construction often may suit staged development.

Protecting the bank: Large storages often suffer badly from bank erosion due to wind-generated waves. Rip rap and other hard surface protective measures cannot generally be justified economically. Protection with grass and more recently water reeds has been used with reasonable success, but the wide variation in water levels makes maintaining a healthy cover difficult.

Grass should only be grown on the inside of the bank and closely monitored to ensure the roots do not form cracks through the bank and increase the risk of storage failure. When the storage is empty, it may be necessary to spray the grass on the inside batter of the storage bank to prevent vigorous grass growth cracking the embankment.

Flat inside batters (no steeper than 5 horizontal to 1 vertical) are essential to allow dissipation of wave energy. Recent work with the top 2 metres of bank height at 8:1 seems promising. Outside batters should not be constructed any steeper than 2:1 to provide stability and reduce rilling erosion from rain. Rilling erosion is also minimised by grading the crest to the inside.

Seepage: To build a costly storage without proper investigation is dangerous. Detailed soils investigation involving (at the least) backhoe pits and possibly electromagnetic (EM) surveys and pits is required to determine soil properties for design and to ensure, as far as possible, that any potential seepage paths can be cut off. It is worth having an engineer on hand to evaluate soils as they are dug from backhoe pits.

Skill and experience are also required to interpret EM surveys.

Supply canal

Where large flows are required and suitable clay soils are available, open canals are efficient and cheap. Before canals are constructed, the soils should be checked by test boring or backhoe pits. (Sealing of canals after construction is difficult and can exceed the initial canal cost.)

The canals should then be hydraulically designed, checking velocity and depth limits for stable flows, assuming uniform flow in most cases. Where possible, the slopes should closely follow the natural ground slopes to reduce excavation and padding, but velocities should be maintained between 0.15 and 0.5 metres per second to prevent

weed problems and bed erosion. A freeboard on the banks above the normal water surface level should be incorporated to allow for bank settlement and flow depth variations due to canal conditions or discharge variations. Freeboards should increase with canal capacity from a minimum of 250 mm up to 500 mm or more.

Canal bends should have a sufficient radius to avoid erosion on the outside of the bends. A common rule is to use a radius of twenty times the water depth, or a minimum of 15 metres.

Head ditches

Head ditches normally have a slope of about 1 in 10,000 to minimise the number of control structures, to maintain uniform water levels above field level (command) and to make the setting of outlets (siphons) easier. Flat ditches have to be carefully maintained to ensure their capacity is not reduced. Steeper ditches require temporary or permanent checks to maintain head at the outlets. If fields are stepped to overcome steep side falls, the head ditch might require stepping at each field boundary. A flatter grade means a larger ditch to carry the same flow.

A low pad is normally constructed to the design grade with laser controlled equipment. The ditch can then be graded or delled to the desired depth, leaving the banks at the required height and on grade. The banks should be sufficiently high to provide a water level 150 to 300 millimetres above the field level, to provide adequate head for siphons or outlets.

The ditches are often designed with some over-capacity to allow for the effects of temporary weed growth and to accommodate flow variations. A flat-bottomed trapezoidal head ditch is more expensive to build than a 'V' ditch but has more capacity and is easier to use. An overflow should be provided at the end to allow non-damaging overtopping in an emergency.

Field design

The principle of surface irrigation revolves around the intake or infiltration rate of the soil. Water is provided to the field so that wetting of the root zone is satisfied by infiltration through the surface. Once the root zone at the top of the field is refilled, the water should advance down the field to continue refilling the root zone without wastage by continued high infiltration at the top. This process requires heavy clay or clay loam soils and reasonable field slopes to complete an irrigation in a reasonable time and to prevent the top end of the field from overtopping.

The appropriate run length can be determined in theory by balancing the advance and recession phase, giving all parts of the field approximately equal irrigation. Until the last 3 to 5 years, the infiltration characteristics of a field were difficult to measure and the field hydraulics difficult to model. Equipment and computer models are now available to optimise the run length to suit the soil and the farmer's requirements.



Ideally, the run length should be as long as possible, to enhance farming operations and limit the number of head ditches and taildrains and the labour in watering. Although longer runs have been used in the past, run lengths now are generally limited to a maximum of about 800 metres. In furrow irrigation, longer lengths require larger furrow streams, leading to furrows being overtopped and eroded. The possibility of furrow erosion from storm run-off is also a risk with long runs. Shorter run lengths are necessary in soils of higher infiltration capacity.

Other factors also impose limits on run length. In picking cotton, for instance, the capacity of the picker basket can limit the length. In many cases, the layout has to fit between two defined boundaries. The distance between boundaries should be divided by the whole number which gives a run length closest to the ideal. Once the run length has been selected, the furrow stream (number and size of siphons) and irrigation setting times are adjusted to evenly apply the required amount of water into the root zone.

Furrows should be designed to run down the slope, although some crossfall can be tolerated. Excessive crossfalls can result in furrow overtopping, leading to erosion across the furrows. Very little or no crossfalls can be tolerated with bay or border check irrigation. Uniform run lengths are desirable in any field and preferably on the whole farm. Furrows should be parallel to side boundaries, avoiding point rows at headland and taildrains.

Landforming is expensive, and it is not practical to change the natural slope too much. Large cuts can also result in the exposure of infertile subsoil, with subsequent yield loss for several years. On the other hand, it is difficult to achieve even gradings where slopes are too flat, say 1:2000. If necessary, shorter run lengths can be used to minimise earthworks on very flat country.

Nearly all fields are now graded using laser controlled equipment. Lasers make construction easier and provide very uniform grades which greatly facilitate irrigation and drainage. Computer programs are available to calculate grading schedules. Fields should be broken into sub-areas to minimise earthworks, and different combinations of run length, down slope and cross slope should be tried.

Be wary of designers and contractors who are overnight experts. Just because they have a computer doesn't mean that they can design a system: 'have computer, can design' or 'have laser bucket, can construct' does not make sense. Training and experience will save large sums of money with field design and construction. To start laser grading a field without a design is like driving to Birdsville without a map.

Taildrains

Taildrains are required to remove furrow or bay run-off following irrigation or rainfall. In most areas, drain capacity will be dictated by storm flows. The capacity provided will depend on the time in which drainage must be provided. Most crops require drainage of stormwater within 24 to 48 hours. For high value, waterlogging-sensitive crops such as cotton, more rapid drainage is desirable, but the costs of drains and culverts increase rapidly. The design capacity is therefore a compromise between the time taken to drain the field and drainage costs.

The selection of the design storm is necessary to complete the hydraulic design of the system. The cost of providing facilities to cater for a large event may never be recouped. A one in five year event is usually selected as the design storm for cotton. The drain capacity is then designed to remove this water from the field in, say, 24 hours.

Taildrains should have gentle grades, but preferably steeper than 1:3300, with almost zero capacity at the end. Drain batters should be very flat to allow ready access across the drain when it is dry and provide a turning area for cultivation practices. Generally a 20 horizontal to 1 vertical slope is used on the field side with say 10:1 batter on the road side. Taildrains must be low enough to completely drain the field without causing erosion into the drain from the irrigation furrows or bays. Generally the depth between the drain bed and the field level should not exceed 300 mm to 400 mm.

Tailwater return system

Scarcity of water and environmental factors mean that re-circulation of tailwater is essential in most areas. The high cost of labour also means that careful supervision of irrigation, cutting off of siphons at precisely the correct time, is often not practical. Re-circulation is an economic alternative.

If possible, tailwater should be collected in a buffer storage to overcome the problem of matching tailwater pumps to the variable tailwater flows. When sufficient volume has collected in the buffer, the water can be pumped to a main storage or directly to the supply system for irrigation. Pumping tailwater directly back into the supply system for irrigation can cause problems with adjusting the necessary control structures to cater for the variable tailwater flow.

The tailwater return system also collects stormwater run-off, which in many areas is a welcome addition to the water supply. Even with buffer storage, there is a need to safely dispose or blow-out stormwater from large events. Tailwater pumps cannot keep up to a large storm or may not be working during a storm, due to access problems, for example. An emergency overflow facility is required, allowing excess water to be disposed of safely. A grassed bywash around the buffer storage may be used, or a gap can be provided in the bank of the tailwater return drain where design water level is at natural surface level. A gated weir structure in the tailwater system is sometimes required to release stormwater but exclude floodwater.

Culverts

All surface irrigation systems require culverts for access and flow control. Culverts are expensive, and a good layout will minimise the number required. Concrete culverts have a longer life, but steel pipe is easier to lay and can be cheap if second-hand pipe is available. Modern surface coatings are now increasing the service life of steel structures.

The choice of correct culvert size is a compromise between the capital cost of the extra size versus the capital and operating cost due to extra head produced by using a smaller pipe. The smaller pipe will require a greater head (water level upstream of the culvert will rise), requiring higher canal banks upstream and resulting in higher pumping costs over the life of the project.

Headwalls should be used to:

- contain the road or canal embankment,
- make the culverts more efficient hydraulically (reducing head loss),
- minimise silting in the culvert, and
- aid maintenance.

Headwalls can sometimes be added in the final stages of the development to save initial cost.

Remote sensing

The technology of remote sensing of water levels in channels and storages and remote control of gates and pumps is becoming very useful. It can provide significant advantages during normal irrigation and when controlling stormwater. The possibilities are nearly limitless:

- alarms can be set when water reaches a certain level anywhere on your farm;
- pumps can be started and monitored;
- gates can be opened and closed from the office or anywhere else to reduce the need to drive on slippery and narrow channel banks.

Remote sensing also provides the opportunity to collect accurate information for the assessment of on-farm water use efficiency and system performance. In the near future, accurate on-farm water balance measurements will be routine. With this technology it will be possible to know where each megalitre is on the farm.

Soils for storages and canals

Soils can loosely be classified by particle size as follows:

Class	Particle size
Rock	Large ↓ Very small
Gravel	
Coarse sand	
Fine sand	
Silt	
Clay	

Generally, as the particle size of the soil becomes smaller, the soil leaks less water. For water-holding and conveyance structures, only silts and clays are suitable. Sands and gravels in a ring tank storage or supply canal or drain will leak too much water. This leakage will also continue indefinitely unless sealed by membranes or clays.



A clay is made up of particles which are microscopic in size and are held together by molecular forces. Once wet a clay will leak only a very small amount. Very heavy clays have a saturated permeability which is so small it is difficult to measure.

Silts are made up of particle sizes which are very small (cannot be seen with the naked eye) but which are considerably larger than clay particles. Silt does leak a little and will continue to leak even when saturated.

Ideally then, all ring tank storages and earthen canals and drains should be constructed out of clay. Once the floor and walls of a clay ring tank or canal become wet the seepage losses are very small.

Any silts, sands or gravelly areas within the ring tank or canal will leak and must be sealed by lining with a layer of compacted natural clay from nearby or by membranes or imported bentonite or similar.

Experience and training is required to distinguish between a silt and a clay because both look very similar, particularly when dry.

Electromagnetic surveying for storage or channel site selection

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Irrigation infrastructure can experience significant seepage losses if inappropriately located on permeable soils. Detailed soils investigation involving backhoe pits are required as a minimum to determine soil properties for storage design. (See, for example, *SOILpak for cotton growers* C1 'Soil pit digging: where, how and when?')

A better option (one which provides more detail) is an electromagnetic (EM) induction survey. EM surveys of existing or planned irrigation infrastructure and irrigated fields can show variations in soil properties. The site selection of channels and on-farm storages has been improved by the use of EM surveys. These surveys allow the delineation of a field into distinctly different areas, based on apparent electrical conductivity, and allow accurate targeting of soil sampling and measurements. The appropriate location of channels and on-farm storages reduces losses to groundwater systems and increases the water resource available for productive use.

EM surveys generate data in the form of apparent electrical conductivity (EC_a). Apparent electrical conductivity is primarily related to the salt, clay and moisture content of the soil. The EC_a value is a potential indicator of soil permeability. The EC_a data are linked to GPS data at the time of collection: this ties them to a specific location for future reference. The resulting point source data are analysed with the aid of computer-generated mapping to look for trends. Several sites in each test area are then selected for 'ground-truthing' by backhoe pits or test boring and higher level analysis. The aim of ground-truthing is to confirm the range and properties of soil variations identified by the EM survey.

Soil profiles can be highly variable, consisting of layers of fine, medium and coarse textured soils, which resulted from prior stream and aeolian deposition that formed the current landscape. Surface soil features do not necessarily give an accurate indication of the nature and permeability of the underlying soil. Most soil based irrigation structures require 3.5 to 5 m of uniform medium to heavy clays below the deepest cut in order to have acceptable seepage losses.

The EM technology allows for a much more thorough subsurface investigation. It also allows for identification of patterns of soil types.

Refer WATERpak Topic 5.3 'Assessing and managing irrigation salinity' for more information on the EM technology.

Refer *SOILpak for cotton growers*, page C7-5.

The perfect layout

Naturally, there is probably no such thing. Obviously the 'perfect' layout for Narrabri, NSW will be different to that for Emerald, Queensland and Hay, NSW.

However, there are a number of desirable qualities a good layout should provide:

- uniform run lengths over the whole farm
- regular rectangular fields
- a minimum number of control and access structures consistent with easy access
- a deep square ring tank to store irrigation tailwater and first flush stormwater and to help manage regulated water
- a supply system on one side of the farm and a tailwater return system on the other side, with drains less than 3 m deep and canals with banks less than 3 m high
- a tailwater return system on the outside of the irrigation area to allow for stormwater blow-out
- a natural depression at the bottom of the tailwater return system which can be used as a buffer storage filled by gravity during large storms; its contents can then be pumped back to the ring tank or fields at leisure
- each field with the same soil type within the field.

What is the **optimum run length**?

Like everything else with an irrigation system, this depends on the crop and the soil and the natural slopes. The objective of selecting a run length is to provide the longest run that allows even application of irrigation water and that applies

the required depth of water in a convenient irrigation setting time without erosion of the soil during irrigation or storms.

As the run lengths increase the furrow flows need to become larger and the tailwater volumes become larger to achieve even irrigation. Further, with longer run lengths it becomes very difficult to apply small irrigation applications. In summary, shorter is better for irrigation efficiency and uniformity of application but the cost of development and operation increases. The best compromise for cotton grown on grey cracking soils is between 400 and 800 metres.

The optimum grades? This answer is simple: as close to the natural slopes as possible, because changing grades is very expensive and damages the thin productive topsoil layer. Anything from 1:500 (0.2%) to 1:1650 (0.06%) can be managed efficiently by varying furrow flows and irrigation setting times. Grades steeper than 1:500 can suffer erosion from storms if runs are too long, and grades flatter than 1:1650 are difficult to drain and yield loss from waterlogging can be a problem.

Conclusion

It is possible to 'put together' a surface irrigation system with little more than some earthmoving equipment and commonsense. Many farmers are prepared to do this, unaware of the complexities of the system with which they are about to become involved (ask someone who has tried!). The result is very often a system that costs more to construct and is a pain to operate. This may be in the short term, due to higher or

unnecessary construction costs and loss of their time, or in the long term, due to higher operating costs.

An irrigation engineer can marry the skills of a civil or agricultural engineer and an agronomist. He or she should ensure that the system is cost effective and that it can be operated efficiently. Design costs generally run to only a few percent of the overall development costs.

Every element of a surface irrigation system can and should be designed to operate correctly. It is a great relief to a farmer to know that what is being built will work properly. A good design repays itself many times over.

References

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- Queensland Water Resources Commission 1984, *Farm water supplies design manual*, Volume II: Irrigation Systems, eds AJ Horton and GA Jobling, Queensland Water Resources Commission.
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2.6 Assessing the efficiency of storages, channels and reticulation systems

Sarah Hood

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Key points

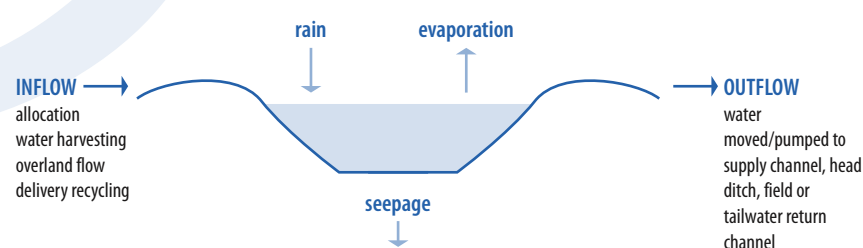
- Don't assume that evaporation and seepage are the greatest losses from your storages, channels or reticulation system.
- Take measurements to find out what your greatest loss is.
- Determine if these losses are a problem by carrying out an economic assessment of the benefit that could arise from addressing these losses.

Whole farm water use efficiencies are reduced by excessive evaporation or seepage losses, or both, while water is being stored in dams, conveyed around the farm, applied to fields or returned to the storage. This topic considers the opportunities for measuring evaporation and seepage losses

from storages, channels and reticulation systems and assessing whether these losses are acceptable based on industry standards.

Channels, storages and return systems have a similar set of inputs and outputs, as shown in Figure 2.6.1 below.

Figure 2.6.1: Components of the water balance of storages, channels and return systems

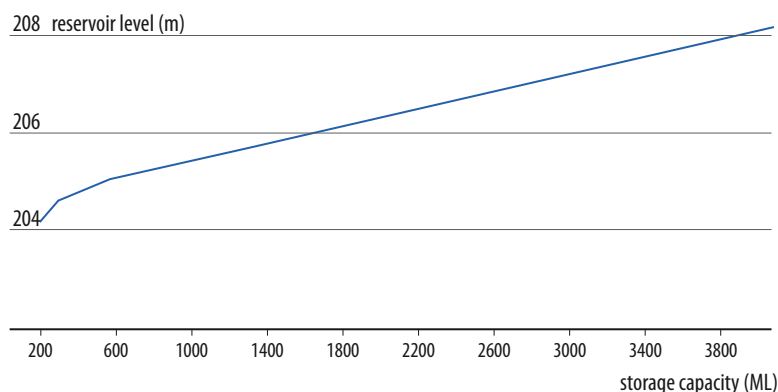


Source: Dalton et al. 2002

Measurement of storage volumes

Engineers produce storage curves for each dam they build. An example of a storage curve for a dam situated at St George, Queensland is provided in Figure 2.6.2. Storage curves relate the amount of water stored or storage capacity in megalitres to the height of the water in the dam. The height of the water is recorded as its height above sea level.

Figure 2.6.2. Storage curve for a St George farm dam



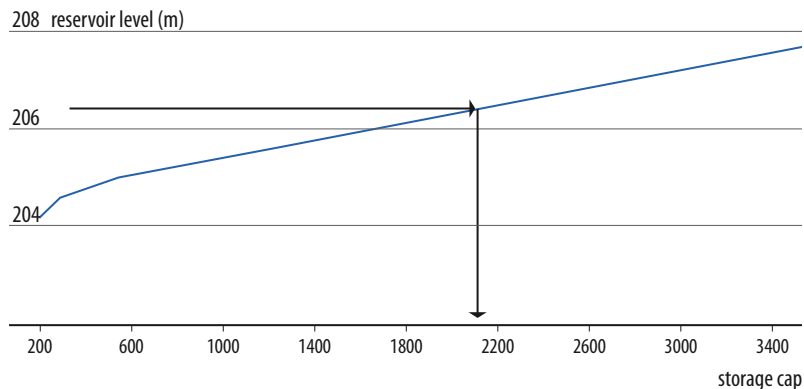
Gauge boards are designed from storage curves. Figure 2.6.3 is a photograph of the gauge board that corresponds to the storage curve in Figure 2.6.2. This is a manual gauge board in that you have to physically go out and estimate the height of the water. Some engineering companies such as Measurement Engineering Australia are providing electronic gauge boards. These electronic gauge boards estimate the height of the water every 15 minute period and can either be manually downloaded or transferred by telemetry back to an office computer.

Figure 2.6.3. Gauge board for the storage curve in Figure 2.6.2



By using this gauge board to determine the height of the water the grower is able to estimate the amount of water in storage by reading the corresponding storage capacity on the storage curve. For example if this gauge board was read as 206.5 m above sea level then, from the storage curve, the corresponding storage capacity is 2100 ML (see Figure 2.6.4).

Figure 2.6.4. Using the storage curve to estimate storage volumes



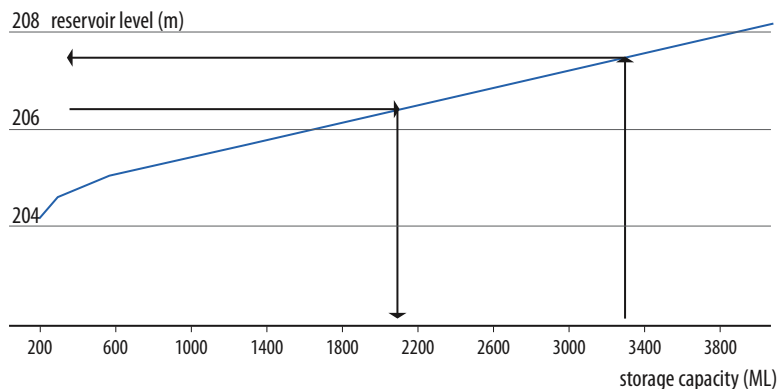
When storage curves and gauge boards are not available, then the grower should consult with the engineer that designed or built the ring tank, as they should have the records necessary to develop these tools. Alternatively the grower could survey their storages using their own or hired GPS equipment and provide these data to an engineering firm to do the same.

When meters have been installed on the inlets or outlets of storages they can be used with the storage curves and gauge boards. For example, the storage being considered in Figure 2.6.4 is estimated to be storing 2100 ML. A pumping event occurs and the flow meters measure an inflow of 1200 ML. The gauge board should now read a height of 207.5 metres above sea level if both instruments are working at the same level of accuracy. (See Figure 2.6.5.)

When the meters and the gauge boards do not correspond, there would be reason to check the accuracy of both instruments. For the gauge board this may involve re-surveying the dam and designing a new storage curve.

Installation is critical to the accuracy of meters. Ensure that the meter has enough laminar flow either side of where it is installed. Laminar flow refers to straight pipe a considerable distance from inlets and outlets so as to avoid turbulence. Some meters also need to be fully submerged before they begin recording. Ensure that all recommended installation and management procedures are adhered to.

Figure 2.6.5. Flow meters with gauge boards and storage curves



If meters were not installed, then the reverse of this procedure could be used to determine pumping volumes. That is, according to the gauge board, the water level went from 206.5 to 207.5, which corresponds to 1200 ML. Furthermore, when water is stored over a period of time without any inflow or outflow, then the drop in water height directly corresponds to net evaporation and seepage losses. If evaporation rates for that period of time were known, then these could be subtracted from the net loss in order to estimate seepage losses.

Estimating evaporation losses

Evaporation cannot be measured but rather is estimated from the prevailing environmental conditions (see Topic 2.12). Evaporation losses from storages can be estimated as a depth of water (mm) over the surface area (ha) of the storage. Weather stations with appropriate sensors (maximum and minimum temperatures, relative humidity, solar radiation and wind speed) can be programmed to estimate and record daily reference evapotranspiration rates (ET_o).

Evaporation rates (based on the Class A Evaporation pan) can also be accessed from the Patched Point Dataset available from the Bureau of Meteorology's SILO Service. Details on this service and the subscription cost can be found at <http://www.bom.gov.au/silo>. Average Class A Pan evaporation rates are also available from the Bureau of Meteorology's website (www.bom.gov.au) or the Rainman software.

Typical monthly pan evaporation rates for centres in or near cotton growing regions are provided in Table 2.6.1. These evaporation rates will need to be reduced by a factor of 0.75 before use in evaporation calculations.

Evaporation rates from Class A Pans (E_{pan}) shown in Table 2.6.1 must be converted to reference evapotranspiration (ET_o) using a pan coefficient (K_p). The relationship between these terms is given by:

$$ET_o = K_p \times E_{pan}$$

The K_p values vary with the size and state of the upwind buffer zone, the relative humidity and wind speed, with the height of the surrounding crop, painting of the pan, and the level at which water is maintained in the pan. For a pan placed in a short green cropped area and 100 m on the windward side of a dry surface, the K_p ranges from 0.7 (with wind speed below 2 m/s and the average relative humidity below 40%) to 0.85 (with wind speed below 2 m/s and the average relative humidity above 70%). For a pan placed in a dry fallow area, 100 m on the windward side of a green crop and with similar conditions, the K_p ranges from 0.55 to 0.75. As such, unless other information is available, growers should use 0.75 to convert pan evaporation to open water evaporation.

Most commercially available automatic weather stations equipped to estimate reference evapotranspiration usually calculate the Penman-Monteith ET_o (see 2.13 'Using automatic weather stations to estimate evapotranspiration'). The evaporation rate from an open water surface (ET_c) is then calculated from ET_o using a crop coefficient (K_c) for an open water surface. The K_c value for a water storage less than 2 m depth, or in sub-humid or tropical climates, is 1.05. The formula to calculate evaporation loss from the storage is thus:

$$ET_c = K_c \times ET_o$$

Example

A grower at St George with the 4.12 ha storage in Figure 2.6.6 wishes to estimate the likely evaporation losses from water that has been stored for two weeks in January. From Table 2.6.1 the average E_{pan} is 10.8 mm/day (335 mm ÷ 31 days). Thus over two weeks the average E_{pan} is 151 mm (10.8 mm/day × 14 days). This value can be converted to an ET_o figure using $K_p = 0.75$.

$$\begin{aligned} ET_o &= K_p \times E_{pan} \\ &= 0.75 \times 151 \text{ mm} \\ &= 113 \text{ mm} \end{aligned}$$

The evaporation loss for this period (ET_c) is found from:

$$\begin{aligned} ET_c &= K_c \times ET_o \\ &= 1.05 \times 113 \text{ mm} \\ &= 119 \text{ mm} \end{aligned}$$

This figure becomes more useful when it is converted to a loss of water in ML over that period of time.

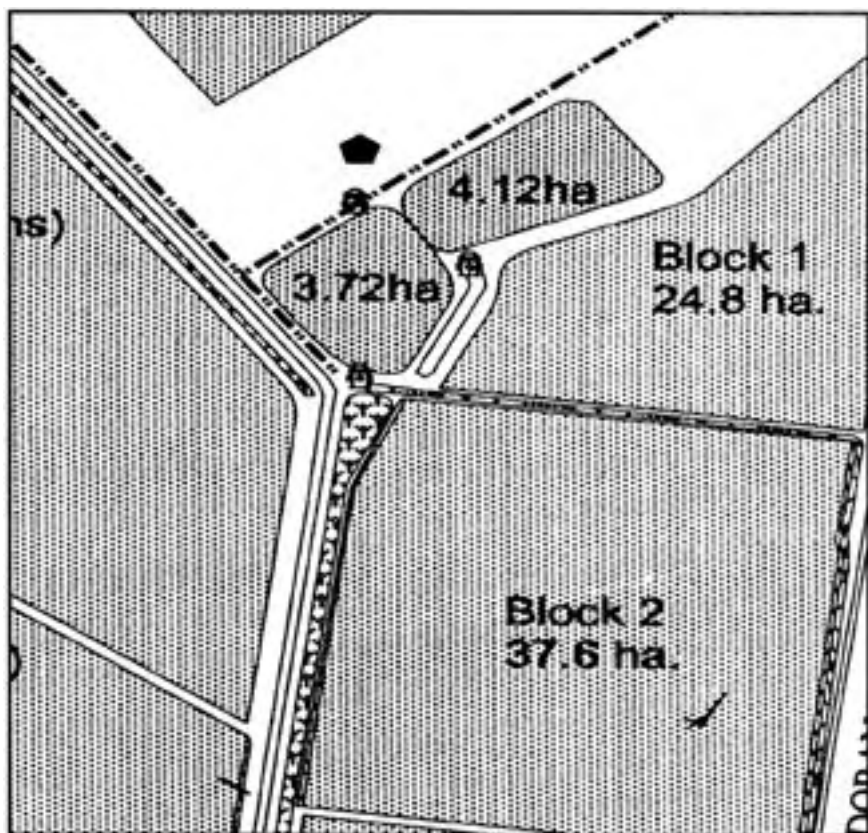


Table 2.6.1. Average monthly Class A pan evaporation (mm) for centres in or near cotton growing areas

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Biloela	223	190	186	144	105	87	90	115	156	198	216	236	1947
Bourke	257	207	183	120	78	57	62	93	126	183	225	264	1854
Collarenebri	341	258	226	147	102	84	87	109	150	220	282	357	2362
Cunnamulla	388	314	267	174	115	90	99	133	189	270	333	415	2786
Dalby	245	202	223	168	124	90	90	109	147	171	219	248	2035
Emerald	276	210	198	159	124	108	118	155	201	260	291	304	2404
Gatton	202	162	164	129	96	84	93	115	153	183	195	214	1790
Goondiwindi	307	244	211	144	99	81	87	112	150	214	261	298	2206
Griffith	316	260	202	123	74	57	62	81	108	164	237	301	1985
Gunnedah	254	207	208	141	93	63	65	93	129	177	213	264	1906
Hillston	273	230	186	114	68	39	47	65	105	161	213	270	1770
Kingaroy	198	160	152	114	84	63	68	93	129	171	186	208	1625
Miles	223	176	177	126	81	60	65	90	135	177	192	226	1728
Moree	291	232	220	147	96	69	71	99	144	211	258	301	2140
Mungindi	341	246	214	147	102	87	93	112	147	211	267	322	2289
Narrabri	310	246	217	144	99	78	84	105	138	198	258	326	2204
Oakey	245	196	198	150	102	78	90	118	156	198	219	245	1996
St George	335	272	233	159	109	90	99	124	174	242	300	353	2489
Tamworth	285	230	205	141	93	72	78	93	126	180	237	295	2033
Theodore	264	193	192	162	124	105	112	136	171	208	258	285	2210
Trangie	291	235	208	138	81	54	56	81	114	177	231	295	1960
Walgett	248	213	192	123	78	51	56	81	123	180	219	257	1820

Source: Bureau of Meteorology

Figure 2.6.6. Farm map showing storages



The evaporation rate of 119 mm can be converted to a volume of water by dividing by 100. The 119 mm is equivalent to 1.19 ML/ha. Over 4.12 ha of the storage surface this is 4.9 ML ($1.19 \text{ ML/ha} \times 4.12 \text{ ha}$) lost over 14 days in January.

Estimating evaporation losses from your on-farm storage

In summary, to estimate evaporation losses from ring tanks you need to obtain:

- an evaporation rate in ML/ha
- the area (ha) of the ring tank.

Step 1 is covered in detail in Topic 2.12, and touched on above.

Step 2 involves calculating the area of water exposed to evaporation. Storage surface areas are calculated by measuring distances and calculating the area mathematically, or by using GPS technology to map out the area. GPS technology could be either a grower-owned instrument or provided through farm mapping services.

Figure 2.6.6 is a section of a farm map that was supplied to the grower showing areas of fields, channels and dams. There are two storages on this property – a 4.12 ha storage and a 3.72 ha storage.

If this map were unavailable to this grower, the area of these storages would need to be estimated by assuming that the shapes are approximately rectangular. For the 4.12 ha dam the length was approximately 400 m and the width was approximately 100 m, according to the tachometer in the vehicle. The area of the rectangle is calculated as follows:

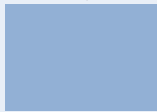
$$\begin{aligned}
 &\text{Area of rectangle (ha)} \\
 &= \frac{\text{length (m)} \times \text{width (m)}}{10\,000 \text{ (m}^2\text{)}} \\
 &= \frac{400 \text{ (m)} \times 100 \text{ (m)}}{10\,000 \text{ (m}^2\text{)}} \\
 &= 4 \text{ ha}
 \end{aligned}$$

Obviously all dams are not rectangular in shape. They can be a range of regular and irregular shapes. However, most irregular shapes can be divided into a combination of regular shapes, the sides of which can be estimated using the tachometer in the vehicle as above or using GPS technology to map out the shapes.

The equations for calculating some of the regular shapes are listed below. For extremely irregular shapes try to divide them into smaller regular shapes.

Calculation of the area of different shapes

Rectangle or square



$\text{length} \times \text{width}$

Triangle



$\text{base} \times \text{height} \div 2$

Circle



$\text{radius} \times \text{radius} \times 3.14$

Measurement of evaporation and seepage losses

If storages, channels and tailwater return systems are all operating under the same water balance, then the same approach can be used to measure evaporation and seepage losses. This approach has three steps:

1. Directly measure inflow, rainfall and outflow.
2. Estimate evaporation.
3. Calculate seepage as the unknown part of the water balance. For example, if you

know how much water has been supplied and you subtract the amount extracted, the amount remaining in the system and the amount evaporated, then the difference is the seepage loss.

Accurate measurement is critical, otherwise evaporation or seepage losses will be over- or underestimated. This may mean that management strategies which are then employed to reduce a loss may be unnecessary and therefore a waste of money and resources. Table 2.6.2 lists the equipment that can be used to monitor each part of the water balance.

Table 2.6.2. Equipment to measure the components of the water balance from an on-farm water storage dam

Component	Equipment
Inflow	Flow meters Storage curve and gauge board
Rainfall	Rain gauge
Outflow	Flow meters Storage curve and gauge board
Evaporation	Weather stations (using Penman-Monteith approach to estimating reference crop evapotranspiration, ETo) Class A Evaporation Pan
Seepage	Water balance (inflow – outflow – water remaining within the system – evaporation)

The following case studies demonstrate how evaporation and seepage losses can be measured in storages, channels and tailwater return systems.

Case study 1 – Farm storage at Dalby

(Source: Dalton et al. 2002)

A 20 hectare storage at Dalby on the Darling Downs was carrying 1000 ML at the start of the cotton season on 21 September 2002. At the end of the season (14 April 2003) this had been reduced to 134 ML.

During the season 250 ML had been extracted from the river during a water harvesting event, 124 ML had been caught in the storage from overland flow following rain, 105 ML had been returned as tailwater and the total rainfall was 312 mm. A total of 856 ML was pumped to the fields over 4 irrigation events.

The calculations below summarise the water in-flows and out-flows of the storage for the cotton season only, not for the whole year.

Inflow = starting volume + water pumped from the river + rainfall + overland flow + tailwater

where:

Starting volume = 1000 ML

Water pumped = 250 ML

Rainfall = 312 mm over 20 ha (storage surface area)

= $312 \div 100 \text{ ML/ha} \times 20 \text{ ha} = 62 \text{ ML}$

Overland flow = 124 ML

Tailwater = 105 ML

Thus, inflow = $1000 + 250 + 62 + 124 + 105 = 1541 \text{ ML} = 77.05 \text{ ML/ha over 206 days}$

Water remaining in storage = 134 ML

Outflow = 856 ML

Evaporation = 1395 mm (over the 206 days that water was stored)

= $1395 \div 100 \text{ ML/ha} \times 20 \text{ ha} = 279 \text{ ML from 20 ha over 206 days}$

= $279 \text{ ML} \div 20 \text{ ha over 206 days} = 13.95 \text{ ML/ha over 206 days}$

= $0.068 \text{ ML/ha/day} \approx 6.8 \text{ mm/ha/day}$

Seepage = inflow – outflow – water remaining in storage – evaporation

= $1541 \text{ ML} - 856 \text{ ML} - 134 \text{ ML} - 279 \text{ ML}$

= 272 ML = 272 ML from 20 ha over 206 days

= $272 \text{ ML} \div 20 \text{ ha over 206 days} = 13.6 \text{ ML/ha over 206 days}$

= $0.066 \text{ ML/ha/day} \approx 6.6 \text{ mm/day}$

Total storage losses = evaporation + seepage losses

= $13.95 \text{ ML} + 13.6 \text{ ML} = 27.55 \text{ ML/ha over 206 days}$

Percent water lost = total losses/total inflow

= $27.55 \text{ ML/ha} \div 1541 \text{ ML/ha} = 36\%$

Storage efficiency = 100 – percent water lost

= 64%



Case study 2 – A tailwater return system

(Source: Dalton et al. 2002)

A meter was installed in a tail drain and in one irrigation event in January the tailwater entering the return channel was metered as 28.8 ML. Another meter at the dam measured that 28.6 ML was re-lifted into storage. The return channel was 0.4 ha and the water was in the channel for 3 days. Class A Pan Evaporation was 8.1 mm/day – this equals 5.95 mm/day evapotranspiration ($8.1 \times 0.7 \times 1.05$ - with a $K_{pan} = 0.7$ and $K_c = 1.05$).

Inflow = 28.8 ML

Outflow = 28.6 ML

Evaporation = 5.95 mm/day over 3 days over 0.4ha

$$= 5.95 \text{ mm} \div 1000 \text{ mm} \times 0.4 \text{ ha} \times 10,000 \text{ m}^2 \times 1000 \text{ L/m}^3 \times 3 \text{ days}$$

$$= 71,400 \text{ L} \quad \quad \quad = 0.07 \text{ ML}$$

Seepage = inflow - outflow - evaporation

$$= 28.8 \text{ ML} - 28.6 \text{ ML} - 0.07 \text{ ML} \quad \quad \quad = 0.13 \text{ ML}$$

$$\approx 0.13 \text{ ML} \div 0.4 \text{ ha} \div 3 \text{ days} \quad \quad \quad \approx 0.108 \text{ ML/ha/day}$$

$$\approx 10.8 \text{ mm/day}$$

Case study 3 – Supply channel, Goondiwindi

(Source: Dalton et al. 2002)

This is an example of a case where inflow and outflow are irrelevant, as over the period of measurement no extra water was put into the system and no water was taken from the system.

A supply channel at Goondiwindi was holding water between irrigations. A gauge board was being used to determine the total loss over this period. It was calculated that the average total loss per day was 14.6 mm/day. The Class A Pan evaporation loss was 13.6 mm/day – this equals 10.0 mm/day evapotranspiration ($13.6 \times 0.7 \times 1.05$, where $K_{pan} = 0.7$ and $K_c = 1.05$).

As there was no inflow and outflow over the period, the seepage losses can be calculated as the difference between these total losses and evapotranspiration.

Seepage = total loss - evapotranspiration

$$= 14.6 \text{ mm/day} - 10.0 \text{ mm/day} \quad \quad \quad = 4.6 \text{ mm/day}$$

$$\approx 0.046 \text{ ML/ha/day}$$

Efficiency assessment

Once losses have been estimated then it is important to consider weather these losses are in fact a problem. The calculation of storage and channel efficiency is useful in assessing the magnitude of the loss. These have been calculated for each of the above case studies.

Channel efficiencies should be higher than dams because water is not usually stored for long periods of time before it is used, and this reduces the opportunity for evaporation and seepage. This is why the installation of cells in larger storages improves their efficiencies. As Dalton (2000) found, a cell that was filled at the start of the season with water that was used straightaway on pre-irrigation had a storage efficiency of 85% while the other cell that was filled at the start of the season but then used on later irrigations had a storage efficiency of 55%.

However, the decision to mitigate either evaporation or seepage is usually based on economics: the cost of mitigation must be less than the expected return from the water that is saved.

Case study 4 – Farm storage at Dalby

(Source: Dalton et al. 2002)

The storage efficiency of the farm dam in Case Study 1 is calculated as follows:

Storage efficiency (%)

$$= \frac{\text{water used from storage during the season} \times 100}{\text{water stored in storage during the season}}$$

$$= \frac{\text{water pumped from storage} - \text{tailwater return} \times 100}{\text{starting volume} + \text{water pumped from the river} + \text{rainfall} + \text{overland flow} - \text{ending volume}}$$

$$= \frac{(856 \text{ ML} - 105 \text{ ML}) \times 100}{(1000 \text{ ML} + 250 \text{ ML} + 62 \text{ ML} + 124 \text{ ML} - 134 \text{ ML})}$$

$$= 751 \text{ ML} \div 1302 \text{ ML} \times 100$$

$$= 58\%$$

Note: Storage efficiency should be above 70%.

Case study 5 – A tailwater return system

Case Study 3 considered a tailwater return system; its efficiency was:

Tailwater efficiency (%)

$$= \frac{\text{outflow from system} \times 100}{\text{inflow into system}}$$

$$= 28.6 \text{ ML} \div 28.8 \text{ ML} \times 100 = 99\%$$

Table 2.6.3 lists the evaporation and seepage losses together with the associated storage/channel efficiencies for each case study above.

References

Dalton, P 2000, 'WATERTIGHT, Whole Farm Water Use Efficiency, Determining Your Own Water Security', in *Proceedings of the 2000 Australian Cotton Conference*, 16th – 18th August 2000, Brisbane.

Dalton, P, Lockrey, T and Spragge, A 2002, *Cotton irrigation efficiency assessment & improvement: volumetric, agronomic and economic irrigation efficiency optimisation training workshop notes*, Queensland Department of Primary Industries, Dalby, Queensland.

Dalton, P, Raine, S and Broadfoot, K 2001, *Best management practices for maximising whole farm irrigation efficiency in the Australian cotton industry*, Final Report for CRDC Project BEC2C, National Centre for Engineering in Agriculture Publication 179707/2, USQ, Toowoomba.

Table 2.6.3. Evaporation, seepage and storage/channel efficiency of the storages and channels presented in the case studies

Case study	Evaporation mm/day	Seepage mm/day	Storage efficiency %
1 – Storage	6.8	6.6	58
2 – Tailwater	5.95	10.8	99
3 – Supply channel	10.0	4.6	N/a



2.7 Managing evaporation and seepage in storages and channels

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Key points:

- Modifying the effect that wind speed and surface area have on evaporation is the key to reducing evaporative losses from storages and channels.
- Seepage issues are most commonly caused by unplanned or poor construction, use of unsuitable soil type, poor soil compaction and poor maintenance.
- Prevention is better than cure! Maintain and monitor storages and channels to save expense and losses in the long term.
- To choose how or whether to mitigate evaporative or seepage losses, balance the cost of the repairs against the short or long-term benefit, and the value given to the water being lost and the crop being produced.

Topic 2.6 covered how to measure evaporation and seepage losses from channels and storages. Once you have measured these losses you can then determine whether there is an economic benefit in improving the efficiency of these systems. Does the return per megalitre of water saved outweigh the cost per megalitre to save it?

This topic looks at various strategies that can be employed to mitigate evaporation and seepage losses from channels and dams and discusses some of the costs associated with each method. Case studies then demonstrate how individual growers decided to manage their channel and storage losses.

Evaporation mitigation strategies

Cells and cell management

Evaporation is most significantly affected by wind speed and surface area. Modification of these factors represents the greatest opportunity for reducing evaporation losses. By dividing a single storage into a series of smaller storages, water can be transferred between cells in order to minimise the surface area exposed to evaporation, and minimise the opportunity time for evaporation to occur. Dalton (2000) found that a cell that was only filled for a month had an efficiency of 85%, while a storage that was filled and not used for 7 months had a storage efficiency of 55%. Dividing a single storage into a series of smaller cells also reduces the impact of wind by reducing wave action, which not only reduces evaporation but protects against bank failures and associated water losses.

Windbreaks

Windbreaks can benefit your dam by reducing wave action and wind speed, minimising both dam wall erosion and evaporation.

If a windbreak is placed to the east or the west, solar radiation will be reduced for a small period of the day, also reducing evaporation.

Windbreaks can reduce wind speed from 25% to 75%, with the effects being felt at a distance of up to 20 times the height of the trees downwind and 4 times the height of the trees upwind.

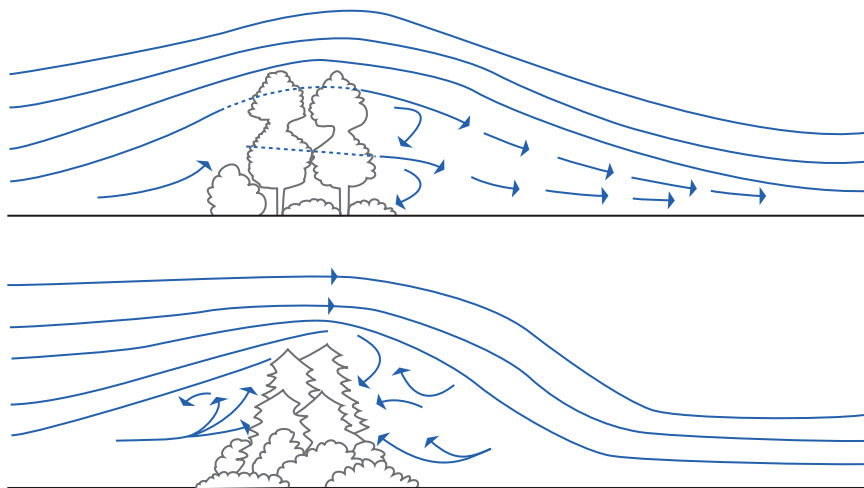
When planning a windbreak there are a number of things that you should consider:

Tree lines should be placed at right angles to the wind that is causing you the most damage. (For example: the wind comes from the north-east 65% of the time, while a hot dry wind comes from the south-west for the rest of the time. You may feel that you are losing more water due to the wind from the south-west, so you place your windbreak accordingly.)

Any tree line planted should be placed at least 15 m away from your dam wall, to ensure that the roots do not penetrate and create tunnels through the storage wall.

Tree species is important in determining the distance the tree line affects, its density and the amount of air that gets through.

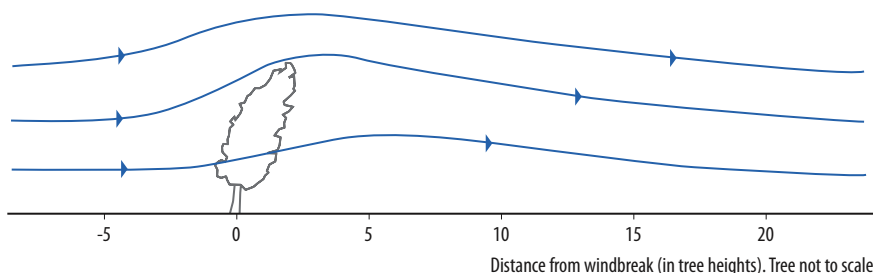
Figure 2.7.1. Your tree line will be more effective if it allows some breeze through.



Windbreaks that block all of the wind are not as effective as shields that let a light breeze through. Winds eddy on the lee side of the trees, and the distance for which the tree line is effective is reduced if the windbreak is too thick.

Source: DNRTree Facts 1996

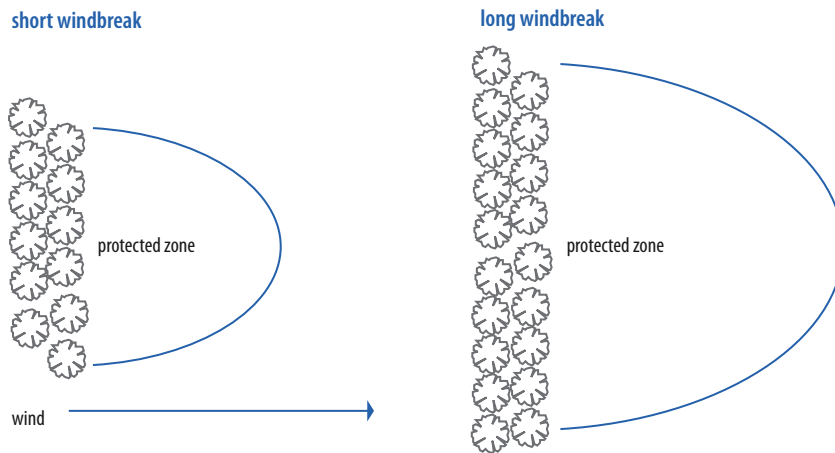
Figure 2.7.2. An effective windbreak can protect for up to 20 times its own height.



Source: Agriculture Western Australia Tree Notes 1999

Ensure that your windbreak is greater than the length of your dam, as wind eddies around the ends of windbreaks.

Figure 2.7.3. To increase the amount of area protected by the windbreak, increase the length of the tree line.

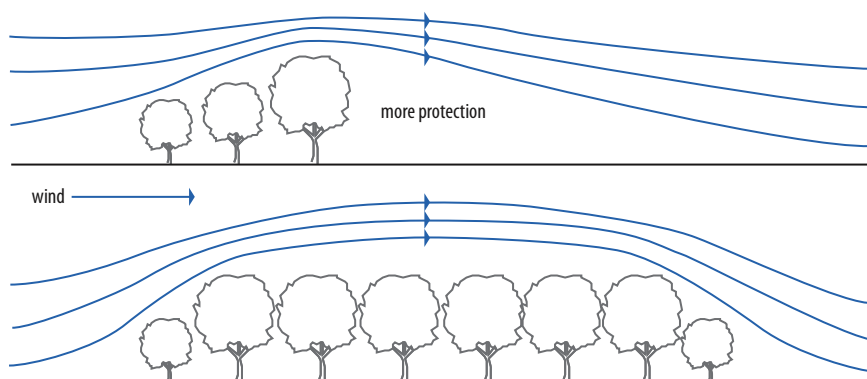


Source: DNR Tree Facts 1996

Doubling its length can increase the area protected by up to 4 times.

For effective protection windbreaks should be about 3 rows of trees wide. Adjoining trees should be offset to reduce the chances of gaps in the wall.

Figure 2.7.4: The width of the windbreak will affect the distance down wind that is protected.



Source: DNR Tree Facts 1996

Establishment and maintenance of the trees is important: prepare your site well. If you have livestock, it would be advisable to fence the area to protect the trees. Control weeds and grass around the trees, and apply fertiliser to the trees as they need it. Regularly inspect the trees to ensure that all trees are healthy and have an acceptable growth pattern. If any trees are dead or are not growing properly, remove them and replace them.

Roots should be pruned on the dam side of the trees and on any side that the trees would cause damage or affect yield. Rip at least 50–70 cm deep about 5 m away from the trees every year. The types of trees that you plant can determine how often you prune the roots of your tree line. Some varieties of trees will sucker where their roots have been cut: in this case the suckers will have to be controlled.

Spacing of the trees is dependent on tree type, its size and shape. Trees should be planted to ensure there is a continuous screen of foliage when the trees are mature.

When choosing the right trees for your windbreak keep in mind other uses for your trees. Other uses to increase the profitability of your tree line may include timber, fruit or cut flowers.

Tree lines, especially when they are a mix of native species, can also provide ecological benefits by being a host for a range of bird species, insects and bats.

For information on what trees are suitable for your climate and soil type contact your local nursery and have them advise you on which trees would be best for you in your tree line. The best trees for your tree line are most probably ones which are native to your area.

Deeper cells

Dam size and shape are important when you are trying to minimise evaporation and drainage. The deeper the cell, the smaller the surface area of the water exposed to the forces of evaporation.

Reducing the amount of water exposed to evaporation has the potential to expose more water to seepage. When constructing deep cells, be careful not to expose base rock or a permeable seam: this is where soil cores are valuable. If you do happen to expose base rock, be sure to cover it with at least 300 mm of compacted clay to prevent seepage.

If you are considering constructing a new farm dam or increasing your dam size it is important to consult local authorities to find out the regulations concerning dam construction.

Surface (suspended or floating) barriers

Surface barriers include covers and floating chemicals.

A **monolayer** is a lime base mixed with industrial alcohol that is approximately one molecule in thickness: it floats and spreads across the water surface. Monolayers have been approved by the World Health Organization for use on domestic water supply dams. Typically only small amounts are required (between 0.5 and 0.75 kg/ha) and can be introduced already in solution or as solid crystals or flakes. Under ideal conditions monolayers have been quite effective, reducing evaporation by 60%, but on open large storages they are also effective, at rates of 35%. Wind and wave action can move the monolayer around, reducing its effectiveness on large open storages. Due to UV light breakdown, monolayers usually need to be reapplied regularly (every 3 or 4 days in the middle of summer).

Plastic covers, either suspended or floating, reduce evaporation by providing a barrier to solar radiation, and can mitigate wind action. On small dams they have reduced evaporation by 95%.

(Further information can be found in the final report from Qld NRM on *Methods for Reducing Evaporation from Storages used for Urban Water Supplies*, GHD Pty Ltd, 2003, which covers general product information on surface barriers, water quality issues, environmental issues, safety issues, effectiveness, ease of installation and maintenance, cost, storage size and availability.)

Seepage mitigation strategies

Pinpointing the cause of seepage issues can be a very difficult task. Most common causes include poor or unplanned construction, use of unsuitable soil type, poor soil compaction, and poor maintenance, to list a few. There are many methods and materials available to mitigate seepage problems. Which method to use depends on the nature of the problem, the cost and associated lifespan of the solution. Several of the most common methods are described below.

Clay lining

If suitable clay can be found on or near your property, clay lining may be a very cost-effective way of sealing a seepage problem. There are different ways to line a storage, depending on the nature of the seepage. In some cases both the excavation base and embankment

may need to be lined. In other cases a clay bench or plug may need to be formed to line any seams or patches of porous material. In all cases a minimum of 300 mm of compacted clay must be used. The clay must be applied in layers at optimum soil moisture content.

The NSW Agriculture Agfact *Leaking farm dams* describes a simple field test to determine correct moisture content for effective compaction: roll the soil into a worm between your palms. If the soil crumbles before it reaches pencil thickness, it is too dry. If the soil can be rolled to a thickness less than that of a pencil, it is too wet.

Bentonite

Bentonite is a naturally occurring non-toxic clay which is commercially mined and swells to many times its dry volume. Several methods are used to apply bentonite including mixed blanket and pure blanket methods, which are applied when the storage is empty, and broadcasting, a method used when water exists in the storage.

The **mixed blanket** method is recommended on light or loam soils and is incorporated into the first 150–200 mm of soil at a rate of approximately 7 kg/m² and then compacted with a roller.

The **pure blanket** is a layer of pure bentonite and is recommended on heavy soils. A pure blanket is spread evenly over the area at a rate of approximately 10 kg/m² and compacted with a roller. Bentonite blankets should be covered with at least 100 mm of site soil to prevent cracking as the storage dries.



Broadcast application simply means spreading the bentonite over the water surface at a rate of approximately 10 kg/m². The bentonite settles to the bottom and seals the storage floor. This method isn't highly recommended, as success is limited.

Synthetic lining

Many commercial liners of varying strength and durability are available to seal dams including woven polythene, black polythene, vinyl, high density polyethylene, butyl rubber and composites of bentonite and polypropylene.

The soil that liners are placed upon must be compacted to hold their shape, and must not contain sharp objects such as stones and roots that may damage the liner. Consideration must be given to the positioning of the lining to prevent seepage underneath, and the liner must be secured somehow. It is advisable to check with the manufacturer, as some products are susceptible to UV and chemical degradation.

Impact roller

Compaction is used to reduce losses from dams and channels. Impact rolling is a method of compacting material that is meant to be more effective than conventional rollers. It is a square roller that is dragged along by the tractor and supplies more energy per area being compacted because it literally 'thumps' the soil.

It works best on soils that contain clay, which should be moist, but not saturated.

A good response can be expected from non or poorly compacted material on channel banks. Impact roller compaction has been used in the floors of some dams but it must be remembered that it is critical to know what other factors are contributing to the excessive seepage rates. For example, impact rollers will be less effective if the floor of the storage has been constructed on inappropriate material.

The square impact roller is hired out with a tractor at approximately \$2500 per day. Other costs include cartage at \$2.30 per kilometre each way to the site, and a set-up demonstration fee of \$1000. Groups of growers in the one valley have considered hiring the impact roller out together to help reduce some of these costs.

Storage maintenance

Prevention is better than a cure! Simple storage maintenance and monitoring can sustain the efficient state of a storage and minimise the long-term costs of seepage mitigation strategies.

Steps involved in maintaining a storage and techniques to monitor the state of a storage are listed below:

- Maintain a vegetative cover of grass along the inside batter of your dam. Trees and shrubs are not recommended along the embankments. Grass is not recommended along the outside or the top of your dam wall as it can dry out and penetrate the core, weakening the wall.

- The outside of your dam wall can be maintained a number of ways: by packing cracks and rills with compacted clay, grading the wall and the crest or applying a soil adhesive like PVA regularly.
- Prevent the formation of cracks and rills on the inside of the dam banks. Fill the rills and cracks with soil and grass.
- An early sign of slumping is cracks along the length of the dam wall. It is best to seek professional advice if this occurs.
- If wet patches are occurring along your dam wall, seepage is a problem. Areas of concern can be packed with compacted clay materials. If the problem spans over a large area, the dam can be lined with either a natural material or a synthetic liner.
- Tunnelling can be controlled through plugging the hole with carefully compacted soils or lining your dam with a synthetic liner. Tunnelling is an indication of poor dam structure and you should seek professional advice.
- Laying stone or establishing runner grasses along areas affected by wave action can reduce the damage. Trees and shrubs can be planted strategically to reduce the energy of prevailing winds (windbreaks).
- Dam weeds can be controlled in four different ways:
 1. environmental control: by reducing the nutrients in the water and variations in water depth, and by reducing sunlight, possibly by using a dam cover.
 2. biological control: introducing insects, animals or diseases. This option is only available for introduced weeds.

3. mechanical control: the physical removal of weeds by hand or machinery (i.e. sloper blade).

4. chemical control: an easy, cheap alternative is herbicide control, but it can cause large environmental problems. Always apply chemicals according to label recommendations and remember that labels are a legal document.

Note: not all water plants are weeds: identify them before you try to control them. For more information on how to control aquatic plants contact the Department of Natural Resources, Mines and Energy, NSW Agriculture or your local chemical supplier.

- High nutrient levels in a dam can encourage algae growth. Kits are available to monitor the nutrient levels in your dam.
- Producers should not allow their dams to dry out. Drying of a dam weakens the wall, allowing cracks to penetrate the core. When filling a dry dam, fill slowly and watch closely for weaknesses in the wall.
- When filling a newly constructed or dry dam, carefully observe the dam and its foundations. The rate of filling should be no more than 300 mm of water a day, and preferably less than 100 mm a day. If problems are observed, filling should cease and water levels should be lowered so the problem can be rectified.
- Fence out any livestock.

Case study 1, Dam covers

Dam covers have proven to be an effective tool for mitigating evaporation losses from 4 to 5 hectare ring tanks in the St George region. The reduction could be in the order of 85% according to an irrigation enterprise that has installed and is investigating the potential of a dam cover on their mixed cropping enterprise in the St George Irrigation Area.

The local Queensland Department of Primary Industries water use efficiency officer estimated evaporation losses from storages in the St George District to be up to 7 ML/ha in the 2002/2003 irrigation season. For some irrigators, this meant they could potentially lose up to one-third of their stored water to evaporation.

The E VapCap® dam cover is made of a virgin grey polyethylene with built-in air cells to enable it to float positively on top of the water. The cover has a white upper to protect against UV damage, and a black underside to minimise algal growth.

The cover was delivered in large rolls to the dam site and sections riveted together on the water. After overcoming challenges with installation, the large amount of on-site work required and bad weather conditions, improvements were made and a patented welding method was used to join the sections of the cover and to bury the edges in a 500 mm trench dug into the dam wall. The cover has since seen out many high wind speed storms and allowed the irrigation enterprise to plant an opportunity melon crop and 40 acres of table grapes from the water saved by the dam cover.

Currently, this particular dam cover costs \$6.00 a square metre fully installed. If the crop being produced is a high value crop, it is estimated that the cost can be fully recovered within one year. For a lower value crop it would take longer to recover costs. Based on long-term cotton prices, the average irrigated cotton grower can only afford to spend \$2.50 a square metre to mitigate evaporation at this rate. It is envisaged that continual improvements in evaporation mitigation technologies will eliminate practical challenges and improve cost effectiveness.

Figure 2.7.5. A dam cover fully installed, proving to be an effective method of reducing evaporation from storages



Case study 2, Dam evaporation and seepage mitigation trial

In 2001, a local Emerald irrigator measured losses of 1 m in less than a month from his newly constructed water storage. Aware that water storages were a source of large water losses on farm, and concerned by the losses he had experienced in his own operation, the irrigator teamed up with Emerald's water use efficiency (WUE) officer and water use efficiency researchers to quantify what was being lost, and what could be done about it.

An on-farm trial was designed to look at accurately measuring losses of evaporation and seepage from on-farm storages and to trial various commercially available tools for reducing seepage and evaporation. Eight 70,000 litre capacity dams were constructed, as listed below in Table 2.7.1.

Table 2.7.1. Trial dams

Dam	Size (m)	Treatment
1	4 × 4 × 4	uncompacted, uncovered (control)
2	2 × 8 × 4	compacted, deep and narrow construction
3	4 × 4 × 4	compacted, lined and covered (Figure 2.7.6)
4	4 × 4 × 4	compacted and top-covered
5	4 × 4 × 4	compacted and lined (Figure 2.7.7)
6	2 × 5 × 6	compacted, shallow and wide construction
7	4 × 4 × 4	treated with bentonite (sides and base)
8	4 × 4 × 4	compacted (base and sides)

Figure 2.7.6. Covered and lined dam. Polypropylene liner and polyethylene cover



Case study 2 continued

Figure 2.7.7. Lined dam



The eight dams were constructed by a private contractor who specialised in building dams. A sheepsfoot roller was used in those treatments that were compacted. Liners and covers were installed by Darling Downs Tarpaulins. In 2001 bentonite was incorporated into dam 7 as a mixed blanket and in 2002 bentonite was broadcast into the dam.

The trial was monitored weekly to measure evaporation and seepage losses. A water reticulation and float valve system was used to top up the trial water levels once a week. A weather station was erected at the site to monitor site conditions. Dams were filled and maintained at the expense of the irrigator himself. Dams 3 (covered and lined), 4 (covered), 5 (lined), and 7 (bentonite) were monitored using ultrasound equipment with the help of Queensland Natural Resources & Mines (NR&M).

Losses from evaporation and seepage that were recorded over a two-year period are shown in Table 2.7.2.

Table 2.7.2. Water storage daily losses (mm) from 2001 to 2003

Treatment	2001/02	2002/03
Covered and lined	4.73	4.55
Covered	10.53	7.44
Lined	6.86	6.18
Bentonite	29.13	55.58

The data for the two seasons show fairly consistent results, with the covered and lined dam retaining the most water, followed by the lined treatment. Water was lost more readily through seepage than through evaporation.

Case study 2 continued

The covers used for this trial were made of a plastic material with air pockets to keep it afloat and holes to allow rain through (E-Vap Cap®). Throughout the two seasons a number of technical problems occurred with the covers. In December 2002 the covers blew off during a storm and during the 2002/03 season silt and algae started to affect the covers' flotation. Further research and improvements are being undertaken by the National Centre for Engineering in Agriculture on these covers and other evaporation-reducing products.

Cost of covers – \$6.60/m², 5 year guarantee

The liner used was a 0.5 mm high-density polyethylene sheeting fusion welded to fit the dam. Holes have started to appear in the lining. It is suspected that kangaroos after having a drink may put holes in the lining trying to get out. Holes in the lining started to diminish the effectiveness of the lining, but it is still reducing water losses from the dam (Table 2.7.2).

Cost of liner – from \$3.56/m² to \$8/m², life expectancy 25-30 years

Bentonite was chosen, as it is a non-toxic, naturally occurring clay chemical compound sodium montmorillonite that swells when wet. This expansion helps to seal pores and cracks in the dams and water channels. Between the 2001 season and the 2002 season the dams were allowed to dry out, allowing cracks to appear. Cracks in naturally lined dams can cause weaknesses, increasing water losses when filled. The bentonite dam lost more water during its second season because of this problem. At the start of the 2002 season, water use efficiency officers broadcast bentonite into the dam. Broadcast is a recommended method of application, but in our trial it was not effective. Basic dam maintenance could have been used to minimise the losses such as maintaining a minimum water level and filling cracks.

Cost of bentonite – \$15/40 kg

Mixed blanket – 7 kg/m²

Pure blanket – 10 kg/m²

In the first year of this trial the irrigator incorporated bentonite into the walls of his own on-farm storage in an attempt to reduce seepage. Due to the dam being regularly filled and emptied throughout the year, the irrigator is unable to maintain a minimum water level. Since the incorporation of bentonite, water has continued to be lost through seepage, but the amount of water being lost from the dam was reduced as a result of the bentonite. Water savings from bentonite will vary and for good results it is important that it is applied evenly, compacted and well maintained.

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2.8 Metering irrigation water

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Key points

- Water meters can be used to establish pump efficiencies and benchmark irrigation system performance.
- Correct installation of a water meter is as important as the choice of water meter.
- There are three main types of flow meters – electromagnetic, ultrasonic and propeller actuated.
- In comparing water meters, irrigators should consider their accuracy, repeatability, ability to handle trash and irrigation water, the effect of wear on their performance and cost.

Measuring water flow to manage it

To manage irrigation water it is important to first measure it. Irrigation water meters are commonly used to measure the quantity of water supplied from an irrigation scheme, harvested from a river or extracted from a bore. Water meters are beneficial when used as a tool for improving on-farm water use efficiency. The information gained from water meters can be used to establish pump efficiency levels and benchmark irrigation system performance.

Knowing how much water is being pumped onto individual paddocks is the key to improving irrigation efficiency. On-farm system checks using water meters have highlighted serious pump inefficiency and variability, as well as large discrepancies between grower's water use estimates and measured volumes.

Water meter installation

To gain the maximum benefit from your investment in a flow meter, correct installation is essential. In fact, installation requires the same level of consideration as that applied to choosing the metering technology used to record water usage.

Flowmeter installations should provide as great a length of straight pipe upstream and downstream from the meter as possible to condition the flow (by, for example, removing excessive swirling) prior to the flow reaching the sensing element. Most manufacturers specify a minimum distance of straight pipe equivalent to 10 pipe diameters upstream of the meter and five pipe diameters of straight pipe downstream of the meter. These distances are to prevent turbulence from adversely affecting flow meter readings. When attempting to accurately measure water flow rate, 40 pipe diameters of straight pipe upstream of the meter and 25 diameters of straight pipe downstream are commonly used. Essentially, the greater the length of straight pipe used for the meter installation, the better.

Meters should not be placed:

- immediately after a pump
- immediately after a gate valve
- immediately after a bend. The worst type of bend is one with two out-of-plane 90° bends – this will induce a swirling flow that will cause large errors in the metered flow.

These poor installation locations cause inaccuracies in the volume of water measured regardless of the metering technology used.

Types of water meters

There are three main types of flow measurement technologies used when measuring irrigation water – electromagnetic, ultrasonic and propeller actuated. There are five characteristics of meters that should be considered when comparing meters - their accuracy, repeatability, ability to handle trash and irrigation water, the effect of wear on their performance and cost.

Electromagnetic meters

Electromagnetic meters (EM) typically consist of a short section of flanged pipe surrounded by a copper coil. Sensors within the short section of flanged pipe measure the small electrical current induced in the coil as water moves through the pipe.

The velocity of the flow through the metering section of pipe is calculated based on Faraday's law of induction, whereby a conductive liquid flowing through a magnetic field induces an electrical current. The amount of current induced is directly proportional to the average flow velocity of water through the meter.

This induced current is measured and the corresponding water velocity is calculated and multiplied by the cross-sectional area of flow to give the flow rate, which is displayed and stored in an electronic register. This measurement technique only requires a low level of electrical conductivity (EC) in the water for it to work, $EC > 2 \mu S/cm$, a level found in virtually any irrigation water.

Accuracy of this metering technology is very high, as the complete cross-section of the flow in the pipe is sampled and no interference to water flow is provided by the sensing technology. Repeatability of the flow measurement is also very good.

The ability of EM meters to handle trash, sand and silt is very good, as there is no obstruction to flow. EM meters are robust, have no moving parts, and have an extremely low maintenance requirement. They are capable of being powered by solar panels and battery systems, and the complete meter can be buried and forgotten. Many of the existing battery powered meters can hold power for up to 5 years.

Existing users of EM meters have encountered problems when poor electrical grounding conditions occur and when electronic displays overheat through lack of heat protection.

Cost starts at \$2000 for meters suitable for 100 mm diameter pipe and rise in proportion to the diameter of pipe. EM meters have been built up to 3 m in diameter (where the price would be in the ~\$60,000 range). Costs for 600 mm diameter meters are around \$6000.

Ultrasonic water meters

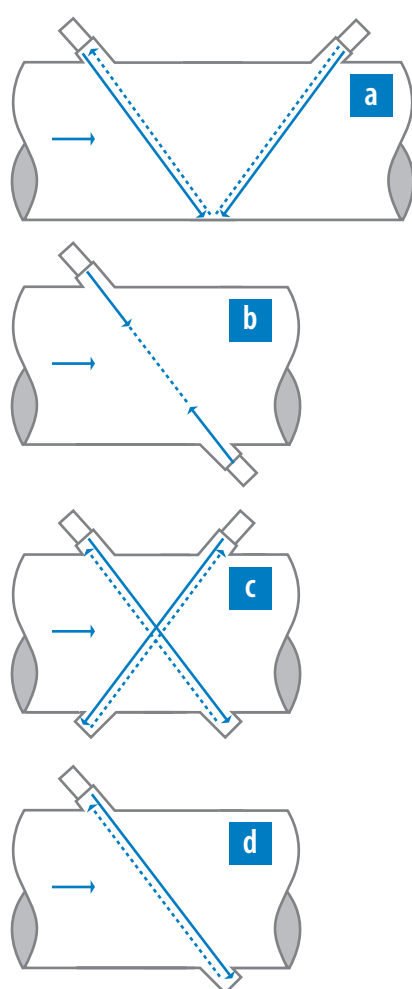
There are two different types of ultrasonic water meters used to measure irrigation water flow rates: these are the ultrasonic Doppler meters, and the transit time or time-of-flight meters.

The transit time or time-of-flight water meters are now becoming more popular as their technology improves and cost of production reduces.



Transit time meters measure the small variations in time for an ultrasonic sound wave travelling upstream and downstream between fixed points. These fixed points are the sensor/emitter head and a second sensor/emitter head or alternatively a reflecting surface on the pipe wall. The velocity of water flowing through the metering section varies the time taken for the sound wave to traverse the pipe.

Figure 2.8.1 Single path examples of some transit time sensors



Source: Pat Weldon, NSW Agriculture, 2003

The variation in the time of flight of the signal is proportional to the velocity of the water through which the signal moves. Water velocities are sampled in a band between the two sensor heads across the entire pipe diameter.

Accuracy levels are high when installed correctly, and these sensors do not rely on particles being entrained in the flow. Repeatability is also good, as there are no moving parts to wear, and the sensing equipment does not interfere with the flow or provide positions upon which trash and particles can get caught and interfere with flow measurement.

Their price starts at ~\$5000 and is independent of pipe size. They can be used in pipes from 100 mm to 1.5 m.

Ultrasonic Doppler meters consist of a sensing head that is inserted into the pipe perpendicular to the flow, and, as the name suggests, they operate upon the Doppler principle. The sensor head transmits an ultrasonic signal that is reflected back to the head off suspended particles in the flow. The reflected signal arrives back at the sensor head with its velocity changed by the particles that have reflected it. This change in velocity is used to calculate the particle's velocity and the overall pipe flow velocity. The pipe velocity is converted to a flow rate by multiplying by the cross-sectional area of the pipe.

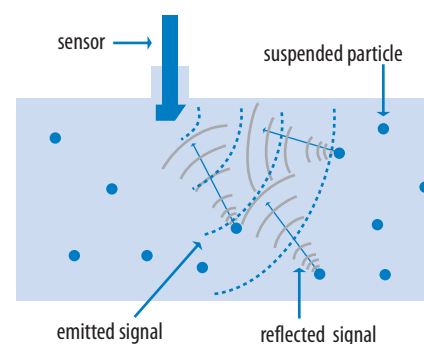
Their accuracy depends on how well they are installed and on the water quality. If the sensor head is not parallel to the pipe axis, then the signal received is not a representative of the true velocities of the flow cross-section and an incorrect velocity profile is recorded.

If the water quality is high, there will not be enough particles in the flow to reflect the ultrasonic signals, resulting in poor accuracy and repeatability. To obtain good signal reflection the particles in the water must be silt size and bigger. Colloidal clay particles are too small to effectively reflect the sound signal and groundwater supplies are often too clean. To some extent, Doppler meters can sense small bubbles and eddies generated close to pumping stations and are unsuitable for high-pressure pipe systems.

Costs start at about \$3000 and are independent of pipe size. A number of irrigation water supply authorities have been using the meter to measure irrigation water flow.

Ultrasonic velocity sensors can be combined with depth/pressure sensors to measure water flow through partially filled pipes, in tailwater return systems and in many open channel situations.

Figure 2.8.2. Ultrasonic Doppler meter operation



Source: Pat Weldon, NSW Agriculture, 2003

Propeller-actuated meters

There are two main types of propeller-actuated (PA) meters and they are differentiated by the orientation of the axle upon which their propeller operates.

The **parallel axle propeller actuated (PA) meter** has its axis of rotation parallel to the flow and pipeline. Three subtypes of parallel axle PA meters are commonly used in irrigation and are different in the way they sample the flow velocities in the pipe.

1. The first subtype samples a small area of flow with a micro-propeller that is inserted into the pipe. A magnetic pulse is generated for each rotation of the propeller and this is electronically recorded and displayed.
2. The second type of PA water meter uses a two-bladed aeroplane type propeller that has the capacity to handle poorer water quality and samples the fluid velocities across the majority of the pipe diameter. The speed of the propeller rotation provides a measure of the flow velocity, from which volumetric flow can be calculated, and its rotating action drives a physical register.
3. The third type of parallel axle PA meter uses a full-bore helical rotor that engages the complete flow at any one time.

Accuracy of all PA meters is generally low. Because they are cheap, they are currently the water meter of choice for water supply authorities. They have a high susceptibility to wear from grit and, as the in-stream bearing systems become dirty, poor repeatability of flow measurement results. They are also prone to clogging from weed and trash because of their physical sampling of flow.

Their cost ranges from \$800 for 100 mm diameter pipe through to \$5000 to \$6000 for 600 mm diameter pipe.

The **propeller actuated Pelton Wheel type water meter** has its axis of rotation perpendicular to the flow of water. The wheel is inserted into a pipe at a predetermined depth according to pipe internal diameter (ID). The velocity of the water is calculated from the rotations of the paddle wheel. Some meters have adjustable depth settings and can be programmed to suit different pipe IDs. It samples a small part of the flow and their accuracy tends to be poor. They can be fitted into irrigation equipment with diameters from 50 mm to 500 mm or greater.

They are one of the cheaper types of water metering technologies with costs starting at around \$1500 and generally not increasing with increasing pipe diameter.

Tables 2.8.1 to 2.8.4 provide a guide to water flow measurement in irrigation.



Table 2.8.1. Irrigation guide to flow measurement – Dethridge meter and electromagnetic flowmeter

	Dethridge meter standard	Electromagnetic flowmeter
Applications		
Open channel farm off-takes	Yes	Yes
Gravity & pressure flow piped farm off-takes	No	Yes
Specifications		
Accuracy (typical)	2%	0.5% to 2%
Flow range	3 to 9 ML/day	Depends on size
Turn-down (flow range)	3 to 1	Up to 1000 to 1
Ideal piping requirement upstream	560 mm	5 diameters
Ideal piping requirement downstream	310 mm	3 diameters
Other special installation requirements	Requires 380 mm level upstream	Requires full pipe
Reliability including tamper-proof protection	Low	Very high
Flow rate indication available	No	Yes
Remote reading capability	Requires separate device	Yes
Output signal type	Requires separate device	Analog & pulse
In-built telemetry output	NA	Yes
Can meter be buried	No	Yes
Average operating life before overhaul	10 years for wheel	20 years
Pressure loss (headloss)	75 mm	Negligible
Resistance to blockage	Low to medium	Very high
Resistance to weed	Medium	High
Relative installed cost	Medium	Medium to high
Power required	No	Yes or solar
Advantages		
	Easy to use	Highly accurate
	No power	No moving parts
	Robust	No wear
	Low head	Robust
	Reliable	Low pressure loss
Disadvantages		
	Variable accuracy	Requires power
	Inaccurate at low flows	Requires full pipe
	Affected by varying water levels	Specialist skills to repair
	Wear of bearings and vanes	
	OH&S hazard	
	Restricts access along channel	
	Yabbies cause channel leakage	

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

Table 2.8.2. Irrigation guide to flow measurement – mechanical flow meters

	Mechanical Insert (paddle or turbine) meter	Mechanical Turbine water meter
Applications		
Open channel farm off-takes	No	No
Gravity & pressure flow piped farm off-takes	Yes	Yes
Specifications		
Accuracy (typical)	2% to 5% of rate	2% to 5% of rate
Flow range	Depends on size	Depends on size
Turn-down (flow range)	Size dependent (9 to 1) to (15 to 1)	30 to 1
Ideal piping requirement upstream	10 diameters	3 diameters
Ideal piping requirement downstream	5 diameters	3 diameters
Other special installation requirements	Requires full pipe	Requires full pipe
Reliability including tamper-proof protection	Medium	Medium
Flow rate indication available	No	No
Remote reading capability	Optional	Optional
Output signal type	Pulse	Pulse
In-built telemetry output	No	No
Can meter be buried	No	No
Average operating life before overhaul	4 years depending on water quality	4 years depending on water quality
Pressure loss (head loss)	400 mm	200 mm
Resistance to blockage	Medium	Low to medium
Resistance to weed	Medium	Low to medium
Relative installed cost	Medium	Medium
Power required	No	No
Advantages		
	Reasonably accurate	Reasonably accurate
	Easy to use	Easy to use
	No power	No power
	Reasonably robust	Reasonably robust
Disadvantages		
	Accuracy deteriorates with wear	Accuracy deteriorates with wear
	Inaccurate at low flows	Wear of bearings and vanes
	Wear of bearings and vanes	Difficult to detect tampering
	Difficult to detect tampering	Turbine can be fouled
	Propeller can be fouled	Specialist skills to repair
	Specialist skills to repair	

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.



Table 2.8.3. Irrigation guide to flow measurement – propeller meter and Ultrasonic flowmeter

	Propeller meter Closed type & open flow	Ultrasonic Flowmeter
Applications		
Open channel farm off-takes	Yes	Yes
Gravity & pressure flow piped farm off-takes	Yes	Yes
Specifications		
Accuracy (typical)	2% of rate	Better than 2%
Flow range	Depends on size	Based on velocity (0-8 m/s)
Turn-down (flow range)	Size dependent (6 to 1) to (16 to 1)	150 to 1
Ideal piping requirement upstream	5 diameters	6
Ideal piping requirement downstream	1 diameters	2
Other special installation requirements	Requires full pipe	Nil
Reliability including tamper-proof protection	Medium	High
Flow rate indication available	Yes	Yes
Remote reading capability	Optional	Yes
Output signal type	Pulse	Analog & pulse
In-built telemetry output	No	Yes
Can meter be buried	No	Yes
Average operating life before overhaul	4 years depending on water quality	15 years
Pressure loss (head loss)	120 mm	Negligible
Resistance to blockage	Medium	High
Resistance to weed	Low to medium	High
Relative installed cost	Medium	Medium
Power required	No	Yes or solar
Advantages		
	Reasonably accurate	Highly accurate
	Easy to use	No moving parts
	No power	No wear
	Reasonably robust	Capable of measuring bidirectional flow
		Can be used for a range of pipe diameters
		Negligible pressure loss
Disadvantages		
	Accuracy deteriorates with wear	Not suitable for filtered water
	Inaccurate at Low Flows	Specialist skills to repair
	Difficult to detect tampering	
	Propeller easily fouled	
	Specialist skills to repair	

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

Table 2.8.4. Irrigation guide to flow measurement –weirs and flumes

Weirs and flumes	
Applications	
Open channel farm off-takes	Yes
Gravity & pressure flow piped farm off-takes	No
Specifications	
Accuracy (typical)	5%
Flow range	Depends on size
Turn-down (flow range)	(10 to 1)V notch, (100 to 1) flume
Ideal piping requirement upstream	20 times flow head
Ideal piping requirement downstream	Sufficient for non restricted flow
Other special installation requirements	Sufficient gradient for free flow
Reliability including tamper-proof protection	Low
Flow rate indication available	Requires separate device
Remote reading capability	Requires separate device
Output signal type	Requires separate device
In-built telemetry output	Requires separate device
Can meter be buried	No
Average operating life before overhaul	15 years
Pressure loss (headloss)	Varies 75 mm to 1000 mm
Resistance to blockage	Low to medium
Resistance to weed	Medium
Relative installed cost	Medium to high
Power required	Yes for flow indication
Advantages	
	Reasonably accurate
	Easy to use
	No power
	Reasonably robust
Disadvantages	
	Accuracy deteriorates with wear
	Inaccurate at low flows
	Specialist skills to repair
	Requires cleaning

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

Further information

ANCID 2001, Selection guide to flow measurement, ANCID's Know the Flow Website, <http://ancid.org.au/ktf>, accessed 1 October 2003.

Baker, Roger C 1989, *An introductory guide to flow measurement*, Mechanical Engineering Publications Limited, London.

Hanson, B and Schwankl, L 1996, 'Error analysis of flowmeter measurements', *Journal of Irrigation and Drainage Engineering*, vol. 124, no. 5, September/October, 1998.



2.9 Assessing field-scale water use efficiency

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Key points

- Relatively small design or management changes at a field level can greatly increase the water use efficiency of a farming system.
- Measuring water use at a field level is an extremely useful management tool. There are techniques available that either irrigators or irrigation consultants can use.
- Water use efficiency at a field level is affected by the volume, uniformity and timing of irrigations and rainfall as well as crop performance.
- Measurement of water volumes can be undertaken by monitoring bulk flows onto a field (any irrigation system) or by monitoring individual furrows and extrapolating data across the field (furrow systems).
- Accurate measurement of soil moisture is important in determining accurate water use efficiencies.
- Commercial services can provide detailed measurement of water use and modelling to assess and optimise irrigation performance of individual fields.

Modifying the application of irrigation water at the field scale potentially has the greatest impact on the water use efficiency (WUE) of your farming system of all possible irrigation system changes. Whilst changes to storage, delivery and recycling infrastructure may provide for a substantial decrease in the volume of water lost, changing application on a field scale can also have an enormous impact on production.

Of course all changes must be made with respect to the capabilities of every other part of the irrigation system. For example, increasing the efficiency of water application to a field cannot be accomplished if the delivery system is unable to cope with a different watering regime.

The aim of this topic is to explain the assessment of WUE at the field scale so that methods of maximising production potential from applied water can be quantified.

This topic is broken into two main sections.

1. The first section describes the WUE indicators available to quantify irrigation performance and discusses the concepts of water application.
2. The second section discusses techniques for obtaining the measurements required to calculate the WUE indicators. Whilst the indicators and definitions provided in this topic are useful for any type of application system, the measurement methods described are generally of relevance to furrow irrigation systems only. Further information regarding collecting these measurements for overhead and drip systems can be found in Topics 4.3 and 4.6.

Water use efficiency concepts and definitions

Water use efficiency indicators

Measuring and improving water use efficiency within surface irrigated fields is more complicated than at any other point within the system. This is because the field acts as both a growing medium and an irrigation application system. Water use efficiency in conveyance and storage systems is typically a relationship between how much water enters that system and how much water is able to leave it. In contrast, water use efficiency within fields is not only a relationship between the amount of water applied to the field and the amount of water available to the crop, but also how uniformly this water is available, how the application of this water affects production and what the combined effects of irrigation and rainfall are. Hence, there is a range of water use efficiency measures that are used when measuring water use efficiency at the field scale. Many of these measures are labelled **water use efficiency indices** to indicate that they are not true efficiencies, which are expressed as percentages.

Application efficiency

Application efficiency is the true efficiency measure that relates the amount of water supplied to the amount of water available to the crop and is represented as a percentage (%). Under most circumstances, the amount of water available to the crop for use is the amount of irrigation water that is delivered to the root zone, that is, the change in soil moisture (ΔSM). For a system aimed at completely filling the soil profile, this is equal to the target deficit.

Application efficiency (E_a) =

$$\frac{\text{Irrigation water available to crop}}{\text{Water received at field inlet}}$$

Example

Furrow irrigation

Total deficit = 70 mm

Target deficit = 70 mm

Total water applied = 1.2 ML/ha = 120 mm

Application efficiency = $70 \div 120 = 58.3\%$

Overhead irrigation

Total deficit = 70 mm

Target deficit = 50 mm

Total water applied = 60 mm

Application efficiency = $60 \div 60 = 100\%$

Note that, in the overhead system, while more water was applied than the target deficit, the total amount was still less than the total deficit. This simplistic example assumes no losses due to wind, interception or high application rate run-off.

Where tailwater recycling is practised, the field application efficiency is effectively increased by reuse of this irrigation water. It is important to calculate a volumetric efficiency of the tailwater return system to be incorporated into the application efficiency term, particularly if a farm irrigation efficiency is to be calculated (see Topic 2.1). Confusion will be minimised if the method of handling tailwater is briefly defined.

Example (cont.)

Furrow irrigation

Total deficit = 70 mm

Target deficit = 70 mm

Total water applied = 1.2 ML/ha = 120 mm

Tailwater available for reuse = 25 mm

Net water applied = $120 - 25 = 95$ mm

Application efficiency = $70 \div 95 = 73.7\%$

Here the volume of tailwater available for reuse is not equal to the amount of tailwater actually leaving the field. In this case, 0.3 ML/ha of water left the field as tailwater, but following distribution losses before reuse, only 0.25 ML/ha (85%) was subsequently available. The application efficiency has been appropriately modified by including the net water application (water applied – water available for subsequent use).



Distribution uniformity

Distribution uniformity is a measure of how evenly water has been applied and is expressed as a percentage (%). Low distribution uniformity results in either part of a field being under-watered, or part being over-watered, in an attempt to apply sufficient water to the rest of the field. It is this practice that most often causes waterlogging to significant parts of a field, which in turn results in potential yield loss. Calculating distribution uniformity for furrow-irrigated fields typically requires computer modelling to simulate an irrigation event. Other uniformity terms may be more applicable for other application systems: please refer to the relevant topics.

Distribution uniformity (DU) =

$$\frac{\text{Average of lowest 25\% of infiltrated depths}}{\text{Average of all infiltrated depths}}$$

Irrigation water use index

Irrigation water use index is a measure that is used regularly, and relates the total amount of production to the amount of irrigation water that was applied to produce this yield. It is a useful measure, particularly for internal economic analysis, as it only accounts for irrigation water (that is, water that was paid for). However, it is less useful as a comparison, particularly between different farms, as it takes no account of rainfall (which may have provided a significant proportion of the crop's water requirement).

Irrigation water use index =

$$\frac{\text{Total production (bales)}}{\text{Irrigation water applied (ML)}}$$

Gross production water use index

Gross production water use index is a measure that is more helpful for comparing the irrigation performance of different fields or farms, and relates total production to the total water used for this production. The index can account for all rainfall, some of which may not have been of use to the crop, or only that rainfall which was effective.

For example, you may wish to compare two fields that both received 350 mm of rain throughout the season. If one field received all of that rain in one event, much more irrigation water would be required for the rest of the season than on another field that may have received the rain in regular, effective events. This may bias the index to indicate that one field produced more bales per megalitre of water applied even though the actual performance of the irrigation systems may be equal.

To minimise the variation resulting from the gross production water use index, the calculation of effective rainfall is needed to provide a very good comparison between fields.

Gross production water use index (total) (applied) =

$$\frac{\text{Total production (bales)}}{\text{Irrigation water applied (ML) + total rainfall (ML)}}$$

Gross production water use index (effective) (applied) =

$$\frac{\text{Total production (bales)}}{\text{Irrigation water applied (ML) + effective rainfall (ML)}}$$

Furthermore, comparing GPWUI (effective) and GPWUI (total) may indicate how effective a particular system is at capturing in-crop rainfall. Effective rainfall is described as the proportion of rain falling on an irrigated area which is effective in meeting the requirements of crop water use. A high intensity rainfall event may result in excess run-off which is not used by the crop and therefore is ineffective. If a rain event occurs when the soil profile is at its maximum moisture holding capacity, no more moisture can be stored and, again, the rainfall event is deemed ineffective. (Refer to Topic 2.1 for more information on effective rainfall.) To avoid confusion it is always important to state whether the GPWUI uses total or effective rainfall.

A combination of all of the above measures can provide a good interpretation of the performance of a field and can allow different fields to be compared. This is especially useful when trying to compare different management systems. It is also important to understand some of the basic processes of irrigation systems at the field scale, especially when poor performance needs improvement. Basic information regarding these processes is available in Topic 2.5.

Water application concepts

Of particular importance is an understanding of the losses that can occur on a field scale, both in terms of water and production. Water application to a field, as either irrigation or rainfall, typically results in a combination of five processes.

1. Useful water is applied to the root zone. This application may continue until the soil profile is filled to field capacity.
2. Additional water applied to the root zone may increase the soil profile to saturation and cause waterlogging (see Topic 3.3).
3. Excess water infiltrates through the soil profile, leaving the root zone as deep drainage (see Topic 2.3). This process may continue after application ceases, as the saturated soil drains to field capacity.
4. Excess water leaves the field as run-off (tailwater).
5. Water is used through evapotranspiration (see Topic 2.12).

Obviously, an ideal system will satisfy the first condition and provide for the fifth condition, whilst minimising the extent of the remaining three. In practice, this can be difficult to achieve. Some of the issues that require consideration follow.

Amount of application

The total amount applied has the greatest impact on the above losses. Applying too much water directly increases the likelihood of waterlogging and the amount of water lost as deep drainage or tailwater. Varying the application amount in a furrow system involves changing the siphon size and time to cut-off.

Uniformity of application

The distribution uniformity influences the amount of water that is required to satisfy the crop requirement. Historically, extra water has often been run to help make up for non-uniformities, so that the entire crop is watered adequately, with some parts receiving too much water. However, there is evidence to suggest that the waterlogging caused by over-watering will have a more dramatic impact on yield than would have been caused by under-watering part of the field.

Distribution uniformity can often be improved through changes to flow rate and watering interval.

Target deficit

The target deficit is the amount of water that the irrigation event aims to supply. Typically, surface irrigation events aim to refill the entire root zone to field capacity so that the interval between irrigation events is as long as possible. In this case, the target deficit would be equal to the total soil moisture deficit (the difference between field capacity and the current moisture content). The moisture content at which

the plant begins to stress, called the Readily Available Water (RAW) content, is typically used as the target deficit for furrow irrigation systems (see Topic 2.10). Whilst this strategy may be appropriate, production is compromised when an irrigation event is closely followed by a rainfall event, as the profile is already full and the rainfall may cause waterlogging. Furthermore, these large wetting/drying cycles make water-related agronomic management difficult.

Another strategy is to aim to only partly refill the soil profile to improve the likelihood of capturing rainfall and allow manipulation of crop stress levels. This strategy of deficit irrigating is one of the advantages of systems able to supply smaller, more frequent events, such as drip and overhead systems (see Topic 7.2). The result is more irrigation events per season, but a greater ability to capture rainfall and manage plant growth and reproduction.

Application frequency

The frequency of application is typically a balance between the amount of moisture in the soil, the likelihood of rain, crop development and the labour requirements for irrigation. Often irrigation intervals are stretched so that fewer irrigations are required during the season and hence less total labour will be required. However, stretching irrigation events can have a negative impact on the performance of surface irrigation systems, as a soil's properties vary with moisture content, and surface irrigation systems rely on



the soil as the application system. Stretching irrigation events will decrease the rate at which irrigation water advances down the furrows (the empty profile takes longer to fill), subsequently affecting the uniformity of application and the total application amount required to fill a certain deficit.

Assessing water use efficiency at the field scale

Two assessment methods will be discussed.

1. The first method consists of relatively simple techniques that can easily be carried out on farm using little equipment. This assessment method can give basic information such as estimates of total water applied, production per ML and application efficiency.
2. The second method consists of detailed measurements using specialised equipment and modelling, a service that is currently available from select engineering consultants. Details of this approach are included so that growers are aware of the kind of information consultants should be collecting and what results can be expected from such services.

Method 1: On-farm measurement

There are a number of measurements that can be taken with relative ease that will help to dramatically enhance the understanding of how an irrigation system is operating at the field scale. Probably the two most important measurements that can be taken by most growers are measures of **irrigation volumes applied** and measures of **soil moisture**.

Measuring irrigation volumes

Measuring water movement onto and off a field can provide valuable information. Unfortunately it is very difficult to measure tailwater without specialised equipment. The most practical method is to measure the amount of tailwater that is recycled using a meter on the pump used to re-lift tailwater. However, tailwater re-lifted into storages is usually a combination of run-off from a number of fields, and this is not useful for individual field analysis. In contrast, measurement of water applied to a field can be achieved in two ways. Because both measurement techniques may not be precise, it is useful to measure both so as to check accuracy.

The first method involves measurement of bulk flows, that is, the bulk water delivered to a field. This can be achieved where meters (as in Figure 2.9.1) are installed on pumps or where water is sourced directly from a metered supply source. However, it is important to be aware of the potential inaccuracies that may exist when metering (see Topic 2.8). The flow conditions (affected by the length of straight pipe upstream and downstream of the metering location) and the meter installation both affect the accuracy of metering devices.

Figure 2.9.1. One of the commercially available water flow meters capable of measuring bulk flows onto and off an individual field



Measurement of bulk flow can become very difficult where more than one field is irrigated by a particular water source at any one time. Accuracy can be severely compromised if fields are grouped together to calculate average water use efficiencies, as the performance of individual fields can vary greatly.

Another difficulty, when assessing surface irrigated fields, is the water that is supplied to the head ditch that does not enter the field. Using bulk flow measurements includes this water, but it has no impact on production. Water that is supplied to head ditches and not used for irrigation purposes should be accounted for when calculating distribution efficiencies (see Topic 2.6). Note that water that enters a ditch and is subsequently used to irrigate another field is not completely lost to the system and needs to be accounted for when calculating water use efficiencies for that field.

The second measurement method involves measuring flow for a selection of individual furrows and then extrapolating that data across the field. Simple techniques for measuring water flow from a single siphon include using a bucket and stopwatch (Figure 2.9.2) or by measuring head height (Figure 2.9.3) and relating this to flow using a siphon head-discharge chart (see Topic 4.2). It is important to keep in mind that these charts offer only an approximation of the flow. The data that needs to be collected to use the siphon head-discharge charts and to then calculate total flow include the head height, siphon internal diameter, siphon length, time the siphon was started and time the siphon was pulled.

Figure 2.9.2. Using a stopwatch and bucket to calculate siphon flow rate



During an irrigation event, dig a hole for a bucket (of which volume is known) under the discharge point of the siphon (or water surface if siphon is submerged). Time how long the bucket takes to fill with a stopwatch.

Flow rate = number of litres/seconds taken to fill

Figure 2.9.3 Measuring head height and using theoretical flow charts to estimate siphon flow rate



A simple field guide to measuring head is by using a brickies' level (a stake with measuring tape or ruler attached and clear plastic tube). Start by sucking water through the tube from the head ditch (no air bubbles), and let the water level reach equilibrium. Head in millimetres is measured from the middle of the discharge point of the siphon (or level of water surface if siphon is submerged) to the top of the water level in the clear plastic tubing. Then, refer to a theoretical siphon flow chart for flow rates relating to particular siphon sizes and head heights.

When measuring head heights for individual furrows there are two main considerations. Firstly, head height will often vary during an irrigation event. This means that if a measurement is taken at a time when the head is at its lowest, the volume applied for that irrigation event will be underestimated, and vice-versa when the head is high. Secondly, flow from different siphons can vary substantially, even from adjacent siphons. It is therefore important to measure the flow rate for a number of siphons and use an average value when extrapolating data across an entire field. This process will often establish the magnitude of these flow variations and their subsequent impact on uniformity and efficiency. It is important to ensure the position of all siphons is as similar as possible to ensure uniform flow rates from each. This variation in flow rate is sometimes also seen between different siphon sets, so measurement of head height should be taken from siphons in a few different sets.

Measuring soil moisture

Measuring soil moisture is important so that the target deficit can be accurately determined. Target deficit is subsequently used to calculate application efficiency. Methods for measuring soil moisture are detailed in the NSW Agriculture Agfact *Soil water monitoring devices*, so they will not be discussed further here. If a measurement of soil moisture is not available, it may be possible to estimate current soil moisture using a previous measure of soil moisture and an estimate of subsequent evapotranspiration as discussed in Topic 2.12.

Putting it together

Having measured irrigation volumes and soil moisture, it is now possible to perform some calculations so that this data becomes more meaningful. Provided water applied and target deficit have been measured, the following measures can be estimated:

- total water applied (ML/ha)
- irrigation water use index (bales/ML)
- application efficiency (%)
- gross production water use index (bales/ML + rain)

Total water applied can be calculated by either:

- dividing the bulk inflow by the number of hectares watered, or
- taking the average individual furrow flow and dividing by the area watered by this furrow.

If all of the irrigations for a season are very similar in terms of duration and head then the total water applied for the season is simply the product of the number of irrigations and the application per irrigation. However, as irrigations usually vary (particularly pre-irrigations), the total water should be calculated for each event separately and summed for the seasonal total.

Example

Total inflow = 120 ML Area irrigated = 100 ha
 Total water applied = $120 \div 100 = 1.2 \text{ ML/ha}$
 Average furrow flow rate = 4.0 L/s Irrigation duration = 9 hours

Total inflow

= $4.0 \times 9 \times 60 \times 60$ (convert hours to seconds)
 = 129,600 L = 0.1296 ML

Furrow length = 600 m Furrows irrigated every 2 metres

Area irrigated by 1 furrow = $600 \times 2 = 1200 \text{ m}^2 = 0.12 \text{ ha}$

Total water applied = $0.1296 \div 0.12 = 1.08 \text{ ML/ha}$

Following calculation of total water application, estimation of the irrigation water use index is now simply a matter of dividing the total production from a field by the total seasonal water use. For very large fields, or where variations in yield are observed between different parts of a field, it is more useful to calculate irrigation water use index using yield for a part of a field and the corresponding water use figure.

Example

head ditch	crop yield – 9.6 bales/ha	total water use – 7.2 ML/ha	tail drain
	crop yield – 11.4 bales/ha	total water use – 7.8 ML/ha	
	crop yield – 10.0 bales/ha	total water use – 7.9 ML/ha	

In top section

Yield = 9.6 bales/ha Water use = 7.2 ML/ha
 Irrigation water use index = $9.6 \div 7.2 = 1.33 \text{ bales/ML}$

In middle section

Yield = 11.4 bales/ha Water use = 7.8 ML/ha
 Irrigation water use index = $11.4 \div 7.8 = 1.46 \text{ bales/ML}$

In bottom section

Yield = 10.0 bales/ha Water use = 7.9 ML/ha
 Irrigation water use index = $10 \div 7.9 = 1.27 \text{ bales/ML}$



Calculating gross production water use index follows this same procedure except that the total water use includes rainfall. If effective rainfall estimates were available then the same process could also be used to estimate net production water use index. Note that rainfall can vary substantially between the house and a field even only a short distance away. It is useful to place a rain gauge at the field to measure rainfall more accurately.

Finally, estimation of application efficiency involves the relationship between the amount of water applied in an irrigation event and the target deficit for that event.

Example

Total water applied = 1.08 ML/ha

(from previous example) = 108 mm

(1 ML = 100 mm over 1 ha)

Soil moisture at field capacity = 410 mm

Current soil moisture = 320 mm

Target deficit = $410 - 320 = 90$ mm

Application efficiency = $90 \div 108 = 83.3\%$

This means that if you were able to satisfy a 90 mm deficit with an application of 108 mm then you are using the water with an efficiency of 83%. It is very important to note that this figure is only an approximation of application efficiency and does not take into account the uniformity of application. If the uniformity was poor, and the 90 mm target deficit had not been met across the entire field, then an additional proportion of the water applied has been lost as run-off or deep drainage, reducing the efficiency. Unfortunately, checking if the deficit has been met across the entire field requires computer modelling or extensive soil moisture monitoring.

Method 2: Detailed measurement

The previous section indicated the kinds of measurements and calculations that can be performed on farm to give general estimates of irrigation system performance. Whilst these calculations can be used to give an idea of system performance, it must be remembered that they are only basic estimates and that they can be prone to error. Furthermore, these calculations cannot identify uniformity: they only give a rough estimate of application efficiency, and they do not indicate what measures should be taken to improve system performance. It could be concluded that taking these initial measurements can help to confirm the need for more detailed investigation.

The aim of this section is to provide basic information about what a commercial service should be able to provide when a more detailed investigation is undertaken.

Modelling

Using a computer model is very useful for a number of reasons. One important use of models is to predict processes that are difficult (or tedious) to measure. In the case of surface irrigation, such processes include the amount of tailwater, amount of infiltration at different points within a field, distribution uniformity, advance and recession curves and application efficiency.

Furthermore, it is possible to change parameters in models with ease, so that predictions can be made regarding how a system could perform if certain changes were made. Such changes could include changing siphon size, in which case the outcome could be predicted before new siphons were even purchased, ensuring money was well spent.

Various models are available to analyse the performance of surface, drip and spray systems, but this section will concentrate on surface irrigation systems. The model principally used to model surface irrigation events in Australia is the Surface Irrigation Model (SIRMOD) developed at Utah State University. This model has been used quite extensively in Australia and, whilst other models are available, SIRMOD has demonstrated excellent accuracy over a significant number of tests.

In simplistic terms, the model solves an infiltration function using irrigation advance data. Because the advance of water down a furrow is specific to every field and set of irrigation parameters, the model does not require soil type data, as the rate of advance characterises the infiltration characteristics of that particular soil.

Data required

Siphon flows: Flow meters should be used in siphons of 50mm diameter or more (Topic 4.2 'Applying furrow irrigation water'). Metering is not usually possible in smaller siphons, so the head measurement technique described in the previous section may be used.

Advance points: An advance point is the time it takes for the wetting front to reach a certain distance down the field. Typically 5 or 6 advance points are measured using automated equipment (advance sensors).

Advance points can be measured manually by driving a series of pegs at five distances along the length of the field and noting the time at which the wetting front passes each peg, but this is very time-consuming.

Irrigation duration: The duration of the irrigation, from the time siphons are started until they are pulled, is required. This can usually be determined from the advance sensors if they are placed at the top and bottom of the field.

Target deficit: A measure of the target deficit, as described in the previous section.

Field slope, run length and furrow shape: These measurements are fairly self-explanatory. Of importance is the slope, as SIRMOD assumes a constant slope: that is, fields should be laser levelled. More than one slope within a field can be modelled but a set of advance points must be obtained for each slope.

Model validation

Following data collection, the model is validated against the measured advance data. This means that the model produces a simulated set of advance points and these are compared with the measured advance points. A parameter is modified and the model is re-run until the simulated and measured points are similar.

Additional validation has been performed on a number of irrigations where tailwater has been measured. This validation involves comparing the measured tailwater amount with that simulated by the model. As the measurement of tailwater is quite detailed, and because these previous tests indicated good correlation of the model, it is not typically necessary to measure tailwater volumes to check the model.

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2.10 Irrigation scheduling of cotton

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Key points

- Irrigation scheduling improves water use efficiency, reduces waterlogging, quantifies the effectiveness of rain and allows better management of soil structure problems.
- A decline in the crop daily water use indicates the crop needs irrigating. Regular and careful monitoring is needed to detect this decline in crop water use.
- Extending the irrigation interval once regular irrigation has started without monitoring soil water levels can result in yield loss. Don't stress the crop during peak flowering and boll filling.
- Every cotton field is different. Soil structure and management have a dramatic impact on soil water availability and the irrigation interval. Do not assume the deficit or readily available water capacity is the same for neighbouring fields.
- Look after the cotton plants near your soil moisture device. If the data seem suspect, check the measuring site.

Irrigation scheduling in Australia is difficult because of the variable and unpredictable climate, frequent summer storms and changes to prevailing air temperatures. Correct irrigation scheduling improves water use efficiency, reduces waterlogging, controls crop canopy development, quantifies the effectiveness of rain and allows better management of soil structure problems.

This WATERpak topic explains how to schedule irrigations and interpret the data collected from soil moisture measuring devices. The NSW Agriculture Agfact *Soil moisture monitoring tools* describes tools that can be used to schedule irrigations. Topic 3.7 discusses irrigation scheduling using plant-based measuring devices, and irrigation scheduling using climatic data is discussed in Topic 2.13.

Factors to consider when scheduling an irrigation include:

- total water availability
- limited water situations (WATERpak Topic 3.4)
- crop growth status and potential yield (WATERpak Topic 3.1)
- rainfall and future temperatures
- practical farm management logistics such as the physical movement of water
- soil water content.

Cotton plant water shortage symptoms and responses to stress

The cotton plant exhibits many plant water stress symptoms that can be used to help schedule an irrigation. These include:

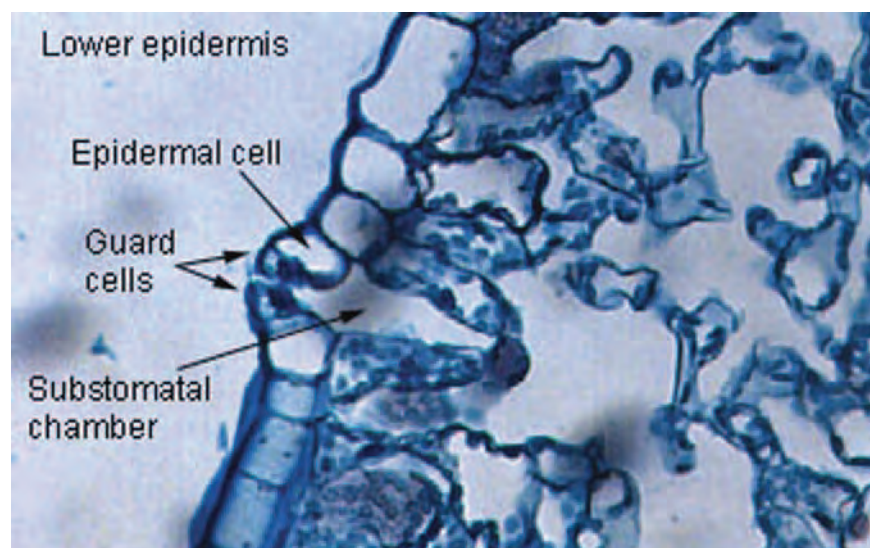
- a change in leaf colour from a bright to a darker green, or almost blue when severely water-stressed. It is most important to look at the health of the youngest leaves that are still growing in size.
- Plant wilting is an obvious water shortage symptom, but take care not to confuse a 'midday wilt' with water stress. Midday wilt is an internal transport problem which occurs when cotton plant roots can no longer absorb enough water to meet the plant's transpiration demand.

Midday wilting occurs on very hot days, particularly when the air is dry. If the wilted plant recovers as the day cools down in the evening, this is a sign of midday wilt rather than a soil water shortage. Checking the soil moisture will help clarify any confusion.

Due to its tropical origin, cotton does not shut its stomates (Figure 2.10.1) in the heat of the day to conserve water, unlike many other plants. This allows gas exchange to continue and thus allows the plant to keep growing at higher temperatures than many other crops. Only when severe stress occurs will the stomata respond and close. This usually occurs after leaf growth has stopped.

- Crops use water to keep cool, so the leaves of water-stressed crops are warmer to the touch. Around solar noon, crops that are not water stressed will be about 4 degrees Celsius cooler than the surrounding air temperature. Water-stressed crops will be less than one degree cooler than the air temperature.
- The number of nodes (branches) above the most recent white flower on the first fruiting position is another plant observation used by cotton growers to schedule irrigations. Early in the season (December) an irrigation may be applied around nine nodes above white flower (NAWF). Mid season, seven NAWF is a rule of thumb used as a target irrigation point for crops, while later in the season around 5 nodes above white flower will be the target as crops 'cut out' (that is, when they stop growing). Crops with more nodes above white flower generally have more vigour and this can be used to help decide which crops should be watered when water is scarce.

Figure 2.10.1. A stomate on a cotton leaf surface



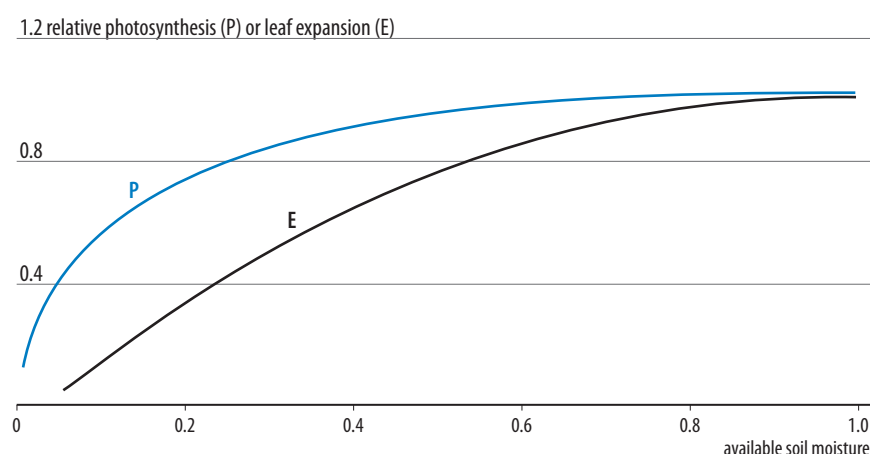
CO₂ enters the leaf for photosynthesis while water simultaneously exits the leaf through the stomate.

Source: G Roth

Water is important to cotton plants for photosynthesis, cell expansion, growth, nutrient supply and turgid pressure. Figure 2.10.2 shows that water deficit reduces cell expansion, observed by agronomists as reduced leaf expansion and stem elongation. Greater levels of water stress cause a decline in net photosynthesis and further reduce cell expansion.

Photosynthesis is the process by which plants use CO₂ from the atmosphere to produce carbohydrates (assimilates) to support boll growth and fibre development. When the plant senses that moisture supply is becoming limited, vegetative growth slows and priority is given to boll development.

Figure 2.10.2. Relationship between available soil water and relative leaf net photosynthesis and relative daily leaf expansion



Note: 'Relative' refers to the ratio between dry and control plants.

Source: Constable and Rawson 1982

Hearn (1994) outlines the water stress sequence in order of sensitivity: water stress firstly reduces leaf expansion, then organ production (leaves and sites), then fibre length, then photosynthesis, then boll retention, then fibre thickening and finally root growth and function.

Like many crops, cotton is most sensitive to water stress during peak flowering. Stress during peak flowering and boll filling is likely to result in double the yield loss compared with stress during squaring and late boll maturation (Table 2.10.1). The extent of the yield loss will vary with circumstances.

Table 2.10.1. Impact on yield of one day's water stress, different growth stages

Growth stage	Yield loss (kg/ha/day)
Squaring	9
Peak flowering	19
Late flowering and boll filling	16
Boll maturation	4

Source: Hearn and Constable 1984

Waterlogging can cause yield losses as great as those experienced by water stress. For example, Hodgson (1982) reported yield losses of 29–48 kg/ha/day due to waterlogging and low soil oxygen levels. Cotton's symptoms and responses to waterlogging are discussed in WATERpak Topic 3.3.

General rules for irrigation scheduling

Milroy et al. (2002) outline the basic rules for irrigation as: pre-irrigating or watering up, not stressing the plant before the first irrigation, sticking to the target deficit and aiming to dry the soil down to the refill point by the time the crop has 60% bolls open.

Pre-irrigating or watering up the crop after planting

The decision for a cotton grower to pre-irrigate or water up the crop is, like so many others, a decision that has to be made specifically to suit a farm. In certain situations it can also be beneficial to combine the two options: pre-irrigate to plant into moisture and give the crop a quick watering to ensure good plant stands.

Every farm is different, and the following questions need to be considered before making a decision:

- What method has traditionally given the best plant stands and early vigour?
- What is the most efficient way to store water (dam, on-farm storage or soil)?
- Do I have enough water available, or do I need to scratch for the last little bit?
- Is my cotton grown on a 'warm' or 'cold' soil?
- Does my cotton traditionally have a lot of pressure from seedling disease?
- How will my water account or carryover rules affect water availability?
- What is the likely rainfall pattern before and after planting?
- Am I likely to get enough rain before planting to plant into moisture?
- Is it likely to rain straight after watering up?
- Do I often have herbicide damage problems?
- Is my soil likely to dry out quickly before planting?
- Is my planter set up for dry or moisture planting?
- Are the beds even enough to get uniform moisture levels after harrowing to seek moisture?
- How does my soil soak up, and how badly does it erode?
- Can I apply a small amount during a quick watering (flush) and not be wasteful?

The likely advantages and disadvantages of the different options are summarised in Table 2.10.2.

Table 2.10.2. Advantages and disadvantages of different options for the first irrigation

Pre-irrigation (prior to planting)	Watering-up (after planting)	Pre-irrigation and late watering
Likely advantages:		
No time pressure to apply the water	Potential to take advantage from pre-planting rain events	Helps in fixing up plant stand problems
In a heavy clay, water losses can be less than keeping it in an on-farm storage	Easier to plant, especially when beds are not 100% even	Can give the crop the necessary 'boost' to get going after a slow start
Soil temperature is less likely to drop after planting - potentially less disease pressure	Faster planting operation and less machinery needed	
Likely disadvantages:		
Soil drying out too quickly	Higher disease pressure	Likely to use more water
Dry rows in uneven fields	Herbicide damage more likely	Similar disadvantages to watering up
Soil stays too wet when followed by rain	Sides of beds might erode when flushing for a long time	
Unable to capture rainfall before planting	Waterlogging if rain occurs after flushing	

Source: S Henggeler

First in-crop irrigation

This is the most difficult irrigation scheduling decision. It requires a balancing act of not stressing the crop while ensuring water stored in the soil profile is fully explored by the cotton roots. It is difficult to get a crop growing again if water stress has stopped growth.

On most heavy clay soils, cotton shouldn't need irrigating earlier than halfway between squaring and flowering (60-70 days from sowing). On lighter texture or compacted soils, crops will need irrigating earlier. Close examination of root extraction patterns using soil moisture data and the daily water use is the best way to monitor the crop's water status. Table 2.10.3 shows an example of the relative decrease in final yield caused by delays in the first crop irrigation.

Table 2.10.3. Effect of timing of the first crop irrigation on yield

First flower occurred between 65 and 75 days after sowing.

Days after sowing of first irrigation	Final yield (%)
60	100
70	96
80	90
90	81
100	66

Source: Hearn and Constable 1984



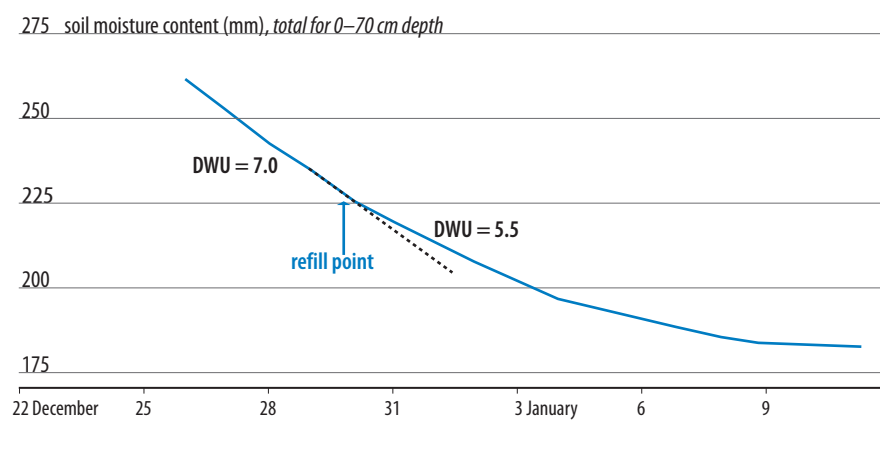
Other irrigations

Extending the interval between irrigations once regular irrigation has started without monitoring soil water levels can result in significant yield reductions. Water can be saved, but yield losses will occur. The other consideration is that, by stretching the irrigation interval, greater amounts of water will need to be applied at the next irrigation and this can have efficiency implications. Stretching irrigation intervals too much can also indirectly cause waterlogging. It prolongs the time water has to be applied to fill the large soil moisture deficit. Waterlogging can be the consequence, especially when the irrigation is followed by a rain event.

If water stress occurs, it is better late or early in the season, but not in the middle, during peak flowering and early boll fill stages. In hot dry summers like 2002/03 it is better to be early than late. In summers when the air is more humid and with storm events, there may be some more room to move.

Careful monitoring of soil moisture extraction graphs and daily water use will enable the correct timing of the irrigation. Once the daily water use begins to fall it is time to irrigate. Figure 2.10.3 shows the gradual decline in daily water use of a cotton crop in Moree from 7 mm/day to 5.5 mm/day and then to 4 mm/day. Individual sensor depths from constant monitoring soil water devices can provide more detailed information for growers looking to finetune irrigation applications.

Figure 2.10.3. Setting the refill point by observing the decline in crop daily water use (DWU)



The final irrigation

The prime objective of the last irrigation is to ensure that boll maturity is completed without water stress. At the time of last irrigation all bolls have been set, vegetative growth is limited and the majority of carbohydrates are used to satisfy boll demands. Once a boll is 10-14 days old, the abscission layer that causes boll shed cannot form: it is for this reason that boll numbers are not significantly reduced by late water stress, but fibre development can be affected. Crops that come under stress prior to defoliation can suffer some yield and fibre quality reduction. The level of reduction obviously increases the longer the stress occurs.

End of season water requirements can be estimated from the date of the last effective flower (nodes above white flower = 4). The last harvestable bolls take 600 to 650 degree days to reach maturity. Therefore, for crops to be defoliated towards the end of March, the last effective flower needs to occur in the last week of January. Crop water

use needs to be considered for this period. At the time of first open boll, crop water use may be 5-7 mm/day and may decline to around 4 mm/day prior to defoliation.

Factors to consider:

1. days to defoliation
2. boll maturity
3. crop water use
4. plant available water – ability to extract water below normal refill point
5. soil moisture objective at defoliation (enough to allow for good defoliation and little enough to cater for a dry soil at harvest)

Definition

Days to defoliation: This is a general example, and you need to generate values for your own district.

- Defoliate when NACB (node above cracked boll) is equal to 4.
- Takes 42 degree days, around 3 days (up to 4 days in cooler regions) for each new boll to open on each fruiting branch.

$$(\text{Total NACB} - 4) \times 3 = \text{days to defoliation}$$

Two examples of final water requirements are listed in Table 2.10.4.

Table 2.10.4 Two examples of water requirements for final irrigation

	Crop A	Crop B
Total fruiting branches	13	13
% open bolls	25–30%	zero
NACB	9	13
Days to defoliation (NACB=4)	$(9 - 4) \times 3$ 15	$(13 - 4) \times 3$ 27
Estimated daily water use until defoliation	5 mm/day	5.5 mm/day
Total water requirement	75 mm	148 mm

To finish it off, Crop A needs 75 mm of water or one irrigation if the plant available water capacity (deficit) of the soil is about 75 mm. If there is 35 mm of water in soil profile, an irrigation could be recommended to top up the profile, which will ensure that, when the crop is mature, it is at the refill point. This will ensure a dry soil profile for picking. Crop B requires close to two full irrigations. Likely rainfall would need to be considered in any such decisions.

If the crop is one irrigation short (that is, it reaches refill point at 20% open), boll size will generally be reduced rather than there being any significant reduction in boll numbers. This will result in a yield reduction (Table 2.10.5). Fibre quality may also be affected, for example in reduced micronaire. Little effect on fibre length would be expected. If the crop is two irrigations short, boll numbers will be reduced. Provided the crop doesn't move into rapid stress, boll size may increase due to the shedding of smaller bolls (<10–14 days old). Fibre micronaire may be reduced on younger bolls. Significant yield reductions can occur, especially in vegetative crops that stress prior to boll opening.

Table 2.10.5. Stress timing and yield reduction from OZCOT cotton simulation model

Crop stage when stress occurs	Average yield (bales/ha)	Yield reduction (bales/ha)	Yield reduction range bales/ha (%)
Full irrigation	8.37		
20% open, one irrigation short	7.77	0.60	0.2–1.1 (2–13%)
6–8 days prior to first open boll	7.17	1.2	0.8–1.9 (10–23%)

*Fibre quality losses also need to be accounted for.

Seasonal and daily crop water requirements

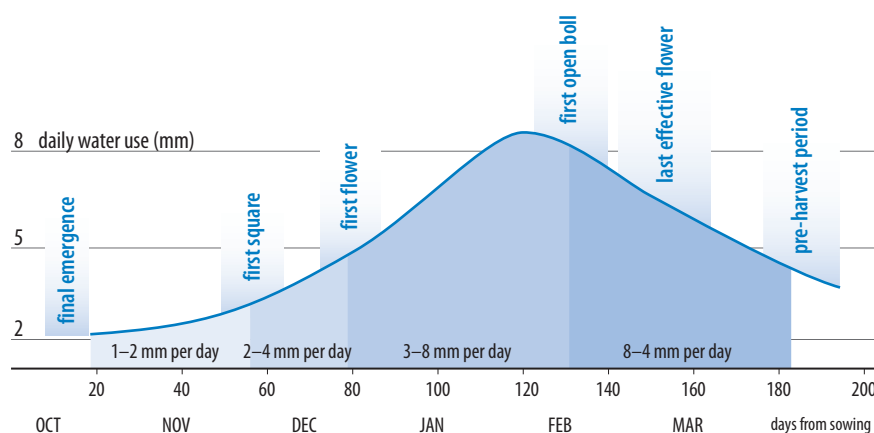
Research and field trials show that, to obtain a maximum yield, cotton crops need to use about 700–750 mm (7–7.5 ML/ha) of water. This can come from rain, stored soil moisture and irrigation during the season (WATERpak Topic 2.2). This figure will be less in cooler areas where the yield potential is less.

The amount of water used is the sum of the evapotranspiration, which is driven primarily by meteorological factors of solar radiation, air temperature and the crop's leaf area. As leaf area, radiation and temperatures increase during the season, so does the demand for water. Maximum demand for water occurs during peak flowering and early boll development.

The daily crop water needs vary with temperature and stage of the crop (Figure 2.10.4). Early in the season cotton plant's water use will be 2–4 mm/day, which will rise to a peak 8–10 mm/day in late January. The daily water use drops to about 5 mm/day in March. By studying your own daily water use figures it is possible to plot your own curve like the one in Figure 2.10.4.



Figure 2.10.4. The daily water use of cotton plants



Important soil moisture terms

There is a wide range of soil moisture terminology used in the irrigation industry. Most of these terms are for research purposes and they are summarised in Figure 2.10.5.

The most important terms for irrigation scheduling are:

Volumetric soil water content (VSW%): A known volume of soil contains soil particles, water and air. The percentage of this volume that is water is the VSW%.

Full point or field capacity: the 'full point', which is more formally known as 'field capacity', is when the soil profile is full of water and no drainage is evident.

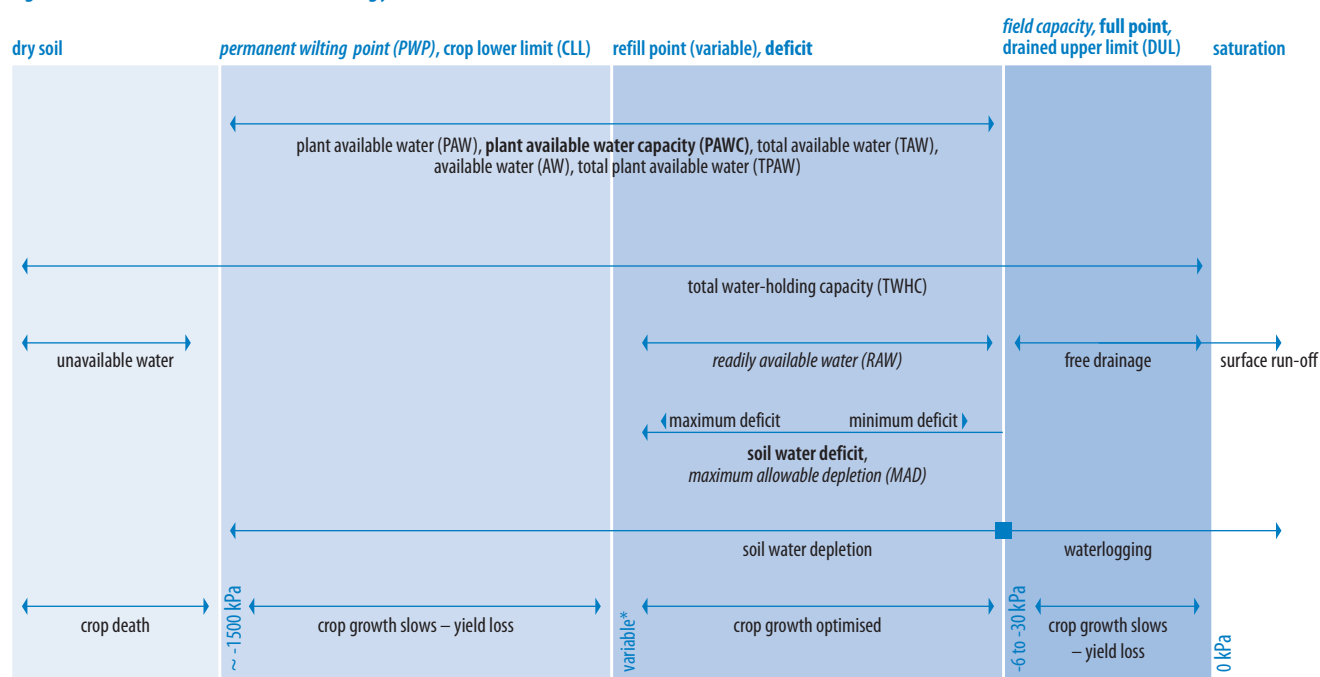
Refill point: If an irrigation is not applied prior to soil water levels passing an accurate refill point, then a yield or vegetative reduction will occur, depending on the stage of the crop.

Daily water use (DWU): The amount of evapotranspiration or water used. Figures are quoted in mm/day. A figure of 8 mm/day refers to a water layer of 8 mm over the crop area in question.

Readily available water (RAW) or deficit is the difference between the full and refill point, that is, how much water there is available to the crop between full and refill points. Sometimes the term **deficit** is also used to refer to how far the soil water status is below full point. Approximate RAW or deficit values for cotton soils are:

- 70–90 mm heavy clay soil
- 60–70 mm medium clay soil
- 50 mm red soil
- 50 mm compacted heavy clay soil

Figure 2.10.5. Soil water terminology



Terms in *italics* are nationally adopted (ANCID); current cotton industry terms are in **bold**.

Units can be kPa, mm or percentage volumetric soil water (% VSW), depending on soil water measurement method.

* variable suction levels depending on soil type and management

Source: David Williams

Plant available water capacity (PAWC) is the amount of water available for plant growth. It is determined by the difference between the full point and lowest level of possible water extraction at permanent wilting point. To calculate the PAWC, take a soil moisture reading at the full point and the driest reading you can obtain, which is likely to be at picking time/defoliation. The difference between the two readings is the PAWC. As a general rule the irrigation will be due around 50% of PAWC (usual point for the refill point) has been depleted. On heavy clay soils it may be possible to stretch this to 60%. Table 2.10.6 shows some estimates of the amount of water (mm) for each of these terms (to 1 m).

Table 2.10.6. Estimates of the amount of water for three soil types (to 1 m)

Soil type	Field capacity	Plant available water capacity	Readily available water
Red brown earth	300	140	50-60
Grey clay	380	150	70-80
Black earth	500	200	90-100

Source: modified from Milroy et al. 2002

A summary of soil moisture terms is shown in Figure 2.10.5.

How to schedule an irrigation using soil moisture data

Determine the **full point**.

The full point, which is more formally known as **field capacity**, is when the soil profile is full of water and no drainage is evident. It is determined by taking a soil moisture reading of the profile 1-2 days after a surface irrigation event or after a large rain event. This point is quite easily identified.

Determine the **refill point**.

If an irrigation is not applied prior to soil water levels passing an accurate refill point, then a yield reduction will occur, depending on the stage of the crop. The refill point changes during the season. Young plants have small roots that only have access to a limited part of the soil profile. As the plant grows, the roots can access more of the profile and therefore tolerate a larger soil moisture deficit before reaching refill point. The refill point is not easy to determine and requires some trial and error. It requires examination of the daily water use figures of the crop. Once the daily water use starts dropping,

this is a sign that the crop is experiencing difficulty getting water and the crop is at the refill point. To collect daily water use figures, soil moisture readings need to be taken every 2-3 days plus before and after any irrigation or rainfall event when using a manual probe. Regularly and consistently measuring the moisture content will make this much easier to determine from the data, especially if you have no historical data, as trends will emerge. The new automatic capacitance probes that record soil moisture levels 24 hours a day are very good at detecting this decline in the crop daily water use.

Figure 2.10.6 shows typical root extraction patterns of a fully grown cotton crop for the full, refill and wilting points. Crops will die when they reach the wilting point. Crops use most soil moisture in the top of the soil profile first and proportionally less, deeper in the profile, depending on root growth.

The area between the full point line and the refill point line represents the readily available water (RAW); the area between the full line and the wilting point line represents the plant available water capacity (PAWC).

Figure 2.10.6. Typical full, refill and wilting points

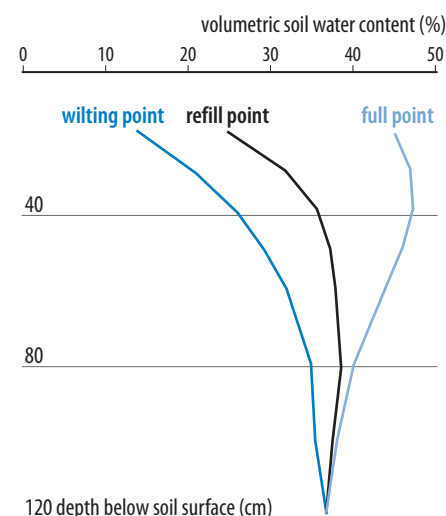
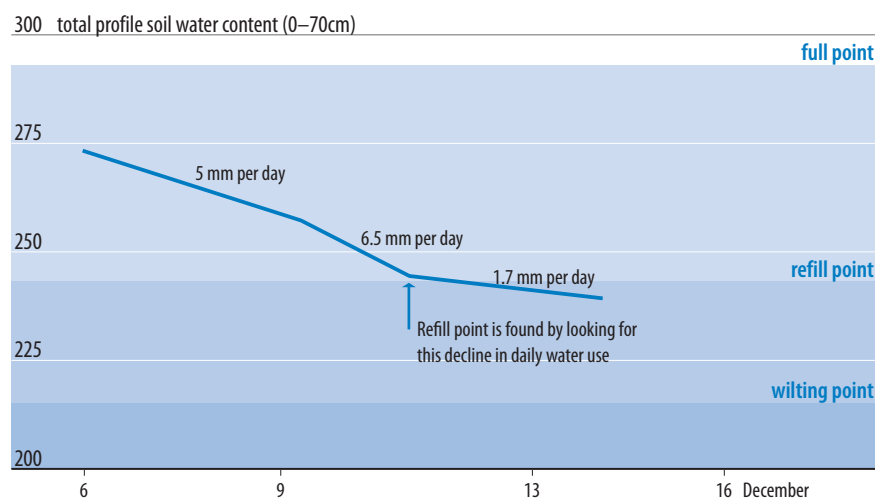


Figure 2.10.7 shows how the crop daily water use declines when crops reach their refill point. This sharp decline in daily water use is attributable to soil compaction effects, and generally the decline is more gradual, as in Figure 2.10.3.

Take care not to confuse a drop in daily water use caused by cloudy weather. If you have daily water use data for an entire season and want to standardise them for changes in the weather, it is possible to do this by dividing the DWU figure by either solar radiation data or air temperature data from a weather station.

Figure 2.10.7. Setting the refill point by examining the drop in crop daily water use

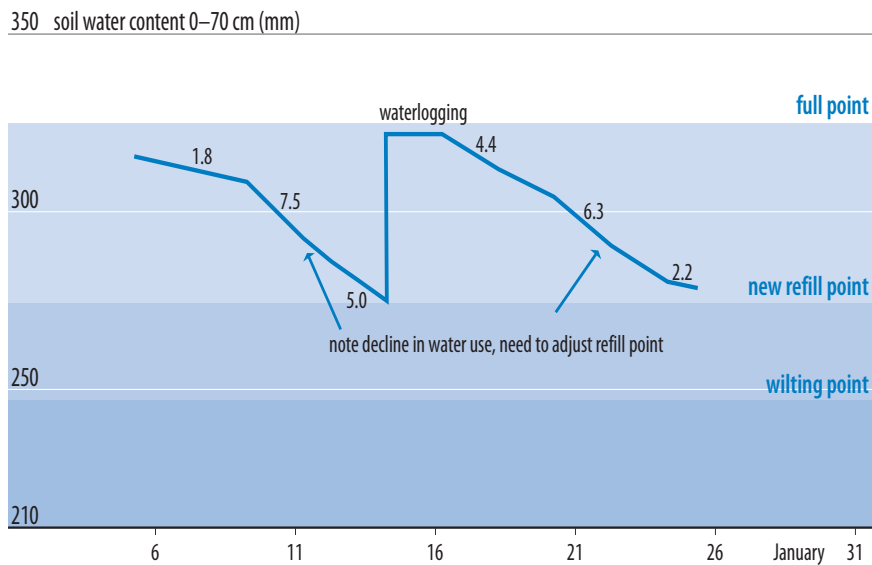


Soil compaction and its impact on setting refill points

This example demonstrates how a wet pick in the previous season influences the setting of refill points the following season. A deficit of 80-90 mm is typical for heavy clay soils around Moree, which have good soil structure. Frequent soil water readings (2-3 times per week) enable the daily water use of the crop to be determined. The daily water use will decline, assuming constant weather conditions, when the refill point has been reached.

Figure 2.10.8 shows low daily water use following an irrigation due to waterlogging (1.8 mm/day). Crops are experiencing stress during waterlogging periods, which need to be minimised. Figure 2.10.8 also shows a gradual decline in daily water use which indicates the refill point needs adjusting. In this case, this was caused by a wet pick in the previous season which has caused soil compaction. Careful monitoring of the crop's daily water use and root extraction patterns as well as crop observations enables refill points to be set correctly.

Figure 2.10.8. Effect of soil compaction on soil moisture availability

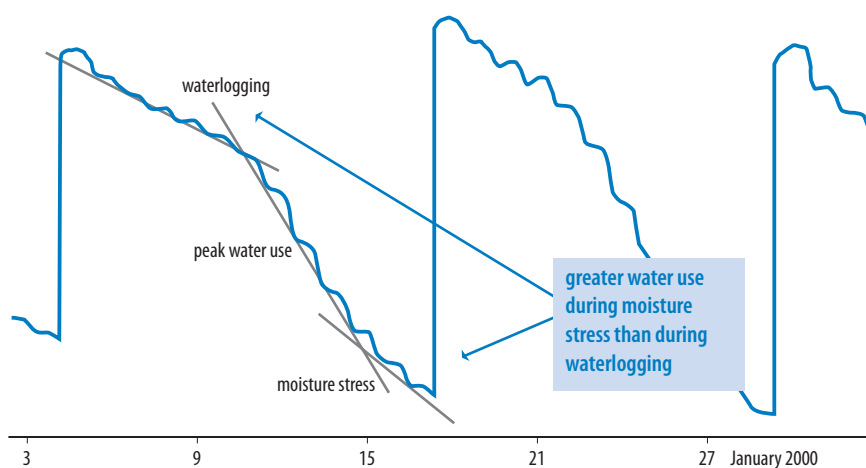


Example of capacitance soil moisture data

Many of the new capacitance probes have the ability to record soil moisture data 24 hours a day. This makes data interpretation much easier than the neutron probe, although the principles are exactly the same. The monitoring of crop root activity at different depths is also possible.

The advent of continuous monitoring using capacitance probes has allowed irrigators to observe daily water use and provided the ability to 'listen' to the crop (Figure 2.10.9).

Figure 2.10.9. C-Probe summed graph



Greater water use during moisture stress than during waterlogging

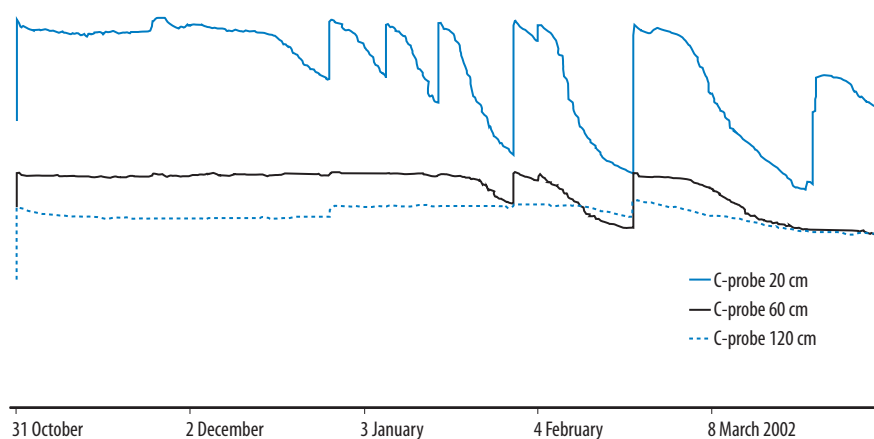
Source: Sloane 2003

Figure 2.10.10 shows a typical crop water use pattern, with most water being used in the top of the soil profile and a number of rainfall and irrigation events depicted by the drying and wetting cycles. It is evident that when the daily water use declines at 20 and 40 cm, the crop begins to extract more water from 60 and 80 cm.

A small amount of root activity can be seen at 80 and 100 cm in mid and late January, early February and greater extraction in March. At 80 cm this activity has transferred into water use from early February onwards. The activity at 100 cm would have transferred into water use as well if the irrigation had not been applied to replenish the upper root zone, allowing the crop to access water more easily.

Figure 2.10.10. Crop water use and root extraction as measured by soil capacitance

Volumetric water content in different depths (20, 60 and 120 cm)



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2.11 Calibrating soil water monitoring devices

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Key points

- Set-up, calibration and operation of neutron and capacitance soil water probes are discussed.
- Different software-based corrections are used to convert raw data into soil water content levels, resulting in discrepancies between devices.
- Calibration of soil water monitoring equipment is not always required to undertake irrigation scheduling of crops.

This topic has been written to explain how two common methods of soil water monitoring work and how these two methods use a calibration process to convert raw data readings into values representing soil water content levels. While a percentage of volumetric soil water is sometimes used, the most common approach is to convert readings into a millimetre figure.

However, there is a perception within the cotton industry that all soil water monitoring devices will present values in millimetres and that, as a result, the data can then be directly compared between devices. In reality, apart from the fact that 'millimetres' are the common unit, this is not correct.

The discrepancies occur in the methods used to determine the 'millimetre' readings. None of the devices actually directly measures the depth or volume of water in the soil. The software associated with each product calculates the final readings based on raw data counts that have a correction applied to obtain a 'millimetre' estimation. This correction can vary depending on how it is determined, and some software programs use a default correction. Where default

corrections are used, then the neutron probe 'millimetres' and the capacitance probe 'millimetres' are at best an estimation of an actual volumetric millimetre. If a full soil-based calibration is undertaken for a specific site, then this discrepancy is alleviated.

What is calibration?

The term **calibration** when applied to soil water monitoring devices can refer to two separate applications.

1. One is where a device is set up so that it can give continued and consistent readings based on a soil water percentage between 0% (air) and 100% (water). This first application has also been termed **normalising**.
2. The other is where the device is calibrated to a specific or default soil type, with a software correction to give this information as a volumetric figure, usually as 'mm' (millimetres). Different soil water monitoring devices use different calibration methods and these can also vary in the level of complexity and accuracy.

Is calibration required to schedule irrigation events?

The short answer to this question is no, but if there is a desire to undertake water balances or to calculate the amount of soil water that needs to be replaced, then an accurate measurement is often required.

In most irrigation scheduling cases the main aim is to identify when to apply the next irrigation. The optimum time to irrigate can be determined by observing changes in soil water levels over time as they move from field capacity to the refill point between irrigation events. Both field capacity and the refill point can be easily determined with sufficient soil water data from most devices. Irrigation scheduling in its simplest form is then a case of keeping soil water levels between field capacity and the refill point. The raw data trends from each device are all that is required to do this.

A secondary aim to precisely control the amount to apply is somewhat limited by the irrigation method. The amount applied is often calculated by determining siphon flows, taking pump meter readings, using rain gauges for lateral move and centre pivot systems or, in the case of drip irrigation, the number of hours the irrigation was applied.

Where the irrigation amount applied can be precisely controlled or where a soil water balance is required then a calibrated device can assist.

What is a 'millimetre'?

So, what is a 'millimetre'? Why are we using a term that defines a length (0.001 of a metre) as a measure of irrigation and rainfall? The answer comes from meteorology, where rainfall is measured in millimetres and relates to the height the rain would reach on an even surface, if it did not drain off.

One millimetre of rainfall is equal to one litre per square metre (10000 litres or 0.01 megalitres per hectare).

In irrigation we define a megalitre (1 million litres) as a volume of water covering one hectare to a depth of 100 millimetres.

From these definitions, it is easy to know what a millimetre (mm) of rainfall or irrigation is. Both daily crop water use figures and evapotranspiration are calculated in millimetres.

Soil water monitoring device software programs look to define soil water levels as millimetres in order to achieve consistency. They do not actually measure an exact volume of water, but apply a correction to their raw data to come up with soil water levels in 'mm'. Although efforts are made to ensure that the corrections are accurate, in most cases they will still contain errors, and provide readings that, while precise, are not always close to the actual volume of water in the soil expressed as in millimetres.

These inaccuracies should be taken into account when comparing data from differing sources and devices to the actual volume of water in the soil expressed as millimetres. The details on how the correction was determined need to be known to make direct comparisons between differing devices and differing sites.

Soil water content when expressed in millimetres is only accurate if calculated under laboratory conditions (using gravimetric or volumetric methods).

The neutron moisture meter

How does a neutron moisture meter work?

The neutron moisture meter (NMM) uses the 'neutron moderation method'. Neutrons are emitted from the probe's radioactive source and are slowed down by collision with hydrogen in the soil water molecules. The meter counts the slow returning neutrons which are related to the amount of water in the soil. The measurement sphere is about a 15 cm radius around the neutron source.



Setting up the NMM

Cable and stops

When cable stops are spaced 10 cm apart, starting 40 cm from the source end of the cable, soil moisture measurements will be taken at 20, 30, 40, 50, 60 cm intervals, and so on, down the soil profile. (These measurements refer to the NMM Hydroprobe® 503DR.) Often from 60 cm depth the cable stops are set every 20 cm apart, giving readings at 60, 80, 100 and 120 cm depths as required.

Standard count

The counts read by the meter are usually divided by a standard count to give a count ratio. A standard count is determined by installing an access tube (sealed at the bottom) into a 44-gallon drum of water and inserting the NMM source probe into the access tube so it is suspended in the middle of the drum. The use of the standard count guards against changes in the count rate brought about by the ageing of the meter's components. The NMM owner's manual explains the procedure for determining the standard count.

Access tubes and installation

Aluminium access tubes sealed at the lower end of the desired length can be installed in the soil by hand or powered augers. Ensure that there is minimal space between the tube and soil. Tubes are installed wherever desired. This could be between rows or on the plant line. Where the irrigation method is drip irrigation, ensure that the location of tube is near a drip emitter so that the site will be watered by the system.

Reading and processing data

Calculating count ratio

The counts read by the meter are divided by the standard count to give a count ratio. The meter counts are usually determined over a 16 second period (if three tubes at one site are averaged) at each position down the profile (see NMM manual to set the count time). It is recommended (but not always undertaken) to determine a new standard count prior to each field NMM soil moisture reading session.

Using calibration curves to calculate 'probe' mm water

When a formal calibration is determined for a neutron probe, a relationship between the count ratio (NMM reading/standard count) and volumetric water content (**volumetric soil water = % water in the soil × bulk density**) is

established for each layer of the soil type in question. This calibration is then site-specific and cannot be used at other sites without errors.

In most on-farm situations the relationship between soil type and count ratio is not assessed, and a default calibration data set is used by most unsuspecting operators.

This relationship might be a straight line of the form:

$$(a) \quad y = a + bx$$

where

y is the volumetric soil water content

x is the count ratio

a and b are the regression parameters.

By simply substituting the count ratio for x, volumetric soil moisture content can be calculated.

However for some soil types the relationship might not be linear and could be represented by a more complex equation which introduces a third parameter 'c', for example:

$$(b) \quad y = a + bxc$$

To convert this to mm water, simply multiply volumetric water content (y) by the depth interval, which will be 100 mm (10 cm) if readings are taken at 10 cm intervals down the profile:

$$\text{mm water} = \text{volumetric water} \times \text{depth interval}$$

By adding the mm of water in each depth interval, the total mm of water in the profile is calculated.

Further explanation of these points and of determination of soil bulk density can be found in Dalgliesh, N and Foale, M 1998, *Soil Matters* (<http://www.farmscape.lqld.csiro.au/SoilMatters/>)

How to get a NMM calibration

Insert NMM access probe tubes into the soil, take NMM readings at intervals (usually 10 cm) down the profile and calculate the count ratio.

Extract soil cores close to the access tube and calculate the gravimetric soil moisture content (see details in *Soil matters*) for each interval corresponding to the NMM interval readings. These readings and cores need to be taken at the soil's upper limit, lower limit and at various moisture contents (intermediate moisture contents) between these limits so that you get a good curve.

Upper limit is the amount of water that a soil holds following drainage for about 48 hours. It can be determined following rainfall or irrigation.

Lower limit is the amount of water left in the soil after a particular crop has extracted as much as it can. This is determined following harvest.

Calibration for irrigation use

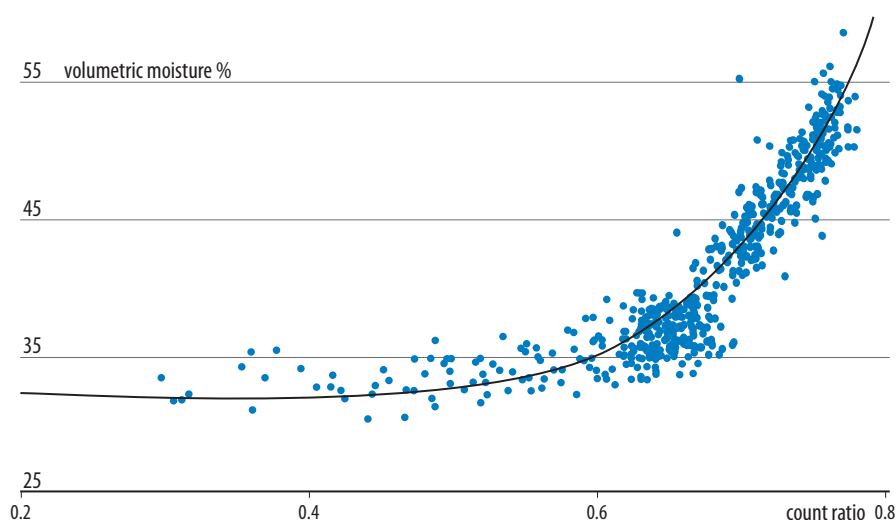
The relationship between the NMM ratio and soil moisture content need only be determined from the upper limit to a moisture content just below the predetermined refill point. Following conversion to volumetric moisture content, the relationship will most likely conform to equation (a) above.

Calibration for rain grown cropping

The relationship between the NMM ratio and soil moisture content will need to be determined from the upper limit to the lower limit and as many points as possible between these. The volumetric moisture content/NMM ratio relationship will most likely conform to equation (b) above, because the relationship between the count ratio and soil moisture content might not be linear as the soil dries to low values.

The volumetric water data are plotted against the NMM count ratio and the relationship calculated for either equations (a) or (b). An example of the relationship for equation (b) is shown in Figure 2.11.1.

Figure 2.11.1. Non-linear relationship of volumetric moisture and count ratio



ThetaProbe (Delta-T Devices type ML1): A ThetaProbe could be used as an alternative to gravimetric sampling for determining soil moisture content in the calibration of the NMM. The built-in probe calibration set to 'mineral' gives volumetric moisture content. This has been shown to be a reasonable estimate for heavy cracking clay soils. The ThetaProbe itself can be easily calibrated to a soil type by following instructions in the owner's manual. This will then result in a more accurate reading than the built-in calibration.

Capacitance soil water devices

How do capacitance soil water devices work?

Capacitance probes such as the C-probe™ and Enviroscan® systems work by measuring the dielectric constant of soil. Charlesworth (2000) describes the dielectric constant as 'a measure of the capacity of non-conducting material to transmit electromagnetic waves or pulses'. He adds:

The dielectric of dry soil is much lower than that of water, and small changes in the quantity of free water in the soil have a large effect on the electromagnetic properties of the soil water media.

Frequency domain reflectometry (FDR) measures the soil dielectric by placing the soil (in effect) between two electrical plates to form a capacitor. Hence 'capacitance' is the term commonly used to describe what the instruments measure. When a voltage is applied to the electric plates, a frequency can be measured. This frequency varies with the soil dielectric.

(Charlesworth 2000)

Capacitance devices have been shown to deliver repeatability of readings with acute sensitivity to changes in soil water content.

Why normalise capacitance devices? Without normalising, these devices would only provide a range of irrelevant raw data that varies slightly with each sensor. By matching the raw reading from each sensor to both 0% and 100% water levels, a comparison of readings

taken by different sensors can be made on a common scale. This simple action allows raw readings to be seen as either graphics or text permitting irrigators to monitor their soil water levels based on change trends. This accepted practice utilising a default calibration equation within a product's software, negates the requirement for a complex site specific calibration.

Setting up capacitance soil water devices

A number of sensors are allocated to depths within the active root zone of the crop. The number can vary from a couple to eight or more, depending of the level of detail required from the site. It is usual practice to install an additional sensor below the root zone of the crop to monitor deep drainage losses past the root zone and to access the effectiveness of any leaching program in saline areas. Once the location of the sensors has been determined, the sensors are located at their assigned positions on a circuit board that will be installed in an access tube in the field.

A calibration drum or vessel that is full of water is used to obtain a 100% saturation reading, and then the sensors are read again in air to give a 0% moisture reading. These readings are entered into the software supplied and the internal default calibrations use the range of readings from each of the sensors to calculate a value for % soil moisture or an estimate of soil water in millimetres. This system allows for replacement sensors to be used without disruption to data integrity.

Higher level soil-based calibrations are available to improve accuracy. Researchers or users seeking absolute values must carry out calibration of the sensors by obtaining a range of values, which are used to produce a calibration curve. A calibration equation can then be determined and described mathematically. This can be done for every sensor and can be done to suit a specific site or soil. This is rarely done for day to day irrigation management, and usually only occurs in the area of research.

The correct siting and installation of access tubes is critical for capacitance devices. As with all devices, capacitance probes need to be installed in a position that is representative of crop type, density and vigour, soil type, irrigation system uniformity and application. Additional care should be taken to locate access tubes where they will not be damaged by machinery.

Capacitance probes and cracking soils

Capacitance probes are perceived as being susceptible in clay soils that crack as they dry. This is due to the relatively small soil volume from which capacitance probes source their readings, but this does not limit their use. Crops irrigated on daily replenishment with laterals, pivots or drip rarely experience severe cracking. Where furrow-irrigated crops are allowed to dry to such an extent that cracking occurs, the resulting airgaps are easily identified in the software when the soil water content of the airgaps heads towards zero levels. This is well below refill points, and stands out well.

Experience with capacitance probes on cracking clays in southern NSW has shown that even though the top 40-50 cm of soil was heavily cracked and had moved from the contact with the tube, there was sufficient reserves of soil water at lower levels which sustained the crops. Once the soil water levels were replenished, the gaps closed and the soil / tube contact was re-established without data being compromised. In annual cropping this cycle was deemed to be acceptable and the devices continued to provide suitable scheduling support.

Conclusion

Both the neutron and capacitance probes will show changes in soil water content over time and will easily satisfy the requirements of an irrigator seeking to schedule irrigations based on variation in plant water use. Neither probe requires a calibrated unit of measurement in order to achieve this task, as the change in rate of water extraction is used instead. This could in reality be done on raw data alone.

Both types of probes have software that converts raw counts to either a volumetric percentage reading or to a 'millimetre' reading. If this conversion process is not supported with the relevant soil data then the resulting 'millimetre' readings need to be treated with caution.

Where a more accurate unit of measurement is required, there are higher order calibration methods available to correlate the relationship between the raw data counts, actual soil water content levels and the water-holding capacity of the specific soil. This calibration is rarely done in a commercial agricultural situation.

What is the device being used for? Is it being used to schedule irrigation events based on trends in plant water use, or is the device to be used to calculate a full soil water balance?

The calibration of soil water monitoring devices and the comparison of the resulting data are areas where much more work is required. The devices are currently very strong in the scheduling of irrigation events based on changes in soil water levels over time. This is evident in the way most irrigators with scheduling devices determine irrigation events based on graphed data depicting actual plant water use over time.

The debate over calibration should not detract from this ability to support the process of day-to-day irrigation management.

References

Charlesworth P. 2000 'Soil Water Monitoring'. National Program for Irrigation Research and Development Irrigation Insights Number 1 (http://www.npird.gov.au/projects/finalrep_pdf/)



2.12 Evapotranspiration

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Key points

- Evapotranspiration is the combined loss of water to the atmosphere from evaporation from soil and plant surfaces, and transpiration through plants.
- Many factors affect the rate of water loss by evapotranspiration – the weather, the crop, the environment and management.
- Crop evapotranspiration (ET_c) can be estimated using a crop coefficient (K_c) and a reference crop evapotranspiration (ET_o).
- The Penman-Monteith approach is the preferred method to estimating ET_o .
- Evapotranspiration is difficult to measure directly. It can be estimated using meteorological data or the Class A Pan.
- The Class A Pan must be correctly sited and maintained for meaningful estimates of ET_o to be made. It should only be used for estimates greater than 10 days duration.

Estimates of ET_o can be used to aid irrigation scheduling and calculate evaporative losses from storage and reticulation systems.

What is evapotranspiration?

Evapotranspiration (ET) is the collective term for water lost to the atmosphere by evaporation from a range of surfaces (rivers, dams, channels, soils and wet vegetation) and transpiration through plants. Transpiration results from the vaporisation of water within plant tissues and its subsequent loss through the small openings on the plant leaf called **stomata**.

Evaporation is the conversion of water from liquid to vapour. This process requires energy, energy provided by direct solar radiation and the air temperature. As water is lost to the surrounding air it becomes saturated, and evaporation will slow down if the wet air is not displaced by dry air. The replacement of this saturated air with dry air depends on wind speed. Thus, solar radiation, air temperature, air humidity and wind speed all affect the rate of evaporation. Where soil is the evaporating surface, the degree

of shading by the crop and the amount of water available at the soil surface will also affect evaporation. The meteorological factors driving evaporation also influence transpiration.

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between them. Apart from soil surface wetness, the evaporation from a cropped soil is mainly determined by the fraction of radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and shades more and more of the soil surface. When the crop is small, water is mainly lost by soil evaporation, but, as the crop develops and completely covers the soil surface, transpiration becomes the main process.

The ET rate is normally expressed in millimetres (mm) per unit time – it expresses the amount of water lost from a cropped surface in units of water depth. The loss of 1 mm of water is the loss of 10 m³ of water per hectare (10,000 litres per hectare).

Factors affecting evapotranspiration

Weather

The weather factors affecting evapotranspiration (ET) are radiation, air temperature, humidity and wind speed. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ET_0): it represents the ET from a standardised vegetated surface.

Crop

Crop type, variety and development stage affect the rate of ET from crops grown in large, well-managed paddocks. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop root characteristics result in different ET levels in different crop types under identical environmental conditions.

Environmental conditions

Factors that limit crop development reduce ET – for example, soil salinity, inadequate nutrition, soil compaction, diseases and pests. ET is also affected by groundcover, plant density and soil water content.

Management

The ET rate is also affected by management practices that affect the climate and crop. Here are some of the ET-related effects of management:

- Cultivation practices and irrigation method can alter the microclimate and affect the crop characteristics or the wetting of the soil and crop surface.
- Windbreaks reduce wind velocities and decrease ET rate of the field directly beyond the barrier.
- Micro-irrigation systems that apply water directly to the root zone of crops leave the major part of the soil surface dry, thereby limiting evaporation losses.
- Surface mulches, when the crop is small, substantially reduce soil evaporation.

Evapotranspiration concepts

Reference crop evapotranspiration (ET_0)

ET_0 is the evapotranspiration rate from a grass reference surface with specific characteristics. This reference surface resembles an extensive surface of green, well-watered grass with a uniform height of 12 cm, actively growing and completely shading the ground. The soil surface is moderately dry, resulting from a weekly irrigation frequency.

This concept was introduced to study the evaporative demand of the atmosphere independent of crop type, crop development and management practices.

ET_0 is only affected by climatic factors. Consequently, it can be computed from weather data. The Penman-Monteith method is recommended as the sole method for determining ET_0 because it closely approximates grass ET_0 , is physically based, and incorporates both physiological and aerodynamic parameters. Procedures have also been developed for estimating missing climatic parameters.

Crop evapotranspiration under standard conditions (ET_c)

Crop ET under standard conditions (ET_c) is the ET from disease-free, well-fertilised crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. A crop coefficient (K_c) is used to estimate ET_c from the Penman-Monteith estimate for ET_0 , using the formula below:

$$ET_c = K_c \times ET_0$$

ET_c differs from ET_0 under the same climatic conditions due to differences in leaf structure, stomatal characteristics, aerodynamic properties and solar radiation reflectance. The crop coefficient for a given crop changes from sowing until harvest, as explained in the DPI Note *Irrigation: water balance scheduling* (see WATERpak Appendix 9.6). Table 2.12.1 summarises the crop coefficient values for cotton.



Table 2.12.1. Crop coefficient values for cotton

Stage of development	Description	K_c
Initial	from planting until 10% groundcover	0.35
Crop development	from 10% groundcover to effective full cover (LAI = 3)	0.35 to 1.15
Mid-season	from effective full cover to the start of maturity	1.15 – 1.2
Late	from start of maturity until defoliation	0.7 to 0.5

Crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$)

The crop ET under non-standard conditions ($ET_{c\ adj}$) is the ET from crops grown under management and environmental conditions that differ from standard conditions. Non-optimal conditions such as pests and diseases, soil salinity, low soil fertility, water shortage or waterlogging may result in low plant density and poor crop growth, leading to reduced ET_c .

$ET_{c\ adj}$ is calculated by using a water stress coefficient (K_s) and/or by adjusting K_c for other stresses and environmental constraints on crop ET.

Determining evapotranspiration

ET measurement

Evapotranspiration is difficult to measure. Approaches used for ET measurement include:

- measure computed from the vertical gradient of air temperature and water vapour via the Bowen ratio method
- estimation of the various components of the soil water balance. This could include cumulative soil water loss measured using soil moisture monitoring tools. Some components such as subsurface flow, deep percolation and capillary rise are difficult to measure. This approach usually can only give ET estimates over periods longer than a week.
- lysimeter studies using crops grown in isolated tanks filled with disturbed or undisturbed soil. A requirement of lysimeters is that vegetation both inside and immediately outside of the lysimeter be perfectly matched. Historically this requirement has not always been the case and has resulted in incorrect ET_c and K_c data.

ET computed by meteorological data

ET is commonly computed from weather data, as it is difficult to obtain accurate field measurements. There are a large number of equations that have been developed to estimate ET_o from meteorological data. Some of these approaches are only valid under specific climatic and agronomic conditions. The Modified Penman method has been found to overestimate ET_o , while the alternative Blaney-Criddle and pan evaporation methods show variable adherence to ET_o .

Since 1990, the Penman-Monteith method has been recommended as the standard method for estimating ET_o . The ET from crop surfaces under standard conditions (ET_c) is found from the formula:

$$ET_c = K_c \times ET_o$$

where K_c = crop coefficient

ET_o = reference crop evapotranspiration

The Bureau of Meteorology has developed maps of ET for Australia. These can be found at <http://www.bom.gov.au/climate/averages/climatology/evapotrans/et.shtml>. The Point Potential ET is calculated using Frederick Morton's potential ET approach. It is very similar to the Penman-Monteith ET_o . These maps have also been published by the Bureau of Meteorology as Wang et al. (2001) Climatic Atlas of Australia – Evapotranspiration – for details, see their website at <http://www.bom.gov.au/climate/how/newproducts/IDCetAtlas.shtml>.

Daily estimates of Penman-Monteith ET_o can be obtained from a nearby weather station fitted with the appropriate measurement sensors (solar radiation, maximum and minimum air temperature, relative humidity, and wind speed). These weather stations may be at a Bureau of Meteorology site or a research station, or part of a weather station network such as those operated by Hydrodata Networks. Irrigators can also purchase and install their own automatic weather station (AWS).

ET estimated from pan evaporation

Evaporation from an open water surface provides an index of the integrated effect of radiation, air temperature, air humidity and wind on ET.

The standard open water surface used in Australia to estimate ET_o is the Class A Pan. It is a circular pan, 1.2 m in diameter and 250 mm deep. It is made of galvanised iron and mounted on a wooden open frame platform which is 150 mm above ground level. The pan must be level. A stilling well located on the side of the Class A Pan has a level sensor and is used to record the water depth. The pan should be located in the centre of a grassed area, 20 m by 20 m, open on all sides. It should be located in the centre or leeward side of large cropped fields. A bird cage should be used to prevent animals from drinking from the pan.

It is filled with water to 50 mm below the rim. Water is lost from the pan by evaporation. The amount evaporated is determined daily by measuring the amount of water needed to replace that evaporated.

The Class A Pan has been used for over 40 years in Australia. The relationship between evaporation from a Class A Pan and ET_o is given by the formula:

$$ET_o = K_p \times E_{pan}$$

Where K_p = pan coefficient

E_{pan} = pan evaporation (mm/day)

The K_p values vary with the size and state of the upwind buffer zone, the relative humidity and wind speed. It can also vary with the height of the surrounding crop, painting of the pan, and the level at which water is maintained in the pan. For a pan placed in a short green cropped area and 100 m on the windward side of a dry surface, the K_p ranges from 0.7 (with wind speed below 2 m/s and the average relative humidity below 40%) to 0.85 (with wind speed below 2 m/s and the average relative humidity above 70%). For a pan placed in a dry fallow area, 100 m on the windward side of a green crop and with similar conditions, the K_p ranges from 0.55 to 0.75.

Because of the variability in the siting and maintenance of Class A Pans, evaporation from them is not necessarily comparable between pans. The appropriate K_p should be used to adjust data from Class A Pans so that a meaningful estimate of ET_o can be obtained. Using these values to estimate ET_o for periods less than 10 days is not recommended.

Despite these limitations, Class A Pan data may be the only available evaporation data for irrigators to use. Daily Class A Pan data is available from a number of Bureau of Meteorology weather stations and can be obtained from the Patched Point Dataset available from the Bureau of Meteorology's SILO Service. Details on this service and the subscription cost can be found at <http://www.bom.gov.au/silo>.

Table 2.12.2 summarises the Class A Pan evaporation rates (E_{pan}) as mm/day for centres in (or near) Australian cotton production areas. Maps of total monthly evaporation for Australia are also available at the Bureau of Meteorology's website at <http://www.bom.gov.au/climate/averages/climatology/evaporation/evaporation.shtml>



Table 2.12.2. Average daily evaporation rates from the Class A Pan for selected Australian cotton centres

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Years of data
Biloela	7.2	6.8	6.0	4.8	3.4	2.9	2.9	3.7	5.2	6.4	7.2	7.6	23
Bourke	8.3	7.4	5.9	4.0	2.5	1.9	2.0	3.0	4.2	5.9	7.5	8.5	27
Collarenebri	11.0	9.2	7.3	4.9	3.3	2.8	2.8	3.5	5.0	7.1	9.4	11.5	Rainman
Cunnamulla	12.5	11.2	8.6	5.8	3.7	3.0	3.2	4.3	6.3	8.7	11.1	13.4	Rainman
Dalby	7.9	7.2	7.2	5.6	4.0	3.0	2.9	3.5	4.9	5.5	7.3	8.0	16
Emerald	8.9	7.5	6.4	5.3	4.0	3.6	3.8	5.0	6.7	8.4	9.7	9.8	Rainman
Gatton	6.5	5.8	5.3	4.3	3.1	2.8	3.0	3.7	5.1	5.9	6.5	6.9	33
Goondiwindi	9.9	8.7	6.8	4.8	3.2	2.7	2.8	3.6	5.0	6.9	8.7	9.6	Rainman
Griffith	10.2	9.3	6.5	4.1	2.4	1.9	2.0	2.6	3.6	5.3	7.9	9.7	Rainman
Gunnedah	8.2	7.4	6.7	4.7	3.0	2.1	2.1	3.0	4.3	5.7	7.1	8.5	27
Hillston	8.8	8.2	6.0	3.8	2.2	1.3	1.5	2.1	3.5	5.2	7.1	8.7	22
Kingaroy	6.4	5.7	4.9	3.8	2.7	2.1	2.2	3.0	4.3	5.5	6.2	6.7	32
Miles	7.2	6.3	5.7	4.2	2.6	2.0	2.1	2.9	4.5	5.7	6.4	7.3	26
Moree	9.4	8.3	7.1	4.9	3.1	2.3	2.3	3.2	4.8	6.8	8.6	9.7	27
Mungindi	11.0	8.8	6.9	4.9	3.3	2.9	3.0	3.6	4.9	6.8	8.9	10.4	Rainman
Narrabri	10.0	8.8	7.0	4.8	3.2	2.6	2.7	3.4	4.6	6.4	8.6	10.5	Rainman
Oakey	7.9	7.0	6.4	5.0	3.3	2.6	2.9	3.8	5.2	6.4	7.3	7.9	28
St George	10.8	9.7	7.5	5.3	3.5	3.0	3.2	4.0	5.8	7.8	10.0	11.4	Rainman
Tamworth	9.2	8.2	6.6	4.7	3.0	2.4	2.5	3.0	4.2	5.8	7.9	9.5	Rainman
Theodore	8.5	6.9	6.2	5.4	4.0	3.5	3.6	4.4	5.7	6.7	8.6	9.2	Rainman
Trangie	9.4	8.4	6.7	4.6	2.6	1.8	1.8	2.6	3.8	5.7	7.7	9.5	31
Walgett	8.0	7.6	6.2	4.1	2.5	1.7	1.8	2.6	4.1	5.8	7.3	8.3	17

Source: Bureau of Meteorology (for centres with Class A Pan data). For centres without Class A Pan data, values from the DPI 'Australian Rainman' software used – derived from latitude and temperature data using the Fitzpatrick equation (indicated as 'Rainman' in the 'years of data' column above).

Use of evapotranspiration

Estimates of ET_0 can be used in several ways. Firstly, they can be used to assist in the design of irrigation systems in order to meet peak water requirements – an example of this is given in WATERpak Topic 4.6 'Centre pivots and lateral move machines'.

Secondly, they can be used to assist in irrigation scheduling decisions. They are the basis of the water balance scheduling approach outlined in *Irrigation: water balance scheduling*, DPI Note FS0546 (Appendix 9.6).

Thirdly, they can be used to estimate the losses of water from storage and reticulation systems on farm. ET_0 estimates (from Class A Pan or meteorological data) are multiplied by an appropriate K_c for open water to estimate evaporation losses in this situation. Where the open water is less than 2 m depth, or in sub-humid or tropical climates, the K_c to use is 1.05.

In more temperate climates, or where the water body is greater than 5 m depth, the K_c during autumn and winter is 1.25, and for spring and summer it is 0.65. In this situation there are large temperature changes in the water body during the year, and the initial and peak period evaporation are lower, as radiation energy is absorbed into the deep water body. During autumn and winter, heat is released from the water body that increases the evaporation above that of grass (hence $K_c = 1.25$). When the water is gaining thermal energy (spring and summer) the evaporation rate falls below that of grass (hence $K_c = 0.65$). Note these are estimates only.

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2.13 Using automatic weather stations

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Key points

- Automatic weather stations (AWS) provide site-specific atmospheric information that irrigators can use to assist irrigation scheduling decisions.
- There are a range of factors to consider when purchasing an AWS: sensor availability, accuracy, robustness, method of calculating ET_o , maintenance issues and availability of technical support.
- The siting of the AWS is critical to the accuracy of climatic data recorded.
- Regular and proper maintenance of the AWS is necessary to obtain accurate data.

Purchasing an automatic weather station

There is a wide range of suppliers and distributors in Australia, including:

- Agrilink (www.agrilink-int.com)
- Campbell Scientific Australia (www.campbellsci.com.au)
- CropTech Laboratories (www.croptech.com.au)
- Envirodata Australia Pty Ltd (www.envirodata.com)
- Environment Information Technology (www.eitechnology.com.au)
- Esis Pty Ltd – Australia (www.esis.com.au)
- Hydrodata Network (www.hydnetwork.com)
- Goanna Telemetry Systems, Goondiwindi (nutrilab@bigpond.net.au)
- Measurement Engineering Australia (www.mea.com.au)

AWS units range in price from \$5 000 to \$13 000 (GST exclusive). There are a range of factors to consider apart from cost when purchasing an AWS: for further details, see the Bureau of Meteorology's *Automatic weather*

stations for agricultural and other applications (www.bom.gov.au/inside/services_policy/pub_ag/aws/aws.shtml) document.

Some key factors are:

- the sensors available, their accuracy, precision, and robustness – for ET_o calculations, sensors for solar radiation, maximum and minimum temperature, relative humidity and wind speed are needed.
- If ET_o is automatically calculated by the AWS, determine what method is used; the Penman-Monteith method is preferred.
- Maintenance should be able to be performed on an AWS without affecting the climate record.
- The format of the data output should be simple, flexible, preferably human-readable without reformatting, and independent of the AWS manufacturer. It should also be possible to remotely download data.
- the availability and quality of technical support if the AWS malfunctions.

Siting an automatic weather station

The quality of the weather data from an AWS is a function of the quality of the sensors used and the appropriateness of its siting. Ideally the AWS should be placed in the centre of an open space of at least 50 m by 50 m, which is covered by a short, green grass and surrounded by crops. The site should be on level ground and not shielded by trees or buildings, which would affect the data recorded. It should not be close to steeply sloping land or in a depression where temperatures are frequently higher during the day and cooler at night. Avoid rock outcrops, stone or gravel surfaces near the AWS.

Table 2.13.1 summarises suggested measurement heights and exposure for different sensors in an AWS relative to an existing (or likely future) obstruction such as a growing tree.

Table 2.13.1. Suggested heights and exposure for AWS sensors

Sensor type	Measurement height above ground level	Exposure considerations
Wind	2 m	No closer than 10 times the obstruction's height
Air temperature & relative humidity	1.25 to 2 m	The sensors must be housed in a ventilated radiation shield to protect the sensor from thermal radiation. No closer than 4 times the obstruction's height and at least 30 m from large paved areas.
Solar radiation	To facilitate levelling/cleaning install at a height of 3 m or less	The sky should not be blocked by any surrounding object. Objects less than 100 above the horizontal plane of the sensor are allowed.
Rain	300 mm (at greater height wind affects the accuracy of measurement)	The sensor should be no closer than 4 times the obstruction's height. The orifice of the gauge must be in a horizontal plane, open to the sky, above the level of in-splashing (that is, above the level of any structures likely to cause splashing into the gauge).

Source: Campbell Scientific Australia 2001; Doorenbos 1976



Varying environmental conditions such as moisture or a growing crop can affect the measurements taken by an AWS in relation to its siting. Three possible effects are:

- the 'clothesline effect', where air passing from dry unvegetated surfaces to moist vegetated surfaces impacts on vapour pressure gradients and heat transfer.
- the 'leading edge effect', where air moves from one type of surface to another surface that differs in temperature, moisture content or roughness. As air passes over the 'leading edge' of this surface change, it gradually adjusts to the new surface. There is a zone where the air is modified but not adjusted to the new surface – placement of an AWS here can give misleading data.
- The 'oasis effect' where an isolated moisture source (a dam or crop for example) is surrounded by a dry area. If the wind draws moist air from the dam or crop, then the relative humidity measurements near this moisture source do not represent the general condition in the area.

Locating an AWS used to calculate ET_o on the roof of a building to make it easier to access data is not acceptable. High air temperatures result from heat convected or conducted from the building surface. The physical and radiative properties of the building material can be important in determining

heat loading. A surface with high reflectivity may cause high irradiance values as incoming solar radiation is reflected onto the sensor from the surrounding walls and roof.

Thoroughly discuss the siting of your weather station with your supplier (and don't forget likely future changes in the exposure of the site, through the construction of new buildings or the growth of trees).

Maintenance

Regular and proper maintenance of the weather station is essential to obtain accurate data. The owner of the AWS can carry out routine and simple maintenance. This should include:

- Regular checking and clearing the rain gauge collector of dust and debris. Bird droppings are a particular problem.
- The wet bulb sensor wick should be changed at least weekly throughout the year and more often during hot, windy weather. The water reservoir should be clean and free of algae. To test if the wick is working, feel for moisture at the top of the wick. Replace it if dry and clean the water reservoir. Algae make the wick hydrophobic, causing it to dry out rapidly in hot weather.
- Weekly maintenance is generally unnecessary on AWS sensors used to directly measure relative humidity. They are prone to calibration drift and are adversely affected by moist or dusty environments.

Therefore metallic screens or cellulose acetate film is often used to protect these sensors. Monthly sensor element replacement is necessary if it becomes contaminated. Monthly calibration is also recommended.

- Check the bearing in the wind-run anemometer by listening for any noises as the cups rotate. The cup rotation can also be halted by hand to check for any friction evident at low wind speed. The only way to check the calibration in the field is with a newly calibrated anemometer.
- Check the solar radiation sensor for dust and debris, and clean as required.

More difficult maintenance such as sensor calibration, sensor performance testing and sensor component replacement generally requires a skilled technician and specialised equipment.

Weather station networks

Hydrodata Network Dubbo have established automatic weather station networks in many cotton valleys. The existing networks (at April 2004) are listed in Table 2.13.2. For more details on accessing these networks, contact Hydrodata Network on (02) 6885 4119 or visit their website at www.hydrodata.com.au

Table 2.13.2. Hydrodata Network weather station networks

Networks	Locations
Darling Downs Cottongrowers Inc	Alderton, Bongeen, Bowenville, Brookstead, Cooranga Creek, Dandine, Dalby, Formartin, Hopelands, Horrane, Jimbour, Jondaryan, Kupunn, Macalister, Nandi, Norwin, Pirriuan, St Ruth, Tyunga, Warra, Yandilla
Lachlan Valley	Brooklyn, Uabba, Whitelea, Yulgar
Clyde Agriculture Ltd	Beemery, Janbeth, Latoka, Rumleigh, Toorale
Gwydir Valley	Bangarang, Bellevue, Cockatoo, Cooma, Deer Park, Kingston, Milliwa, Milo, Norwood, Redmill
Lower Namoi	Belpais, Myall Vale
Macquarie Valley	Bellevue, Newhaven, Ockben, Pillicawarrina

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Section 3

Irrigation management of cotton

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3.1 Cotton growth responses to water stress

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James Neilsen and Greg Constable

Cotton CRC, CSIRO Plant Industry, Narrabri

Key points

- Cotton plant responses to water stress vary depending on the stage of growth at which the stress occurs, the degree of stress, and the length of time the stress is imposed.
- The plant aims to establish a balance between carbohydrate supply and demand. Water stress at any stage of growth will affect both the production and distribution of carbohydrates throughout the plant. Carbohydrate demands on the plant, primarily made by developing bolls, restrict excessive vegetative growth.
- Through adaptation, the cotton plant survives during periods of water stress by prioritising the maintenance of different physiological processes to ensure the production of viable seed and therefore cotton fibre. The impact of water stress on final yield depends on the degree to which each physiological process is affected.

By understanding some of the principles of plant growth and how cotton plants have adapted to reduce the impact of water stress on growth, growers may better use their available water resources to improve water use efficiency.

Plant growth = carbohydrate supply and demand.

Cotton has an indeterminate growth habit (that is, it is a perennial that keeps growing), and therefore under favourable conditions the number of leaves, new nodes, fruiting branches and squares can increase rapidly, unlimited by a phenological time frame, and continue to be produced while conditions remain favourable.

During the pre-flowering stages of growth, production of carbohydrates (through photosynthesis) is in excess of demands, and as a result vigorous vegetative growth occurs.

As plant growth continues, the demands for carbohydrates by the component plant parts such as bolls increase, and production becomes limited by environmental conditions. Boll growth exerts large demands for carbohydrates and it is through the balance between boll demand and leaf production that vegetative growth is restricted.

The overproduction of squares by the plant is an adaptation by the cotton plant which ensures that a balance is achieved between carbohydrate supply and demand. Square shedding during periods of cloudy weather, for example, is mediated through reduced carbohydrate supply and is an example of how plant growth is balanced between carbohydrate supply and demand.

Water stress can restrict both vegetative and boll growth. It has been shown that no matter what degree of water stress is imposed on a crop, the proportionality between vegetative growth and boll development remains relatively constant. Similar results have been achieved with crops receiving different amounts of nitrogen. This implies that, independent of water or nutrient supply, the plant will always attempt to form a balance between vegetative growth and boll development. Table 3.1.1 shows the distribution of dry matter in cotton plants grown under different irrigation frequencies and with or without nitrogen fertiliser (averaged over three seasons' data).

Table 3.1.1. Distribution of dry matter in cotton 140 days after sowing

Irrigation	Fertiliser kg N ha ⁻¹	Dry weight of tops gm ⁻²	Distribution of dry weight (%)		
			leaf	stem	boll
Frequent	0	450	15	34	51
Frequent	150	747	15	42	43
Infrequent	0	460	18	34	48
Infrequent	150	695	18	39	43

Source: Constable and Hearn 1981

Carbohydrate production and water stress

Production of carbohydrates through the process of photosynthesis and their storage are the primary functions of leaves.

Leaf age is an important plant factor affecting daily photosynthesis. In non-stressed plants, peak carbohydrate production from an individual leaf occurs when the leaf is around 20 days old. Peak plant carbohydrate production will occur when the combination of photosynthesis per unit leaf

area and leaf area is maximised. In non-stressed plants this usually occurs some 60 to 70 days from the unfolding of the first true leaf (75 to 85 days after planting). Decline in daily carbohydrate production after this date results from increasing canopy leaf age and increased self shading and the increase in boll demand for carbohydrates, which restricts any new leaf development.

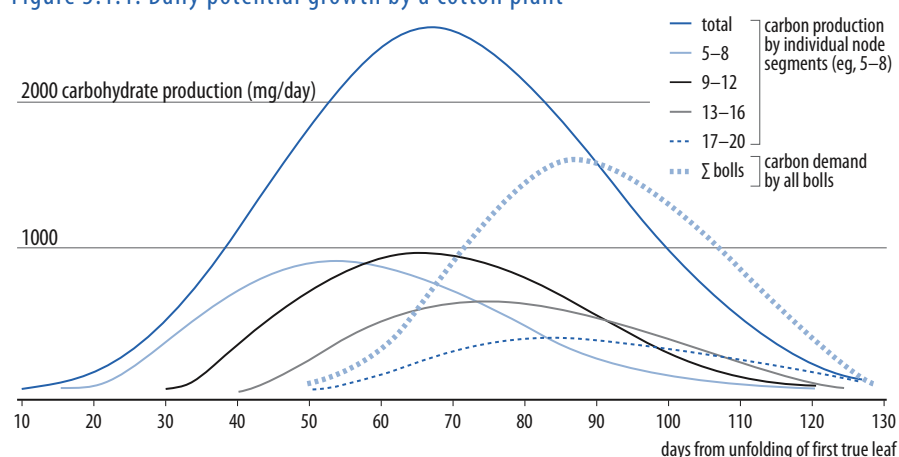
Figure 3.1.1 shows daily potential carbohydrate production for individual node segments and an accumulated total for the total canopy; boll demand has been superimposed over production.

It is evident from these data that factors which affect leaf development, particularly early leaf development, will affect total plant carbohydrate production and therefore yield potential. Water stress has been shown to reduce whole plant leaf area largely through reductions in total leaf numbers. However, the rate of leaf expansion is also reduced, which in turn reduces the size of individual leaves.

Reduction in leaf area will obviously affect the level of total canopy photosynthesis. Photosynthesis is maintained in priority over leaf expansion and development. This allows the plant to maintain current photosynthetic capacity but limits future capacity. The value is that it also stops demand for water increasing when there is not enough to meet even current demands.

Figure 3.1.2 shows the relationship between available soil water and relative leaf net photosynthesis and daily leaf expansion.

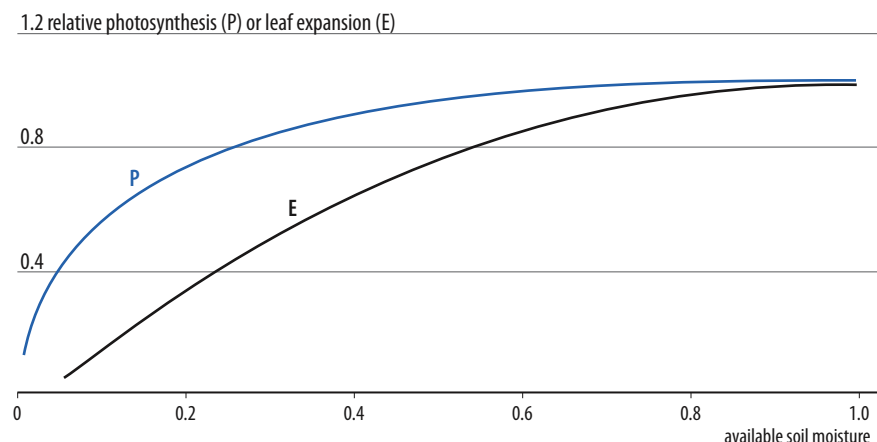
Figure 3.1.1. Daily potential growth by a cotton plant



Source: Constable and Rawson 1980



Figure 3.1.2. Available soil water and its effect on relative net photosynthesis and relative daily leaf expansion



Relative refers to the ratio between stressed and non-stressed plants.

Source: Constable and Rawson 1982

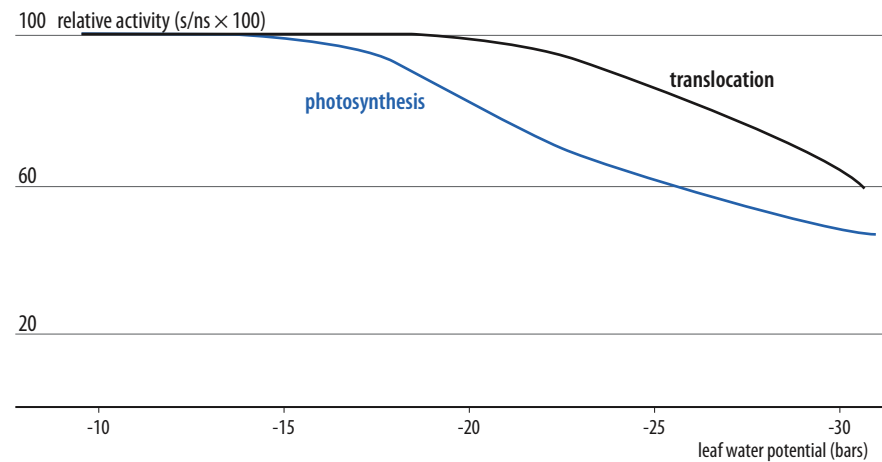
It can be seen that leaf expansion has been greatly reduced by the time photosynthesis has started to decline. In terms of plant growth, the maintenance of photosynthesis will enable boll and root growth to continue longer during periods of water stress than vegetative growth. This drought adaptation will also allow the plant to recover quickly from small periods of mild stress, particularly during early, pre-flower growth stages.

Carbohydrate redistribution

The export or redistribution of carbohydrate from an individual leaf is initially small, to allow effective leaf growth. Once leaf growth has stopped at around 20 days of age, however, carbohydrate in excess to leaf requirements is produced and this can either be stored as starch for later use or be directly exported to actively growing plant parts.

The rate of export of carbohydrate from the leaves is determined by the demand imposed by other plant parts. Actively growing organs such as roots, bolls and growing terminals act as 'sinks' which actively compete for the available carbohydrate. The pattern of distribution will depend on the leaves' capacity to satisfy the requirements of individual sinks. Since it is particularly important for the plant to have the capacity to utilise excess carbohydrate during periods of stress, plant adaptation allows the processes involved in transferring carbohydrates away from the leaves to continue at higher water stress levels than those that reduce photosynthesis (Figure 3.1.3). Therefore, water stress not only affects production of carbohydrate but also alters its distribution.

Figure 3.1.3. Relative activity of photosynthesis and translocation in cotton leaves as a function of leaf water potential



s = stressed; ns = non-stressed

Source: Krieg and Sung 1986

Root development

At the time of flowering, around 80% of the plant's root system may be developed and thus the root system imposes the greatest demand for excess carbohydrates during early plant growth. After flowering, boll development begins to compete with the root system for carbohydrates and the rate of root expansion declines. Under water stress, however, the plant is adapted to place priority on root growth. As a result, root expansion occurs at the expense of vegetative and boll growth. Figure 3.1.4 compares vegetative and root dry matter levels for crops produced with adequate moisture (blue line) and with moisture stress (black line).

Figure 3.1.4. Pattern of dry weight over time

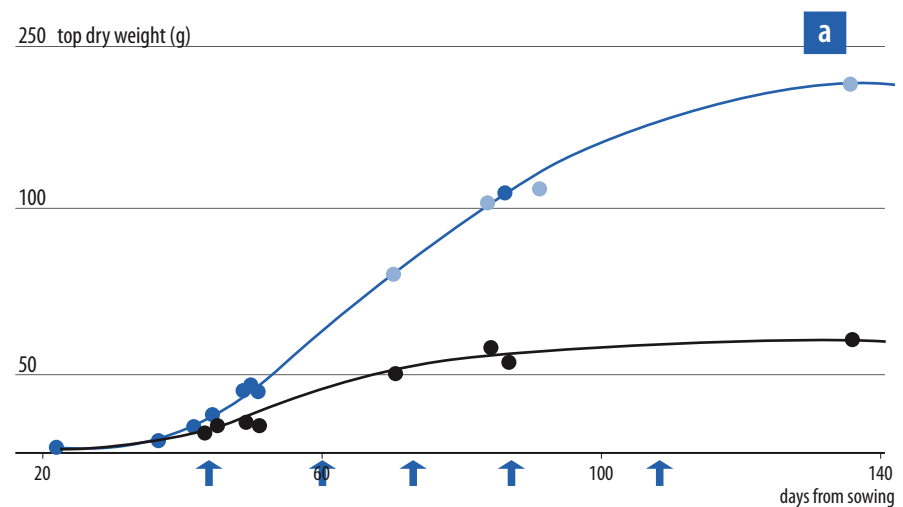
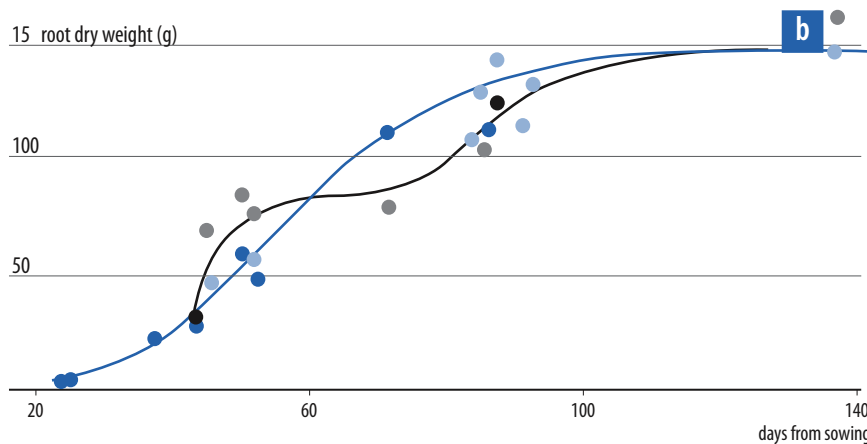


Figure 3.1.4. (cont.)



(A) top vegetative growth and (B) roots as affected by moisture stress.

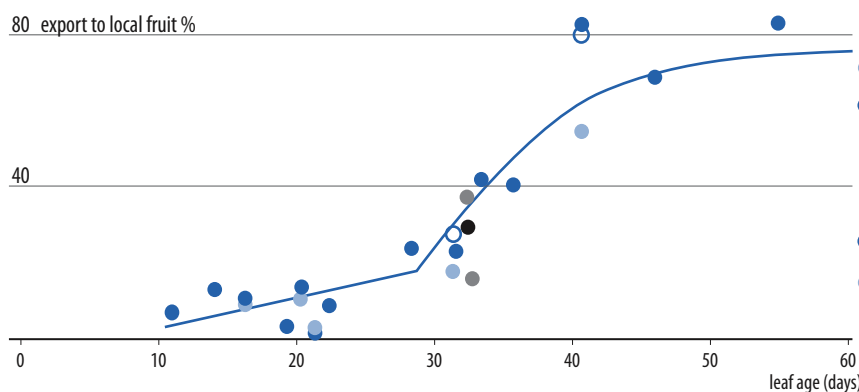
Blue line = adequate moisture, black line = moisture stress

Source: Constable and Rawson 1982

Boll development

Squares exhibit little carbohydrate demand on the plant during early growth, with bracts supplying the majority of their requirements. A rapid increase in demand for carbohydrates occurs after flowering (Figure 3.1.5). This is the reason that the majority of fruit is shed as flowers or two- or three-day old bolls. Shedding of bolls can occur up to an age of 10 to 14 days, after which cell wall thickening between the boll and stem prevents an abscission layer from forming. In the case of a rapid onset of water stress, young bolls in which growth has stopped may be retained by the plant and appear as 'mummified' dry bolls. Figure 3.1.5 illustrates that up to 80% of the carbohydrate produced by this leaf is exported to the local boll. It has also been shown that the proportion of carbohydrate distributed from leaf to boll is not affected by water stress. This implies that boll development is affected by total carbohydrate supply and not by the rate of distribution from adjacent leaves. This is consistent with the fact that redistribution of carbohydrate can occur at stress levels beyond those that affect production (Figure 3.1.3).

Figure 3.1.5. Relationship between leaf age and the proportion of carbon export from the leaf found in the adjacent fruit as affected by soil water

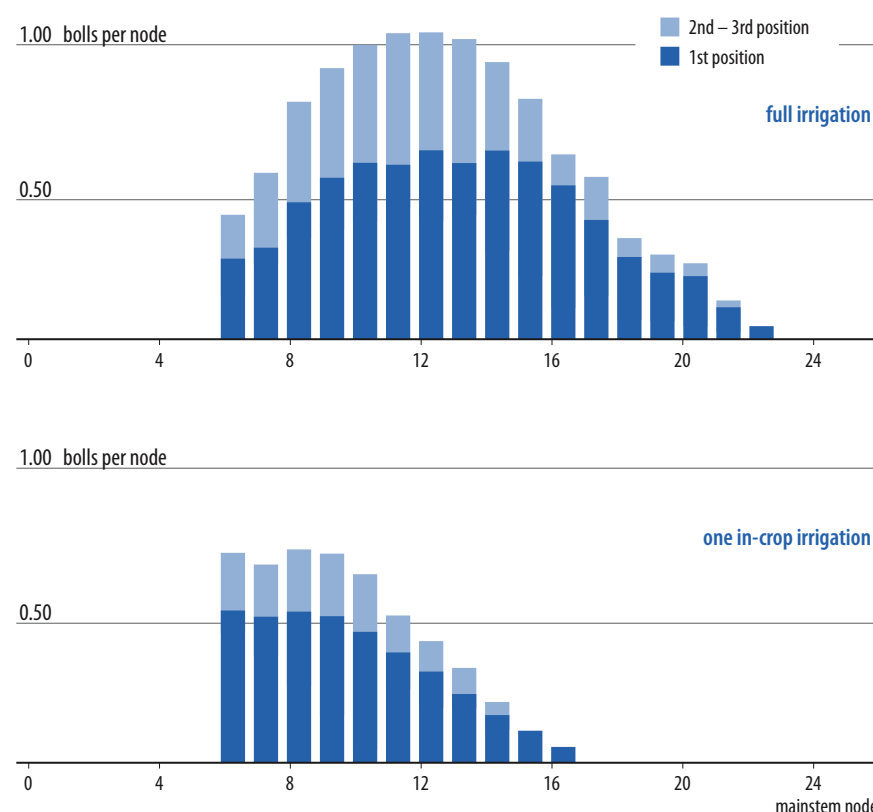


Source: Constable and Rawson 1982

As boll demand exceeds supply from the adjacent leaf, inter-boll competition for further carbohydrate occurs. Older bolls compete more effectively than younger bolls and this results in the movement of carbohydrates away from the extremities of the main stem and individual fruiting branches. Those bolls unable to compete effectively are either shed by the plant or are reduced in size, hence the occurrence of smaller boll towards the top of the plant. It is for this reason that the majority of fruit, particularly secondary position bolls, is retained by lower fruiting branches.

In non-stressed irrigated crops, increased early vegetative growth results in shading of lower leaves and this causes reduced retention and boll size on the first two or three fruiting branches. The final results of this combination of inter-boll competition and leaf shading in fully irrigated crops is the common bell-shaped distribution of bolls throughout the plant (Figure 3.1.6). In the case of crops under water stress, the same inter-boll competition occurs, but there is generally less total carbohydrate to be distributed amongst bolls. Reduced vegetative growth also minimises shading of lower leaves, resulting in the higher boll retention and boll size occurring amongst the first fruiting branches. Figure 3.1.6 shows the differences in boll distribution throughout the plant that can occur between a fully irrigated crop and a crop that had received one in-crop irrigation.

Figure 3.1.6. Pattern of boll distribution as affected by water stress



Source: D Gibb and Colly Farms

Water stress and crop yields

The degree of plant response to stress will vary depending on the level of stress which occurs and the timing at which the stress is imposed, relative to crop growth. Table 3.1.2 summarises the plant's responses to differing degrees of water stress. The effects on final crop yield, fibre development, maturity and water use efficiency are also discussed.

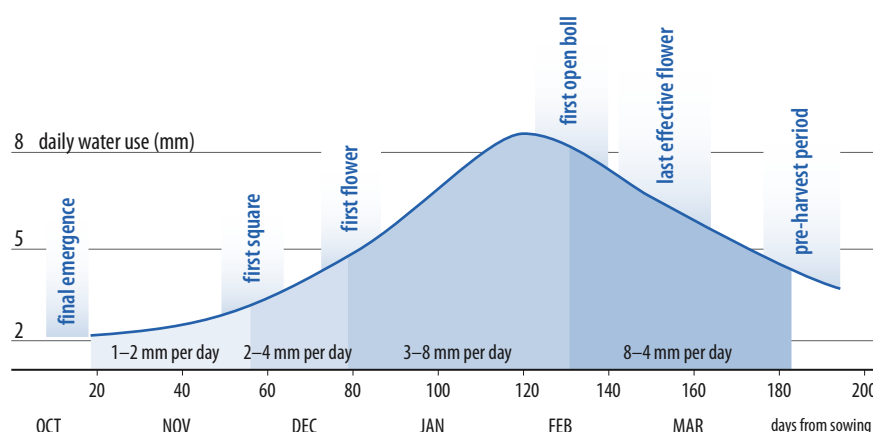
Table 3.1.2. Summary of responses to water stress

Degree of water stress	Possible causes	Physiological plant responses	Yield effects on maturity and WUE
Minimal stress	Reduced irrigation deficit	Excessive vegetative growth	Reduced yield
	Excessive rainfall	Increase in leaf area	Reduced boll size
	Cloudy weather	Extended flowering cycle	Delayed maturity
	Excessive early insect damage	Reduced carbohydrate surplus for bolls	Normal fibre length but low micronaire
	High plant stands	Reduced root development	Poor WUE
		High boll capacity but poor boll retention	
Mild stress	Optimum irrigation deficit	Optimum vegetative growth rate	Maximum yield
	Average temperatures (not excessively hot)	Leaf expansion restricted	High quality cotton
		Photosynthesis remains unaffected	No delay in maturity
		Maximum carbohydrate surplus	Maximum WUE
		Maximum boll development	
		Good fibre development	
Moderate stress	Increased irrigation deficit	Reduced vegetative growth and leaf expansion	Reduced yield
	Extremely hot temperatures with low humidity, windy conditions	Reduced photosynthesis	Early maturity
	Little cloud cover	Reduced surplus carbohydrates	Increased short fibre micronaire
		Reduced boll carrying capacity	Slight decrease in WUE
		Increased fibre development	
Severe stress	Less than 3 irrigations	Vegetative growth greatly reduced - stops after flowering	Low yields
	Dryland crops	Greatly reduced carrying capacity	Short fibre
		Little surplus carbohydrates	High or low micronaire depending on stress pattern
		Low boll retention	WUE depends on rainfall

Crop water use and plant growth

A cotton crop's requirement for water changes throughout the growing season, following the pattern of evapotranspiration. The rate of evapotranspiration is determined primarily by meteorological factors and the availability of soil water. Total crop evapotranspiration will vary with canopy size, or leaf area. Crop leaf area peaks 3 to 5 weeks after the start of flowering and this results in a peak in daily water use of between 8 and 10 mm (Figure 3.1.7).

Figure 3.1.7. Nominal seasonal daily water use (mm/day) for cotton production



Maximum demand for water also coincides with the growth period between peak flowering and early boll development. Exposing the plant to water stress at this stage of growth can result in significant yield reductions. The impact of water stress at different crop growth stages on final yield is directly related to the water demands expressed by the crop. Stress during periods of high water demand can produce large reductions in yield. Table 3.1.3 shows yield reductions resulting per day of stress for different crop growth stages. Stress during peak flowering can double yield losses compared with early or late seasonal stress. The impact of any one stress period is increased if followed by further stress.

Table 3.1.3. Effect of stress at different stages on cotton yield

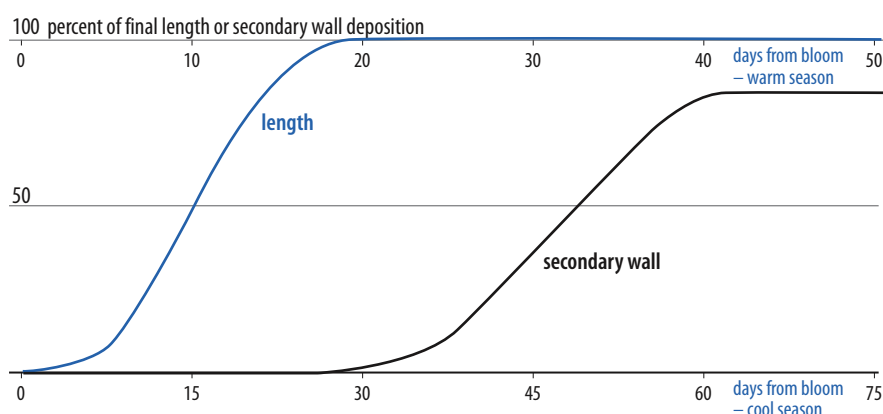
Growth stage	Reduction in yield with one day of stress (kg lint/ha)
Squaring	9.2
Peak flowering	18.8
Late flowering	16.1
Boll maturation	3.6

Source: Hearn and Constable 1984

Fibre development

Fibre development begins the day after flowering and is a two-stage process with fibre elongation (length) preceding secondary wall development (thickening). In a non-moisture stressed situation, fibre length reaches a maximum between 20 and 30 days post flowering with fibre wall development being completed some 40 to 60 days post flowering, depending on temperature (Figure 3.1.8).

Figure 3.1.8. Time of biological maturation of cotton fibres (warm and cool seasons)



Although temperature is the main determinant of the length of the period between flowering and boll opening, carbohydrate supply directly affects the degree of fibre development and final boll size. As discussed previously, under water stress younger bolls are shed to enable the development of older bolls. The plant has increased its adaptation for survival during drought by placing priority on seed and fibre development over total fruit retention. This is demonstrated by the fact that young boll shedding can occur at lower moisture stress levels, while fibre development is not affected until higher stress levels are reached. The increase in micronaire generally associated with cotton suffering from water stress at the end of flowering is a good example of this plant adaptation. Increase in micronaire occurs because younger bolls are shed, and more carbohydrate becomes available to lower bolls. With fibre development continuing under higher stress levels, any extra carbohydrate available is allocated to increases in fibre cell wall thickening, leading to increases in micronaire. Moisture stress during peak flowering will tend to affect fibre length rather than fibre maturity, while stress later in the season will primarily affect fibre maturity.

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3.2 Managing irrigated cotton agronomy

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Key points

- Crop rotation, mepiquat chloride and nitrogen rate, and row configuration can affect the irrigation requirements and scheduling during the season.
- Several tools exist to help growers manage their farm and irrigation water.
- Climatic risk and rainfall probabilities can be determined for any location in the Australian cotton industry.

To a large extent, agronomic management to achieve efficient irrigation is an outcome of the indeterminate nature of the cotton plant. Like management for maximum yield, the objective is to balance the vegetative development of the plant and the developing boll load. While a vigorous plant carrying a large number of bolls is obviously necessary, the crop should not be pushed to the extent that it produces excessive vegetative growth. In terms of water use efficiency this is likely to result in increased water use by the crop with no yield benefit.

Clearly, a wide range of management factors can impinge on the water use efficiency of a crop. Insect management and soil structure are two major considerations. These are covered in other documents and computer software and will not be dealt with here. In this topic we will consider cropping history, stubble management, nitrogen management and mepiquat chloride.

Cropping history and stubble retention

The choice of cropping sequence can be made for a variety of reasons: not the least of these will be economics. Weed, disease and pest management and fertility may all play a part. However, it should be recognised that the choice of crop alternative may influence the water management of the subsequent crop.

Rotation crops which dry the soil down well can be used in the system to assist in repairing previous damage to soil structure. Wheat dries the soil well over the zone where compaction due to traffic is likely to occur. Sunflower and safflower dry the soil to a greater depth than others. The drying process helps re-establish soil peds, as well as providing macropores, through cracking and root channels, which will increase the ease of root penetration by the subsequent crop (refer to SOILpak). The result can be to provide a greater rooting depth for the following crops, which will result in a greater available water and nutrient reserve. This will affect yield directly but will also mean that a longer irrigation interval is possible. A longer irrigation interval will mean that the proportion of the cycle in which the crop is

exposed to the risk of excess soil water or inadequate water supply is reduced. However, the benefits need to be balanced against the value of conserving moisture for subsequent crops. This is well recognised in dryland cropping, but even in irrigated production, it should not be forgotten that when water is the limiting resource rather than land, stored rainwater can reduce the amount of water required for pre-irrigation. Some vertosols can store up to 150 mm of plant available moisture, which is a significant contribution to the crop's water requirement. The water saved by this substitution can be taken into account when calculating the area that can be planted based on the available water supply. In addition, a very dry profile may not be fully re-wet by the first irrigation.

Stubble retention has been introduced in Australian agriculture primarily for its value in erosion control and the contribution of the decomposing material to soil organic carbon pools. It needs to be recognised however that stubble retention will also interact with irrigation management to a greater or lesser degree.

The reduced rate of run-off, the basis for stubble's value in erosion control, also contributes to a higher infiltration rate. In the fallow phase or prior to crop planting, this means that more water is captured and stored for use by the subsequent crop. This reduces the amount of water required to fill the profile at

the pre-sowing irrigation. Similarly, if the stubble can be retained between the planted rows, infiltration is increased and run-off reduced. The cover provided by the stubble also reduces the rate of soil evaporation to some extent, again conserving moisture. However, these effects can also prove disadvantageous during periods of high rainfall or rainfall after irrigation. The higher amount of water retained and slower movement of water off the field can leave the crop more prone to waterlogging. In terms of the application of irrigation, the slower in-furrow flow rate and the higher proportion of water infiltrating needs to be taken into account in the rate at which water is applied to the field and the duration of the irrigation. The general rule would be to increase the application rate somewhat, which would reduce the required application time. The exact optimisation of the application technique is rather complex and tools such as SIRMOD (see Topic 2.9) should be used.

Most movement of soil from the field occurs from the top and side of the ridges or beds, so the amount of stubble required for adequate erosion control declines as the plants develop to cover this strip. Initial experiments by NSW Agriculture suggest that cultivating the bottom of the furrow prior to the first irrigation may prove an effective compromise and assist field drainage.

Nitrogen

Approaches to the assessment of nitrogen requirements are spelt out elsewhere, in particular in the Cotton CRC NUTRIpak publication. The optimum amount of nitrogen application before sowing is by and large determined by soil type and the nitrogen status of the soil. However there is a strong interaction between fertiliser application and the amount of water applied.

Excessive nitrogen fertiliser can negatively affect crop growth. When adequate water is available, high rates of nitrogen can promote vigorous vegetative growth. The primary effect of the more vigorous growth is a higher rate of transpiration. Except for when the soil is wet to the surface, the rate of evapotranspiration from the crop is governed by the leaf area index (LAI); that is, the leaf area per unit ground area. Vigorous crops have more and larger leaves and thus a higher LAI. This means that the rate of water consumption per day is higher in crops that have received high rates of N and water. This extra growth and water consumption may or may not lead to commensurate improvements in yield. Where good retention is achieved and there is adequate season length, strong growth will lead to high yield. However, the greater canopy size may instead lead to a reduction in retention due to shading of the lower leaves and fruit. In tropical or subtropical conditions the combination of high water, high nitrogen and high temperature can trigger the 'rank growth syndrome'. This is induced when high growth results in the shedding of fruit which in turn results in a lower



carbohydrate demand by the fruit and hence there is more available for vegetative growth and thus there is continued vegetative vigour. The result is a large late crop with a possible reduction in yield. A similar situation occurs in short season areas when too much nitrogen is applied. While the classical 'rank growth syndrome' may not be induced, the added vigour of the crop and delayed maturation of the crop may result in yield loss if the crop is truncated by cold weather. In either case, water consumption can be increased with little benefit in terms of yield, and possibly a negative effect on yield.

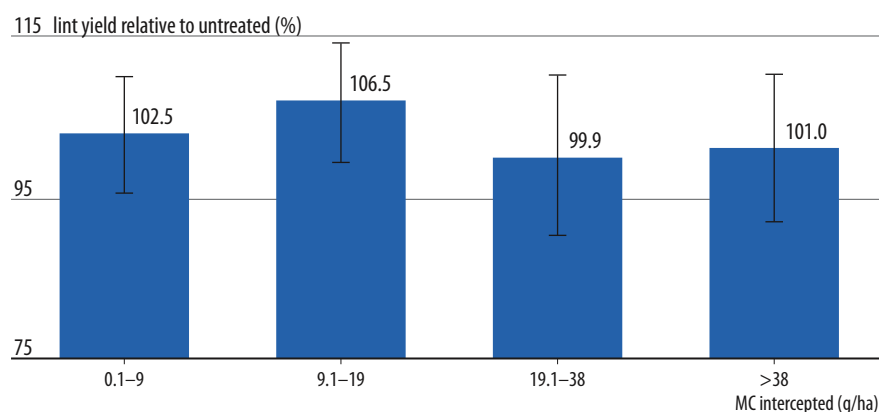
If excessive nitrogen is unintentionally applied, the temptation is to apply water at the rate that the more vigorous crop demands it. This is not necessarily

the best option. A slightly restricted water supply will reduce the vigour and reduce the overall risk of delayed development. The condition can also be dealt with by monitoring the vegetative vigour of the crop and using mepiquat chloride as required. However, trials in Kununurra have demonstrated that under northern tropical conditions, very early intervention is required to have adequate effect. Even so, the yield advantage is small (Figure 47). This reinforces the need to apply N fertiliser as required, based on measured soil nitrogen. If measured soil nitrogen is not available, a rule of thumb can be used based on region, soil type and cropping history. This is available on the CRC website: www.cotton.crc.org.au/Tools/n-rate.cgi

At the other extreme, when water is limited, the crop is less responsive to applied nitrogen, simply because growth is limited by water stress. The water limitation causes a reduction in leaf area and overall growth rate. There is therefore less need for nitrogen to build these structures. Thus, in limited water situations the crop is likely to require less applied nitrogen.

Waterlogging reduces nitrogen uptake. There appears to be two mechanisms: firstly the ability of cotton's roots to extract nitrogen from the soil is impaired, and, secondly, the amount of nitrogen in available forms in the soil is reduced because of the chemical reactions that take place in the anaerobic soil. The application of foliar nitrogen to waterlogged crops has been shown to have definite yield advantages in certain circumstances but it cannot fully compensate for the impact of waterlogging.

Figure 3.2.1. Effect on final yield of mepiquat chloride concentration (MC) in tropical conditions



Source: extracted from Yeates et al. 2002

Mepiquat chloride

Mepiquat chloride (MC) or Pix® suppresses the expansion of vegetative organs. During fruit growth, this may reduce the within-plant competition between bolls and leaves for the available carbohydrate. The outcome can be a shift in the partitioning of dry matter to the bolls. However there is little evidence for this being a significant benefit in crops sown at normal times where water and nitrogen are well managed. In these situations, no yield advantage has been demonstrated and any advantage in dry matter partitioning disappears by maturity as the crop moves back to its inherent pattern of partitioning.

MC is an advantage where a crop has become too vigorous. In this situation the suppression of leaf expansion and the subsequent shift in partitioning bring the carbohydrate supply and demand back toward the optimal balance. Interrupting the ongoing expansion of the crop also reduces the subsequent water usage. The outcome of these two responses mean there is the potential for both increased yield and increased water use efficiency.

It is important to remember that high rates of mepiquat chloride will **stop** growth and could potentially **limit** yield. Careful consideration needs to be made when deciding to apply a growth regulator, particularly when the crop is under stress and experiencing hot growing conditions.

A number of cotton farmers have used mepiquat chloride at peak fruiting during January. Cotton plants usually produce far in excess of two hundred fruits per metre but hardly ever mature more than 125 to a harvestable stage, even when achieving very high yields. MC applications at peak fruiting may be a means to promote boll fill and to slow down 'unnecessary' fruit production and vegetative growth. This strategy has shown several advantages:

- Reduced top growth from MC applications at peak fruiting means better coverage and less crop dilution for late season insecticide applications and often result in at least one insecticide spray less due to better efficacy.
- MC applications at peak fruiting also promote uniformity of crop canopy as well as maturity and therefore have a positive impact on the efficacy of defoliation chemicals.

It should be noted, of course, that reduced water or nitrogen availability will also control leaf expansion. The most efficient way to reduce the risk of excessive vegetative growth becoming a problem in the first place is correct nitrogen fertilisation and careful irrigation management. This will not cover every eventuality, and the use of MC will be required from time to time when growth becomes excessive. This pattern of growth may occur in warm production areas or late sowings, after heavy insect damage or unfortunately timed rainfall events which have 'released the brake' on the plant through shifting conditions in favour of vegetative growth.

Apply nitrogen fertiliser based on soil test or cropping history, schedule your irrigation by measurement and monitor internode lengths. Use MC only when the internode extension rate indicates it is required.



Planting area decisions

Several information sources exist that may be accessed by cotton growers to help determine the best cropping option and climatic risk for a particular location. Historical farm records of irrigated cotton area, irrigation and total water use during seasons, and average farm yields can be used to make decisions on how much area to plant to cotton. Further

general information can be found in the *Australian Cottongrower* article 'High prices and low rainfall: A recipe for frustration or an opportunity for a calculated risk?', where Dr Brian Hearn used the OZCOT model to demonstrate the range of crop responses that could be expected from various water allocations.

There are several new software tools which can provide useful information when making the decision on cropping area.

HydroLOGIC

Decisions about the amount of irrigated cotton to plant in any one season can be made using the HydroLOGIC software. A historical analysis of potential yield under a range of water allocation scenarios and an average crop response can be determined for each of the water allocations. The trade-off between allocation, area and yield can then be determined.

Table 3.2.1. Comparison of multiple simulation results from Narrabri and Emerald

Multiple scenario comparison – end of season status Farm: Big Bolls – Narrabri

Field: Field 1, Crop: 2003-04 plant

Variety: SICOT189, sown 01.10.03

Scenario	Run date	Final irrigation	Total irrigation	Pre-run pumped (ML)	Post-run pumped (ML)	Water pumped (ML)	Water left (ML)	Total rain (mm)	60% open	Total bolls (/m ²)	Yield (bales/ha)	Irrigation water use index (bales/ML/ha)
3 ML/ha	01.10.03	20.12.03	2	0.0	2.7	2.7	0.3	353	21.02.04	82	4.6	1.7
5 ML/ha	01.10.03	24.01.04	4	0.0	5.2	5.2	-0.2	375	03.03.04	106	7.2	1.38
7 ML/ha	01.10.03	29.01.04	4	0.0	2.8	5.8	1.2	388	12.03.04	119	8.9	1.53
3 scenarios					4.5	4.5	0.4			102.3	6.90	1.54

Multiple scenario comparison – end of season status Farm: Emerald

Field: Field 21, Crop: 2003-04 crop

Variety: SIOKRAV16, sown 01.10.03

Scenario	Run date	Final irrigation	Total irrigation	Pre-run pumped (ML)	Post-run pumped (ML)	Water pumped (ML)	Water left (ML)	Total rain (mm)	60% open	Total bolls (/m ²)	Yield (bales/ha)	Irrigation water use index (bales/ML/ha)
3 ML/ha	01.10.03	19.12.03	2	0.0	3.0	3.0	0.0	303	30.01.04	82	5.70	1.90
5 ML/ha	01.10.03	06.01.04	3	0.0	4.8	4.8	0.2	322	06.02.04	94	7.20	1.50
7 ML/ha	01.10.03	06.01.04	3	0.0	4.8	4.8	2.2	324	18.02.04	97	7.50	1.56
3 scenarios					4.2	4.2	0.8			91.0	6.80	1.65

For example: To determine the crop response to reduced water allocations at Narrabri and Emerald, HydroLOGIC scenarios can be developed for both locations, with water allocations of 3, 5 and 6 ML/ha at sowing (Table 3.2.1).

For further details regarding the HydroLOGIC software package, please refer to WATERpak Topic 3.5.

Rainman StreamFlow

The aim of the Rainman StreamFlow software, developed by the Queensland Department of Primary Industries, is to provide rainfall and stream flow information for better management of climatic risks and opportunities throughout Australia.

The software contains records for historical monthly and daily records for 3800 locations in Australia, historical monthly rainfall records for some 9500 locations worldwide, and monthly and daily stream flow for nearly 400 locations in Australia. Rainman StreamFlow gives you the power to:

- analyse individual locations for seasonal, monthly and daily patterns in rainfall and stream flow records
- determine when the major drought and flood years occurred in the past in your area
- forecast the amount, timing and frequency of seasonal rainfall and stream flow based on the Southern Oscillation Index (SOI) and Sea Surface Temperatures (SST)
- examine the reliability of forecasting tools for your location

- group locations for spatial analysis
- import monthly and daily rainfall and stream flow data, including agency-modelled IQQM data.

The Rainman StreamFlow CD also contains:

- Will it rain? The effect of the Southern Oscillation and El Niño on Australia – the book as interactive multimedia with animated illustrations
- a map library of historical rainfall, and of forecasts for Australia and the world based on SOI phases
- tutorials on managing climatic risk in agriculture (theory and practical exercises for individuals about rainfall and stream flow, and facilitator manuals for educators)
- scientific papers on Rainman methods and applications.

There are editions of Rainman StreamFlow for everyone interested in climate variability and the impacts of the El Niño phenomenon. The Standard edition is aimed at farmers and business; the Educational edition is for universities, colleges and schools; and the Professional edition is for agricultural advisers, consultants, water managers, government planners and researchers. Site licences are available for the Educational and Professional versions.

This software package replaces Australian Rainman Version 3.3 (released in 1999) and the

StreamFlow Supplement to Rainman (released in 2001). Feedback from cotton growers at a recent training workshop indicated the forecasting capabilities of the package were seen as very useful for managing climatic risks, particularly in relation to decisions about planting area and allocation of water to the crop through the growing season. The minimum computer specifications required are a Pentium II, Windows 95 and a CD-ROM drive. Rainman StreamFlow Version 4.3 may be ordered from the Client Services Centre, Department of Primary Industries Queensland, PO Box 102, Toowoomba Qld 4350, Tel: (07) 4688 1200, Email: qcca@dpi.qld.gov.au.

FLOWCAST

FLOWCAST is an analysis tool, developed by the Queensland Department of Natural Resources, for exploring and forecasting time-series data and for investigating methods to improve the reliability, range and accuracy of these forecasts. It is comprised of a data management and analysis tool, and a forecast analysis interface, linked together by unique and powerful graphical controls for manipulating and designing the analyses. FLOWCAST was originally developed as a post-analysis tool for hydrological models, and has now evolved into a tool capable of analysing any time-series data such as rainfall, crop production and stream flow.

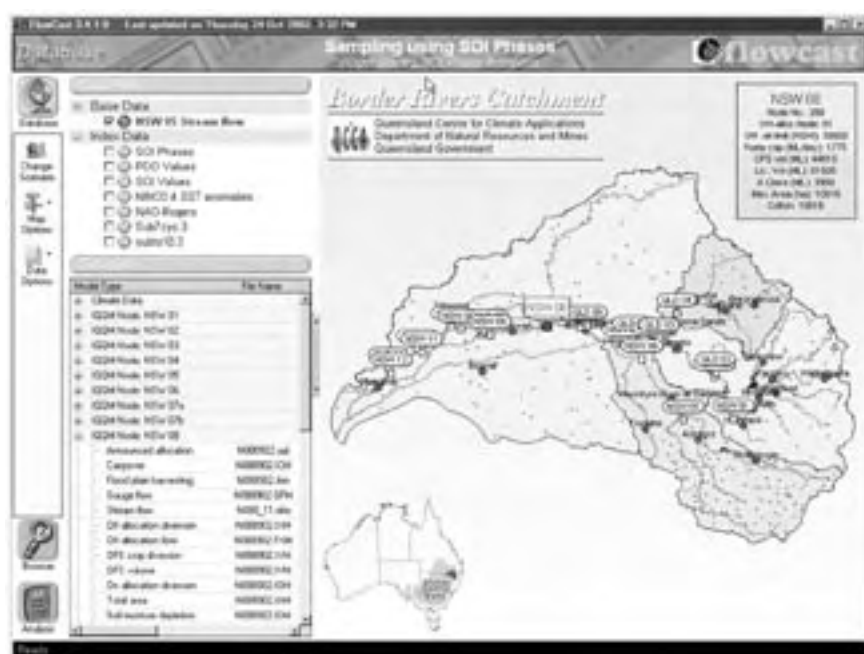


FLOWCAST is designed for researchers and decision makers such as climatologists, water managers, consultants and corporate irrigators. Climate researchers can use FLOWCAST to determine which climatic factors have the most influence on regional variables. Water managers can use this information to forecast river flows for purposes such as dam management, irrigation allocations, and the management of environmental flows. Consultants and irrigators can predict the water available from various sources (including allocations) to determine crop type and planted area.

FLOWCAST is able to generate forecasts though historical comparisons of time-series datasets. Forecasts are presented as probability distributions of annual events extracted as subsets of the historical record and exhibiting unique identifying characteristics. These characteristics are defined through external 'predictors' such as climate indices, like the Southern Oscillation Index (SOI), that are correlated with the variable we wish to forecast. Forecasts can be generated for any period, based on a range of statistical measures for data in this period. For example, the user could generate a forecast for the **total** rainfall for the period **October to February**, or the **minimum** stream flow value in the **March to August** period.

FLOWCAST does not come with any data preinstalled. The program has been developed to allow users to import their own data from a range of model types (including IQQM, SILO, and APSIM) and output formats. Users can create and switch between different datasets using the inbuilt data management tools. Associated with each dataset are a geographical map and a database containing local information for data sources within the geographical region (Figure 3.2.2).

Figure 3.2.2. FLOWCAST interface and screen overview.



To access FLOWCAST irrigators should contact their local water authority or relevant departmental natural resource officer.

Whopper Cropper

Dryland cropping is also an option to be considered when deciding on the cotton cropping area. Whopper Cropper is an easy-to-use computer program designed to provide crop management advisers with the latest technology in rain-fed cropping systems modelling and seasonal climate forecasting. The simulations use the 100-year climate record to predict the year-to-year variability in outcomes associated with management options (Figure 3.2.3).

Whopper Cropper combines seasonal climate forecasting with cropping systems modelling to predict the production risk that growers face in the coming cropping season. This helps producers to choose the best management options for the coming season. Whopper Cropper also enables price and production risk to be combined, so that the economic risk of alternative crop management options can be analysed.

Whopper Cropper enables crop management advisers to predict the likely distribution of crop yields for the upcoming season, based on starting soil conditions and knowledge of the current phase of the SOI. APSIM has been used to simulate a range of management options based on around 100 years of historical climate data.

The Agricultural Production Systems Research Unit (APSRU) has developed a cropping systems model, Agricultural Production Systems **SIM**ulator (APSIM), that can be used to support improved risk management in cropping systems.

Whopper Cropper is the result of many years of interaction between researchers and crop management advisers developing and distributing this modelling technology. The information in Whopper Cropper enables crop management advisers and producers in the grain and cotton industries to make better crop management decisions.

What is Whopper Cropper?

Whopper Cropper is a database of 600 000 pre-run APSIM simulations (currently 21 sites from Clermont to Dubbo). For each of the 21 districts, combinations of the following options can be examined:

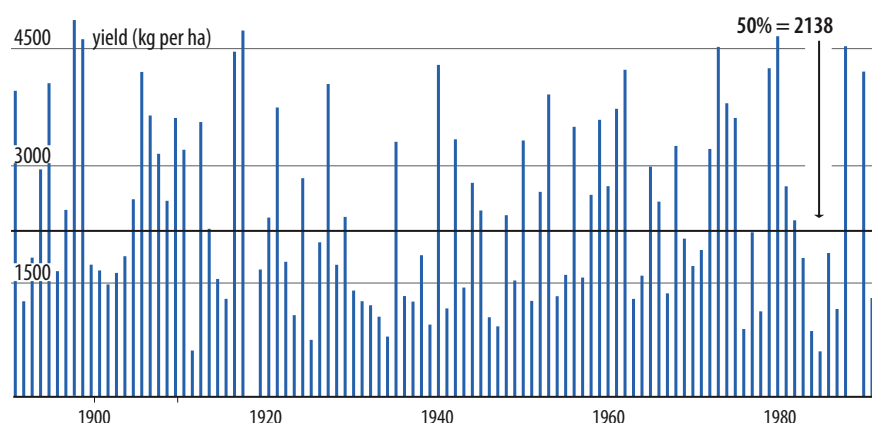
- 8 crops (including cotton)
- 4 soil water-holding capacities
- 3 starting soil water amounts
- 6 nitrogen fertiliser rates
- 3 crop maturities
- 5 sowing dates
- 3 row spacings
- 5 plant populations
- 2 soil fertilities
- gross margin analysis.

What does Whopper Cropper do?

- Allows exploration of changes to management inputs that may be required under current climatic conditions
- Includes a database of 600,000 pre-run simulations (scenarios) available to the user in an easy-to-use package
- Provides simulations for resource constraints and management inputs for 21 districts in Queensland and northern NSW. The decision components include: soil water-holding capacity, soil water at sowing, crop type, time of sowing, N fertiliser rate, crop maturity type, sowing density, and SOI phase effect on likely yields
- Provides a high quality graphing capability of the scenarios for use with grower meetings and timely publications
- Engages the users in the process of revision of the software and training process
- Demonstrates realistic production effects from the changes in rainfall as described by the current SOI climate forecasting system
- Demonstrates the yield and gross margin effects of different crop types, soil water-holding capacity (PAWC), soil water at sowing, sowing date, crop maturity effect, crop density, soil fertility, nitrogen fertiliser rate, future climate SOI phases, and price.

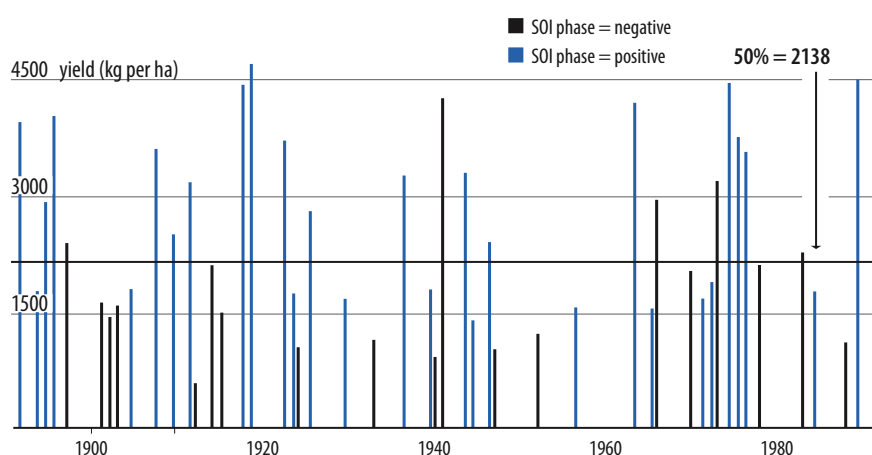


Figure 3.2.3. Simulation results for 100 years of climate records



The 100-year simulations of crop yields can be divided into groups of analogue years in which the SOI phase in a particular month was the same (Figure 3.2.4).

Figure 3.2.4. Analysis of simulation results using SOI phases



Distributing simulated yields by SOI phase enables crop management advisers to discuss with farmers the best management options for the coming season.

The Whopper Cropper Project is a collaborative project between the Agricultural Production Systems Research Unit (APSRU) of the Queensland Departments of Primary Industries and Fisheries (DPI&F) and Natural Resources, Mines and Energy (NRME), CSIRO's Divisions of Sustainable Ecosystems and Land and Water, and the University of Queensland, and the Queensland Centre for Climate Application (QCCA).

For more information about Whopper Cropper contact:

DPI&F/APSRU
PO Box 102 Toowoomba QLD 4350, Australia
Ph 07 4688 1381 Fax 07 4688 1193

Reference

Yeates, SJ, Constable, GA, and McCumstie, T 2002, 'Developing management options for mepiquat chloride in tropical winter season cotton', *Field Crops Research*, 74, pp. 217-230.



3.3 Waterlogging: its impact on cotton

Michael Bange, Stephen Milroy and Pongmanee Thongbai

Cotton CRC, CSIRO, Narrabri

Key points

- Waterlogged soils reduce the access of the roots to oxygen, impairing root growth and function and ultimately nutrient uptake. Toxic gases in the waterlogged soil can also increase.
- Waterlogging reduces cotton yields by reducing the number of bolls on the plant.
- The risk of waterlogging can be reduced by optimising field design, bed formation, and irrigation scheduling. The application of some foliar fertilisers may also assist in fields known to waterlog.

Cotton is known to be poorly adapted to waterlogged conditions. In Australia, cotton production is concentrated on soils with inherently low drainage rates, which, combined with the almost exclusive use of furrow irrigation and a summer dominant rainfall pattern, results in a significant risk of intermittent waterlogging.

Causes of waterlogging

When a soil is waterlogged the access of the roots to oxygen is impaired, reducing their ability to respire and thus reducing root growth and function and ultimately nutrient uptake. There is also a build-up of toxic gases such as carbon dioxide and ethylene that are generated by the roots and micro-organisms and which can impair root and whole plant function.

The waterlogging problem can be exacerbated through additional factors such as:

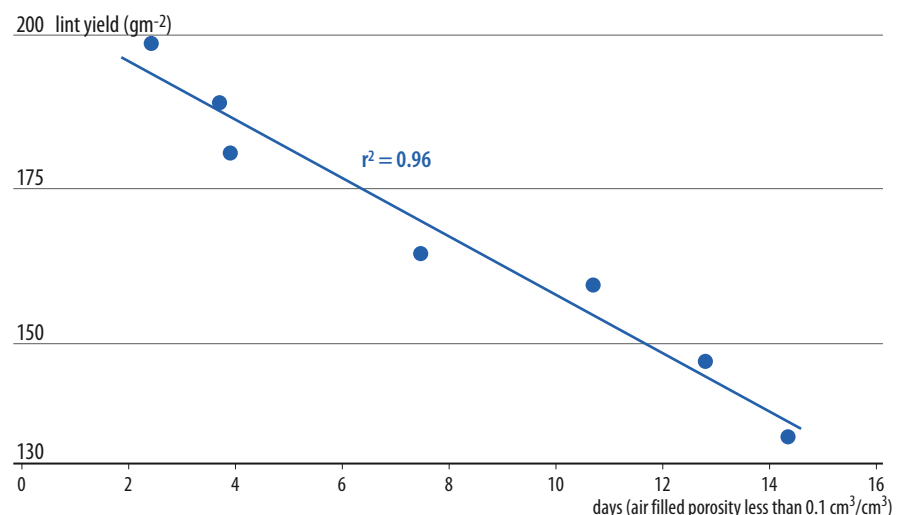
- soil compaction. There is less space for air to be present in the soil and transfer of air is impeded.

- excessive field length. This can lead to prolonged water application times, which in turn can cause waterlogging, especially at the head ditch end of the field.
- inadequate slope or poor levelling. Low slopes or areas within a field may not allow excessive water to move freely away from a growing crop.
- poor bed formation. Well-formed beds allow cotton roots to grow in soil that is freely drained.
- poor irrigation scheduling. Too frequent irrigations may predispose the crop to waterlogging.
- substantial rainfall after an irrigation event. This could expose the crop to longer periods of inundation.
- long periods of cloudy weather. Low rates of evaporation and reduced radiation (sunshine) may prolong waterlogging.

Impacts of waterlogging on crop yield and quality

Investigations in the early 1980s by the late Arthur Hodgson in Narrabri into the effects of waterlogging showed that the yield of field-grown cotton declined with the duration of inundation at each irrigation event. To generate the effects of duration of inundation, Hodgson varied the period of irrigation of the crop between 4 and 32 h. However, the degree of yield depression differed between his experiments. When the data of the experiments were combined, yield was strongly related to the number of days when air-filled porosity of the soil (proportion of air present in the soil) at a depth of 10 to 20 cm was below 0.1 (0.1 cm³ of air/cm³ of soil, or 10% air by volume). Lint yield was reduced by 48 kg/ha (0.2 b/ha) for every day when the soil was low in oxygen (Figure 3.3.1). Hodgson found that there were no further reductions in yield after 96 h (4 days) of inundation across the growing season.

Figure 3.3.1. The relationship between yield and duration of inundation by irrigation



In recent field studies, also conducted at Narrabri, Bange, Milroy and Thongbai found some contrasting results to those of Hodgson. In some instances where certain agronomic practices were employed, no effects on yield or fibre quality were seen even when the crop had been inundated continuously for up to 72 h (3 d). Field experiments were conducted in which cotton crops were subjected to intermittent waterlogging by extending the duration of irrigations. Investigations compared the timing of waterlogging events, cultivar and landforming (hill height). To generate marked effects of waterlogging on yield it was necessary to reduce hill height. (Hodgson reported reductions in yields with the duration of 32 hours without the need to modify hill height.) The recent results also showed that waterlogging early in crop growth had far greater influence on yield than waterlogging at mid-flowering or later. The effects of these treatments are summarised in Table 3.3.1.



Table 3.3.1. Different agronomic effects on yield and yield components after waterlogging (up to 72 h inundation)

Agronomic treatment	Maturity	Yield	Final boll number	Final boll size	Fibre length	Micronaire
Hill height (5 cm versus 15 cm)	X	✓	✓	X	X	X
Variety (Sicala V-2i versus Nucotn 37)	X	X	X	X	X	X
Early waterlogging Pre flowering	X	✓	✓	X	X	X
Late waterlogging Mid flowering	X	X	X	X	X	X

Source: 1990s studies by Bange, Milroy and Thongbai

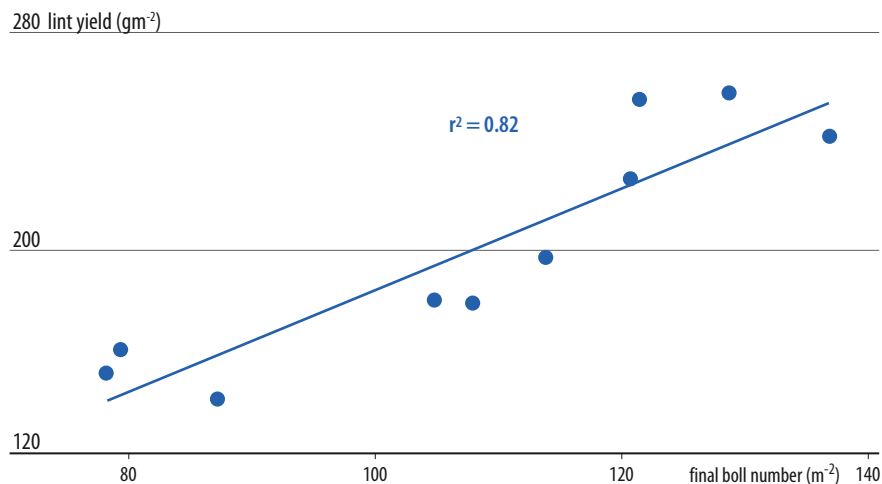
The differences in severity of the impact of waterlogging between the two studies could be due to a number of reasons. It is feasible that oxygen levels were not as severely affected by inundation in the more recent experiments because since the 1980s there has been increased awareness within the Australian cotton industry of management practices aimed to maintain good soil structure. As a result, compaction is less severe and less widespread. In addition, there has been considerable improvement of water flow in furrow-irrigated fields through the use of laser-guided levelling systems. Indirect selection of cultivars more suited to the intermittent waterlogging experienced in the Australian growing environments may also have played a role. To clarify differences between these studies, further analyses are continuing with more detailed measurements of plant growth and soil oxygen.

Causes of yield reduction due to waterlogging

Waterlogging of cotton has been reported to cause reductions in root growth and nutrient uptake, leaf area and photosynthesis, all leading to restrictions in overall cotton growth and fruiting development.

Results of detailed measurements of crop growth in both the studies of waterlogging mentioned above show that when yield was reduced due to waterlogging it was associated with final boll number being reduced (Figure 3.3.2). Boll size and percentage lint were not affected. Reductions in boll number are commensurate with reductions in growth due to lower radiation use efficiency (amount of dry matter produced per unit of intercepted light), which impacts on the amount of assimilates available for plant growth. Results from recent studies also suggest that this reduction in boll number is most likely associated with reduction in fruiting site production rather than increased shedding alone.

Figure 3.3.2. Results of studies by Bange, Milroy and Thongbai showing the relationship of yield and final boll number influenced by different waterlogging treatments



The suppression of radiation use efficiency is consistent with the reduction in photosynthesis and the reduced function of photosynthetic enzymes by waterlogging. Reduced concentrations of nitrogen (N) in a leaf can reduce leaf photosynthesis, and the amount of N in leaves is affected by N uptake. Work undertaken by Hodgson and MacLeod (1988) showed that, while leaf N of cotton was reduced due to waterlogging, applying foliar N in the days prior to waterlogging did not fully alleviate the reductions in growth in all cases nor did it rectify the leaf yellowing that occurred. This suggests that other mechanisms, in addition to those acting through the reduced uptake of N, were likely to be acting on leaf performance. The exact reasons for the reduction in photosynthesis and radiation use efficiency with waterlogged cotton are still to be clarified.

In addition to the physiological impacts of waterlogging on the crop there are also significant impacts on nutrient availability and uptake. The availability of N, Fe and Zn (reduced) and Mn (increased) are directly affected by the decline in soil oxygen, and uptake of N, K and Fe by the roots is also impaired. For more detail on the impacts of waterlogging on nutrient uptake and availability refer to NUTRIpak.

Management options to reduce waterlogging risk

Field design. A uniform slope of at least 1:1500 is best for draining irrigation water or rainfall from a field. Tail drains should also be designed to remove run-off as quickly as possible.

Hill height. Well-formed high beds will decrease waterlogging in an irrigated field.

Irrigation period. Keeping the period of single irrigation events to a minimum will minimise the risk of waterlogging. This could be achieved by use larger siphons or using two siphons per row, or by reducing the length of the irrigation run.

Increasing the **pumping and application capacity** will help to get the water on and off the field quickly as well as reduce the time it takes to irrigate the whole farm. Higher application capacity gives farmers more flexibility to react to climatic influences such as a heat wave or waiting for a forecasted rainfall event.

Foliar fertiliser. Apply 8 kg N/ha just prior to a waterlogging event. Be careful not to use too high rates because foliage may burn. Applications on an already waterlogged field may have little impact. In some circumstances applications of foliar iron (Fe) may prevent leaf yellowing. See NUTRIpak for further details.

Irrigation scheduling. Ensure proper irrigation scheduling. Too frequent irrigations increase the risk of waterlogging. The use of soil moisture monitoring equipment and the use of HydroLOGIC irrigation management software can assist with optimising irrigation scheduling to reduce waterlogging risks and improve yields (see Topic 3.5).

Monitor weather. If feasible, monitor weather and delay irrigation if there is a high chance of significant rainfall to occur at the time of the scheduled irrigation. The following websites may be useful for this purpose:

<http://www.bom.gov.au/silo> (SILO)

<http://www.bom.gov.au/>
(Bureau of Meteorology)

<http://www.longpaddock.qld.gov.au/>
(The Long Paddock)

<http://www.cvap.gov.au/>
(Climate Variability in Agriculture R&D Program)

3.4 Managing irrigation with limited water

Steve Milroy and Dirk Richards

Cotton CRC, CSIRO, Narrabri

Key points

- Do not risk low crop yields by spreading water too thin. A positive gross margin on a smaller area of crop is better than a negative one on a large area! Consciously decide how much risk you are prepared to accept.
- Calculate the area you are able to fully irrigate with the supply available. Select 'high priority' fields on efficient supply and good yield history.
- Choose a cultivar suited to your production region. Avoid excessive nitrogen, which encourages rank vegetative growth and wastes irrigation water.
- Reduced fibre length is the main quality concern with limited water. Varieties with inherently long fibre buffer the risk of penalties.
- Maintain your normal irrigation strategy and only increase the irrigation interval in extreme cases. Delay the first irrigation rather than stress the crop during flowering.
- Approach defoliation as normal, deciding on the last harvestable boll, and monitor plant maturity to determine the defoliation date.

In a limited water situation, the usual factors are considered but with a shift of emphasis. In particular, the measure of efficiency moves from bales/ha to bales/ML. Agronomic decisions that need to be made prior to sowing include nitrogen application, sowing date and varietal selection. Agronomic management must not result in an excessively vigorous crop nor delay crop maturity too much.

Field choice

If only part of the irrigable area can be planted with the available water supply, the choice of which fields to sow and irrigate will be governed by yield expectation and efficiency of water supply. Survey results indicate that, on most properties, there are far greater gains to be made in storage, distribution and application efficiency than in crop water use efficiency: the efficiency with which water is supplied to the field is more variable than the efficiency with which a crop uses the water delivered to it. Thus proximity to the best storages or being supplied by the best channels is the first factor to consider in field choice. Fields with a history of high yield may be valuable, but reference to water use records may show that yield is commensurate with water use. In this case, yield history alone

would be of limited advantage. Rather it is necessary to consider either water use efficiency or yield under restricted water supply.

How much cotton should I plant and irrigate?

When water becomes the limiting resource for production, the relative importance of various management decisions begins to change. Three key questions arise:

1. What area of land should be prepared for cotton to take advantage of sudden changes in water availability?
2. How much of this area should be planted?
3. What proportion of this area should be irrigated?

The answers are a function of the total water supply available for application to the crop from all sources, from the river and bore allocation, on-farm storage and any expected off-allocation pumping. No single option is the best in every season, but research has indicated which option is the best when taking into account year-to-year variation in weather.

One of the first questions confronting growers in situations of limited water supply is 'How much should I plant?' Given that dryland production on part of the farm may be a profitable option, the question really has two components: 'How much should I plant?', and, 'How much of this should I irrigate?' These questions are difficult, and can only be properly approached through the use of simulation models so that year-to-year variation in the amount and distribution of rainfall can be taken into account.

A number of studies have been undertaken to consider the area to dedicate to irrigated production. The results are summarised in Table 3.4.1.

Table 3.4.1. Water supply required on 1 September

ML/ha required to reduce the risk of failing to break even to less than one in ten, and the supply required to maximise returns per megalitre.

Note: These figures includes the requirement for pre-irrigation and assume an irrigation efficiency of 75%.

Region	Supply to break-even in 9 years out of 10 (ML/ha)	Supply to maximise returns per megalitre (ML/ha)
Emerald	4.5	5
Darling Downs	5.0	5
St George	5.5	5
Border Rivers	5.2	6
Gwydir Valley	5.3	6
Namoi Valley	5.2	6
Macquarie Valley	6.3	6

Generally the answer is to aim to irrigate an area that will allow 5 to 6 megalitres of supply per hectare. To indicate the risk level involved, data have been presented on the supply required (which includes a requirement for pre-irrigation) to ensure that the break-even yield is attained in 9 years out of 10. In most cases, the supply which maximises the average returns is greater, and so, based on the long-term weather record, the risk of failing to break-even using this supply is less than 1 in 10. Note that these figures refer to the available supply, not the expected application, and are calculated based on an irrigation efficiency of 75% (that is, $\frac{3}{4}$ of the water supplied is used by the crop as evapotranspiration. This accounts for storage, distribution and application losses.) If your irrigation efficiency is markedly less than this, the figures will need to be adjusted accordingly.

This question can be re-examined just prior to the first irrigation. At this time, the supply that needs to be on hand is less, as the water to establish the crop has already been dealt with. The long-term weather record suggests an irrigation supply of 3 to 4 megalitres per hectare will maximise returns at this point. The results for the various regions are given in Table 3.4.2 and the supply for breaking even is again presented.



Table 3.4.2. Water supply required on 1 December

To reduce the risk of failing to break even to less than one in ten and the irrigation supply required to maximise returns per megalitre. (Note: Assumes an irrigation efficiency of 75%.)

Region	Supply to break-even in 9 years out of 10 (ML/ha)	Supply to maximise returns per megalitre (ML/ha)
Emerald	2.3	3
Darling Downs	3.2	3
St George	3.5	3
Border Rivers	3.2	4
Gwydir Valley	3.4	4
Namoi Valley	3.2	4
Macquarie Valley	4.0	4

In light of this, sowing more cotton than the estimated water supply would suggest allows reassessment prior to the first in-crop irrigation. If this favourable rainfall does not occur, some area can be converted to dryland production. The question of what total area to sow to cotton is independent of the question of how much to irrigate: dryland cotton may be a legitimate cropping option for the remaining, non-irrigated area. This depends on your location. The decision of how much dryland cotton to sow should be based simply on those factors which dictate whether dryland cotton production is viable. Key variables here are the amount of stored soil moisture and the anticipated rainfall, and hence the yield expectation. You may also wish to consider other cropping options with a lower variable cost structure. For further details on risk and reduced water allocations, refer to the September-October 1992 *Australian Cottongrower* article by Dr Brian Hearn.

Nitrogen fertiliser

As discussed in WATERpak Topic 3.2, nitrogen fertiliser application for any crop should be made on the basis of measured soil N status or at least cropping history. This is given added significance in the water-limited situation. Crops which are water limited are less responsive to applied nitrogen and so excess nitrogen is, at best, non-productive. Further, if excessive water supply from irrigation or rainfall occurs in combination with high nitrogen, it may lead to the development of a large canopy, resulting in increased water requirements that cannot be met. It may also lead to a delayed maturity resulting in a need for continued water supply.

Cultivar choice

Choice of cultivar should be based on matching the cultivar to your production region. This is particularly so with respect to disease and season length. Many studies in Australia (for example recent work by W.N. Stiller, CSIRO) have shown that the cultivars which do best under irrigated conditions are generally those which do best under dryland or reduced irrigation conditions also, so choose a maturity type suited to your region. The advantage of early maturing cultivars under dryland production which is seen in some overseas production areas does not apply in Australia. The advantage of short season cultivars in these situations is based on the need to avoid a terminal drought.

Using such cultivars in Australian growing areas imposes an absolute yield limitation from the time of sowing. There is thus no scope to take advantage of any changes in water supply or rainfall that may occur during the season. Such cultivars also tend to shut down abruptly when any stress is encountered and, once they have ceased, fruit production does not readily recommence. Clearly this is particular risk where water is limited.

Okra-leafed cultivars as a group do relatively better under dryland conditions and may offer an advantage under limited water situations also. Cultivars with inherently long fibre provide a buffer against reductions in fibre length which may occur due to water stress. If sowing is significantly delayed in the hope of receiving planting rain

or further soil recharge, a shorter season cultivar than usual may need to be considered. Although the disease scenario changes between fully irrigated and dry situations, Fusarium susceptible varieties should never be considered where any Fusarium risk exists.

Sowing date

The optimum date of sowing differs between a fully irrigated crop and crops grown with a restricted allocation. Cotton yield declines with delayed sowing due to the shorter time available to initiate and mature an adequate number of bolls. As a general rule, as the available water supply decreases, the expected decline in yield potential with sowing date begins somewhat later. This is because the crop is already yield-limited and so doesn't need as much season length to achieve the new water-limited yield potential. This is illustrated in Table 3.4.3 using simulation output from the OZCOT model. It should be noted that, in this example, some of the supply levels are below that which might be expected to provide break-even returns anyway. While there is more flexibility in sowing date with lower allocation, excessive delay must be avoided. This may increase the risk of quality downgrades due to the chance of maturing late bolls in cool weather.



With smaller supply, the date when the yield begins to decline from the potential generally becomes later.

Table 3.4.3. Sowing date after which yield declines for different irrigation supplies

Region	Irrigation supply per hectare		
	2 ML	4 ML	6 ML
Emerald	30 Nov	30 Nov	30 Nov
Darling Downs	15 Nov	30 Oct	30 Oct
St George	30 Nov	15 Nov	15 Nov
Border Rivers	30 Nov	15 Nov	30 Oct
Gwydir Valley	15 Nov	15 Nov	15 Oct
Namoi Valley	15 Nov	30 Oct	15 Oct
Macquarie Valley	15 Nov	30 Oct	30 Sep

In northern areas where there is a longer growing season and more summer rainfall, low allocations may show an optimum sowing time rather than a simple decline. This is because (1) the impact of late sowing is less in these areas, and, (2) there is potential to match crop water demands to the long-term rainfall distribution.

Row configuration

Both ultra narrow row (UNR) and irrigated skip row systems have been suggested as offering some potential for increasing FWUE in water limited situations. However, there is no evidence that UNR cotton has higher or lower water use efficiency than conventional 1 m spacing in our production systems. The rapid development of leaf area in UNR cotton may mean that the first irrigation may be required earlier than with conventional spacing.

If, when calculating the area to plant, the irrigation supply is pushed below 5-6 ML/ha, then partially irrigated skip row may become an option in some regions. One consideration with using skip row in an irrigated situation is the likelihood of lower yield potential. However, this lower yield may be offset by lower growing costs and a reduced risk of negative quality traits. Therefore current cotton prices and growing costs need to be considered in addition to yield when making decisions on different row configurations.

Past research has indicated that, where expected yields are above 4.0 bales per hectare with the water available, then the best option is to plant in a solid configuration. If expected yields are between 2.5 to 4.0 bales per hectare, then a single skip configuration is recommended, whilst an expected yield below 2.5 bales per ha indicates double skip configuration may be an option.

In reality, if the yield predictions are below 2.5 bales/ha, then the irrigated area should be reduced to increase the available irrigation water to the remainder. Alternatively, other crop options could be investigated.

Research trials have established that row spacing has a larger effect on yield and quality than number of plants per metre of row. Evidence from the rain-fed cotton trials shows there is little or no yield reduction between 4 and 12 plants per metre. In common with solid planted cotton, large gaps in the skip row plant stand and plant stands below 3 to 4 plants per metre should be avoided.

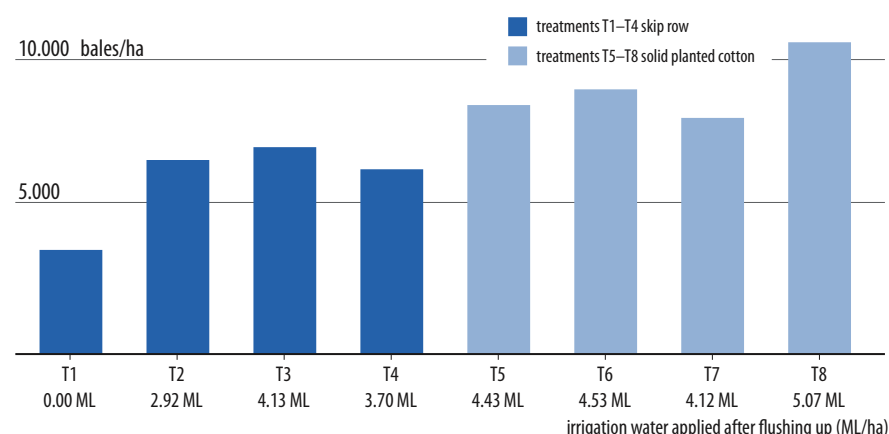
The number and timing of irrigations in skip planted cotton will vary with location, soil type and previous history, and weather conditions, with the interval between irrigations increased with skip row plantings. Ideally the irrigation deficit used (plant row) should be similar to that used in solid plantings, and careful crop monitoring is necessary to time irrigations correctly. During the 2001/2002 season, a Darling Downs grower achieved similar yields from single skip and solid planted cotton crops. However, the skip row crop was produced with about half the irrigation water to that applied to the solid planted crop. Both crops had similar pre-planting irrigation of 1.1 ML/ha.

Row configuration case study: Irrigation trial, Auscott Limited Namoi Valley, 2002–03

The aim of the irrigation trial was to evaluate the impact of different watering treatments on yield and fibre quality and especially financial return of solid and skip row planted cotton crops. A combination of eight different irrigation and row configuration treatments were tested. All treatments received a pre-irrigation and a flushing but then received none, 2, 3, 4 or 5 in-crop irrigations with two additional 'on-demand' treatments. Four of the eight treatments were grown in a 2:1 pattern or single skip row configuration.

The yields achieved ranged from 3.4 to 10.5 bales/ha with higher yields achieved with more irrigations and water applied. The exceptions were the skip on demand with 3 irrigations and solid plant with 4 irrigations, which were waterlogged during a rain event following the first crop irrigation. Subsequently the solid plant treatments achieved higher irrigation water use indices (bales/ML applied) than the skip plant treatments, which improved with higher numbers of irrigation events.

Figure 3.4.1. Lint yield versus water application



The skip irrigation treatments followed a negative IWUI trend with increased application volumes. In other words, the yield gains were not big enough to increase the IWUI. The trial results from this year lead to the conclusion that the cotton area in a year with limited water supply should be limited to allow for a full irrigation program.

Irrigation scheduling with limited water

By and large, the general practice when irrigating with limited water is to adhere to the optimised irrigation strategy for your region using the suggested level of supply. This will mean a reduction in the irrigated crop area. A generalised approach has been outlined in an earlier Cotton CRC information sheet (*Irrigation Scheduling of Cotton*, July 2002). Watering-up is preferred to pre-irrigation, although the general management difficulties associated with watering-up need to be borne in mind. Don't risk stretching the irrigation interval beyond the target deficit. While this may pay off in some seasons, it is better to skip the last irrigation to allow maximum chance of catching rainfall or increased allocation before locking in to a reduced yield potential. With very severe shortages there may be some advantage in delaying first irrigation a little. This is preferable to risking stressing the crop during flowering, when the crop is more sensitive (WATERpak Topics 2.1 and 3.1).

Limited water case study: Defoliation under drought conditions, Darling Farms, 2002-03

On Darling Farms, between 3 and 6 irrigations were applied to upland cotton, with the majority of the farm receiving 4. Fields had their last irrigation applied as early as 9 January and as late as the 14 February, where traditionally this is applied in the last week of February. The management approach taken was to irrigate as required, rather than stretching the first irrigation. Most plants remained relatively green and retained most of the fruit, provided they had 3 or more irrigations. Based on advice from dryland cotton consultants and early trial work at Dirranbandi, defoliation was approached as normal.

Maturity was determined by the cut boll method on the last harvestable boll. Many of the very top fruit were spongy and would crack open if pressed long before the seed was mature. As a result, defoliation dates were only slightly earlier than if the crop had received full water. Given that some crops were dried down (last irrigation to defoliation) for 45-50 days, boll maturity was found to move up the plant at a slightly slower rate than normal. Generally 3 days per node is required, however under these circumstances 4-5 days per node was found.

The defoliation program was:

1st application

80-100 mL Dropp® liquid applied 3 days before the designated top boll was mature.

2nd application

1-1.5 L of Ethephon® applied either alone or with 20 mL of Dropp® liquid if significant green leaf remained on the plant. The second application occurred when enough leaf shed exposed bolls, generally 7 days later.

Opening the very top fruit on water-stressed plants depends on the size of the discount on fibre quality versus extra yield obtained from picking this fruit. It was felt that in all cases it was worth chasing the extra yield and the chance of quality discounts.

Table 3.4.4 below shows the effect of different irrigations on fibre length and micronaire. The assumption has been made that limiting water would affect length and micronaire but not necessarily colour or leaf/trash content. A Premium & Discount 2002 crop sheet was used to calculate discounts using a grade 31, leaf 1 for all calculations, with only length and micronaire varying. Although this is not the actual premium or discount we received, it does highlight the effect of limiting water on fibre quality.

Table 3.4.5 details the different response between varieties to fibre quality to limited water situations.

Table 3.4.4. Upland cotton grades (length and micronaire) by irrigation number

Irrigation	av. date last irrig	Staple length %						Micronaire %					Premium and discounts		
		32	33	34	35	36	37	3.0–3.2	3.3–3.4	3.5–3.7	3.8–4.5	4.6–4.9	Length points	Micronaire points	\$/bales
3	9 Jan	2	14	18	51	15			4	27	62	6	-332	-14	-\$ 31.50
4	19 Jan		4	5	34	52	5	1	4	27	67	1	-80	-26	-\$ 9.60
5	5 Feb						100				100		0	10	\$ 0.91
6	14 Feb					100					97	3	0	10	\$ 0.88

Table 3.4.5. Upland grades (length and micronaire) by variety by irrigation number

Variety	Irrigation number	Staple length %						Micronaire %					Premium and discounts		
		32	33	34	35	36	37	3.0–3.2	3.3–3.4	3.5–3.7	3.8–4.5	4.6–4.9	Length points	Micronaire points	\$/bales
189 / 289i	3 (3)	3	10	15	49	23		1	30	59	10		-301	2	-\$ 27.18
	4 (19)			2	37	52	8		15	85	1		-16	8	-\$ 0.68
	5 (2)						100				100		0	10	\$ 0.91
	6 (2)					100					100		0	10	\$ 0.91
S70	3 (2)		36	41	23			17	40	43			-683	-83	-\$ 69.63
	4 (1)				34	66			79	20			0	2	\$ 0.19
	6 (2)					100					88	13	0	9	\$ 0.80
S80	3 (1)				100						100		0	10	\$ 0.91
	4 (3)		1		15	82	2	1	75	24			-11	-5	-\$ 1.40
	6 (1)					100					100		0	10	\$ 0.91
V3i	4 (3)			13	87			17	61	14	8		-91	-491	-\$ 52.88
Nupearl	4 (3)	1	29	21	19	29	2				98	1	-487	10	-\$ 43.41

Numbers in parentheses indicate the number of fields used to make up the dataset.

It was noted that limiting water appeared to affect only fibre length. The timing of moisture stress relative to the development of the boll load is important here, in addition to the canopy size and boll load. With reduced length comes a lower requirement for carbohydrate required to thicken the fibre. This limited dataset shows that some varieties, such as 189/289i and S80, produce less short fibre than other varieties, given 3 or 4 irrigations. It highlights that the cotton plant is a remarkably robust plant, and fruit continued to develop and mature relatively similar to normal even under extremely stressful conditions.

Acknowledgment: Thanks to Dr Phil Goynes, Mr Mitch Abbo, Mr Jason Fritsch and Mr Stefan Henggeler for their contributions to this topic.



3.5 HydroLOGIC[®] furrow irrigation water management software

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Key points

- HydroLOGIC is a software tool designed to help growers manage furrow irrigation in cotton.
- Predictions of crop growth are made using the OZCOT crop growth model and historical climate information.
- HydroLOGIC has maximised yield and water use efficiency under trial conditions, in both full and limited water situations.
- HydroLOGIC complements existing soil moisture and weather station technology.

'Irrigation decisions are compromises between reducing the risk of water stress and increasing the risk of waterlogging.' (Hearn and Constable, 1984.)

HydroLOGIC is an irrigation management system to assist effective and timely application of irrigations for furrow-irrigated cotton crops. HydroLOGIC has been developed by CSIRO Plant Industry, as part of the Australian Cotton CRC, incorporating up-to-date cotton research into a management decision aid to optimise water use and yield. Using the HydroLOGIC software can help to evaluate the consequences of different irrigation strategies on yield and water use, using a range of simple plant and soil moisture measurements.

There are four ways in which HydroLOGIC can help irrigated cotton growers make decisions (Figure 3.5.1):

1. Optimise cropping area

– predictions of yield can be made using historical climate information, with a range of water allocations. The optimum irrigated cropping area can then be determined for a given water allocation.

2. Schedule the next irrigation

– HydroLOGIC can be used to predict the date when a field will next need irrigating.

3. Conduct scenario analyses

– HydroLOGIC can be used to assess the consequences of different irrigation management strategies. Two types of irrigation issues can be explored:

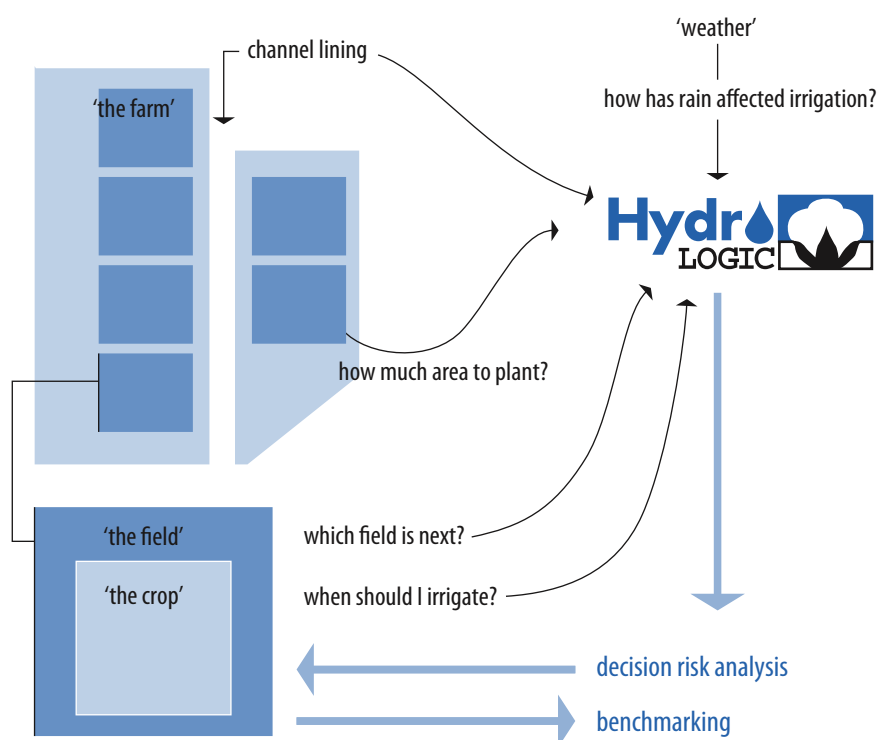
- **Timing of irrigations** – the effect of changing first and last irrigation dates, and the impact of stretching irrigation deficits. For example 'what if I delay irrigating this field in an attempt to save water?' or 'what if I irrigate at a lower deficit and more frequently?'
- **Amount of water** – the effect on yield and water use efficiency with different water availability (allocation and irrigation system efficiency). For example, 'what will crop yields be if I receive and apply an extra 2 ML/ha off-allocation flow?'

4. Benchmarking performance of previous crops

– Benchmarking is one way to assess crop productivity and track changes over several seasons, and compare with other fields on the farm. It can be used to:

- Calculate crop water use efficiency figures in conjunction with actual field results, to allow comparisons between crops and seasons.
- Help assess the impacts on crop growth if irrigation management from the previous year had been different.

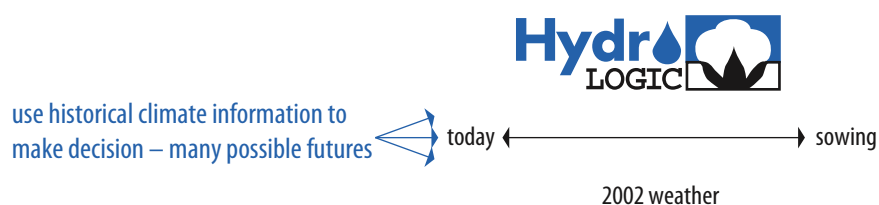
Figure 3.5.1. HydroLOGIC can operate on many levels of farm decisions.



An important component of HydroLOGIC is the use of actual crop growth (fruit load and leaf area), soil moisture measurements, current weather information (rainfall and temperature) and irrigation information for a crop to the present date in the season. The prediction of crop growth and water usage for the remainder of the season is based on the modelled soil water balance, historical climate information and different management scenarios (Figure 3.5.2).

Importantly, HydroLOGIC is designed to complement, not replace, continuous soil moisture monitoring systems, as information can be used from any existing soil monitoring equipment that has been properly calibrated.

Figure 3.5.2. The prediction logic of HydroLOGIC



Background

HydroLOGIC uses the OZCOT model developed initially by Dr Brian Hearn and CSIRO. OZCOT simulates the effects of environment (soil, water and temperature) and crop management (for example, sowing time, nitrogen and irrigation) on yield development. Over the last decade OZCOT has shown considerable versatility in simulating commercial irrigated crops with different management regimes. Within HydroLOGIC, each cotton field is treated individually, since irrigation scheduling is conducted on a field basis.

Central to the HydroLOGIC software is the weather information provided through the Bureau of Meteorology SILO project. Most cotton growers will be familiar with another SILO product, the SILO day degree calculator hosted on the Australian Cotton CRC website. The other major advance in access to climate data has been the development and availability of the Patched Point Dataset for research. This is a continuous dataset containing daily rainfall, minimum and maximum temperatures, radiation, evaporation and vapour pressure for any weather recording station in Australia. It combines original Bureau measurements for a site, with any missing data filled using estimation from measurements at surrounding stations. Historical climate for any official recording station may be accessed directly from SILO, and then used within HydroLOGIC.

HydroLOGIC performance in the field

In detailed field evaluations conducted during the 2002-03 season, the use of HydroLOGIC for scheduling irrigations was shown to optimise yield, maturity, and water use under both full and limited water situations. A large-scale field trial at Narrabri consisted of 3 treatments:

1. standard management with 8 ML/ha
2. HydroLOGIC management with 8 ML/ha ('full'), and
3. HydroLOGIC management with 4 ML/ha ('limited').

The trial was sown on 9 October 2002 with Sicot 289RRi, and had approximately 180 kg/ha of available soil nitrate to 1.8 m depth at sowing.

The standard irrigation treatment was irrigated on 14-day cycles or when plant stress was apparent. A series of simulations was conducted using HydroLOGIC to determine the optimum soil moisture deficit to irrigated at, and to maximise final yield predictions (Table 3.5.1).

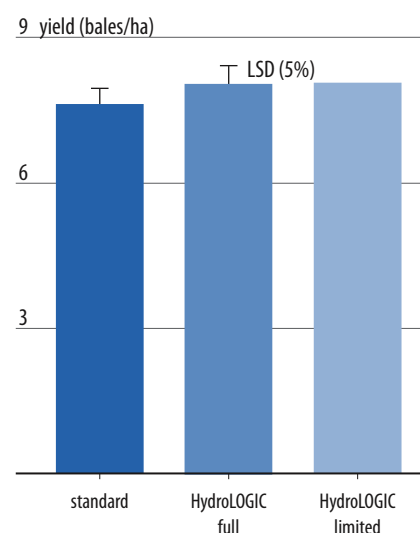
Table 3.5.1. Irrigation dates used in the Narrabri field trial

Standard	HydroLOGIC full	HydroLOGIC limited
6/11/02	6/11/02	6/11/02
10/12/02	18/12/02	3/1/03
3/1/03	9/1/03	22/1/03
20/1/03	22/1/03	
4/2/03	5/2/03	
	20/2/03	

Yield and fibre quality

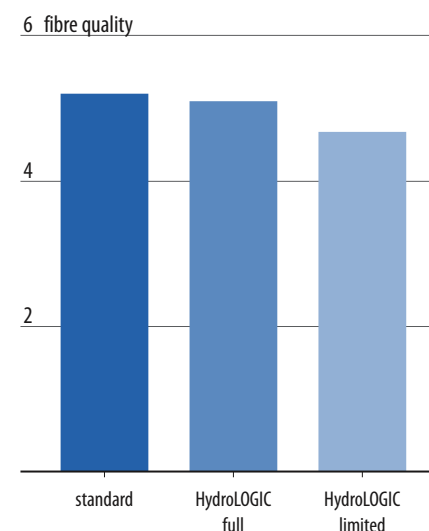
Timely water application ensured optimal plant growth and fruit development within the HydroLOGIC treatments. The highest square and boll numbers were achieved under the HydroLOGIC management. This resulted in a harvest of 8.1 bales/ha under full allocation and 5.8 bales/ha under limited water allocation. These results compare favourably with the standard scheduling treatment which yielded 7.6 bales/ha (Figure 3.5.3).

Figure 3.5.3. Final machine picked yields from the large scale HydroLOGIC evaluation trial at Narrabri



Micronaire was not significantly different between the standard and HydroLOGIC managed treatments (Figure 3.5.4). The HydroLOGIC limited treatment was less but was still within an acceptable range. These results demonstrate that HydroLOGIC was able to minimise water stress and negative effects on fibre development. Other fibre quality properties were not affected by the different irrigation scheduling and water allocation.

Figure 3.5.4. Micronaire results (handpicked samples) from the HydroLOGIC evaluation trial at Narrabri



Water use efficiency

During the 2002-03 season only 197 mm of rain fell on the crop, which provided ideal conditions to evaluate the value of HydroLOGIC. To determine the total irrigation water applied to the treatments, water flow was measured at the siphon and furrow (tailwater) in each treatment during all irrigations. The total seasonal water use was then calculated using the volume of irrigation applied, the change in soil moisture from sowing to defoliation, rainfall and estimates of deep drainage. These figures allow several water use efficiency indices to be calculated (Table 3.5.2):

Table 3.5.2. Water use efficiency indices

Water details	Standard scheduling	HydroLOGIC full allocation	HydroLOGIC limited allocation
Total water applied (ML)	7.2	8.5	4.6
Total seasonal water use (ML/ha)	9.3	10.8	6.7
Irrigation application efficiency	81	78	88
Gross production water use index (bales/ML/ha)	0.8	0.8	0.8
Irrigation water use index (bales/ML)	1.1	1.0	1.2
Crop water use index (kg/mm)	2.6	2.7	2.4

Gross production water use index (GWUI) is the yield (bales) produced from all water applied to the crop, which includes soil moisture, rainfall and irrigation water.

Irrigation water use index (IWUI) allows irrigators to determine how efficient their irrigation water has been in producing bales of cotton. It is calculated by dividing the yield (bales/ha) by the water applied as irrigation (ML).

Crop water use index (CWUI) calculates how efficiently the water used by the cotton crop in evaporation and transpiration (mm) was converted into lint harvested (kg).

The differences between the total water applied as irrigation and total seasonal water use indicate there should have been considerable differences in crop growth. However, comparisons of GWUI showed no differences between treatments. Comparisons between treatments indicated that IWUI (Table 3.5.2) was maximised in the HydroLOGIC reduced allocation treatment, where 1.2 bales were produced for each megalitre of water applied. This was compared with 1.1 bales/ML and 1.0 bales/ML from the standard scheduling and HydroLOGIC full allocation treatment.

Crop water use index showed little variation between the different management treatments, with comparable results achieved under a limited water scenario using HydroLOGIC. The HydroLOGIC full allocation treatment

achieved the highest crop water use index of 2.7 kg of lint/mm of evapotranspiration.

These results demonstrate that HydroLOGIC can be used to maximise yield and achieve optimal WUE, through scheduling irrigation applications to satisfy plant water demand and maintain good crop growth.

Future features of HydroLOGIC

New features will be incorporated into the HydroLOGIC software in future versions, following feedback from cotton growers and consultants. Some of the features planned include:

- the ability to select particular seasons for comparisons, for example, drought years, and analogous seasons based on the current seasonal climate forecasts.
- the ability to customise soil moisture parameters used for predictions of crop growth and import data from existing soil moisture measuring devices.
- a farm water accounting system.

Software

Copies of the HydroLOGIC software are available from the cotton industry development officers, situated in each cotton-growing valley, or by contacting the Australian Cotton CRC's Technology Resource Centre at Narrabri. Further details can be found at <http://www.cotton.crc.org.au/CottonLOGIC/>.



3.6 Irrigation and cotton disease interactions

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David Nehl

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Joe Kochman and Greg Salmond

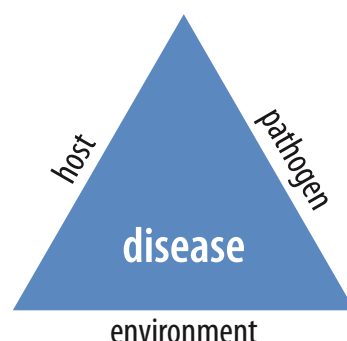
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Key points

- Irrigation practices have contributed significantly to the Fusarium wilt, black root rot and Verticillium wilt problems of the Australian cotton industry.
- Irrigation practices can and should be modified to reduce the rate of increase of plant disease problems.

Plant diseases occur when a virulent **pathogen** interacts with a susceptible plant **host** under favourable **environmental** conditions. These three factors constitute the three sides of the 'disease triangle' and all three must be present for a disease to develop (see *Integrated disease management*). Plant diseases are usually a problem created by human activity. Irrigated cotton farming systems generally favour the survival and dispersal of the pathogens that cause diseases of cotton and often provide environments conducive to infection. Irrigation practices have contributed significantly to the development of the Fusarium wilt, black root rot and Verticillium wilt problems that are causing concern to Australian cotton growers.

The disease triangle



The objective of this topic is to discuss the positive and negative impacts of irrigation practices on the three components of the 'disease triangle' and to propose possible strategies to minimise the negative impacts on the sustainability and profitability of cotton farming.

Impact of irrigation practices on the pathogen

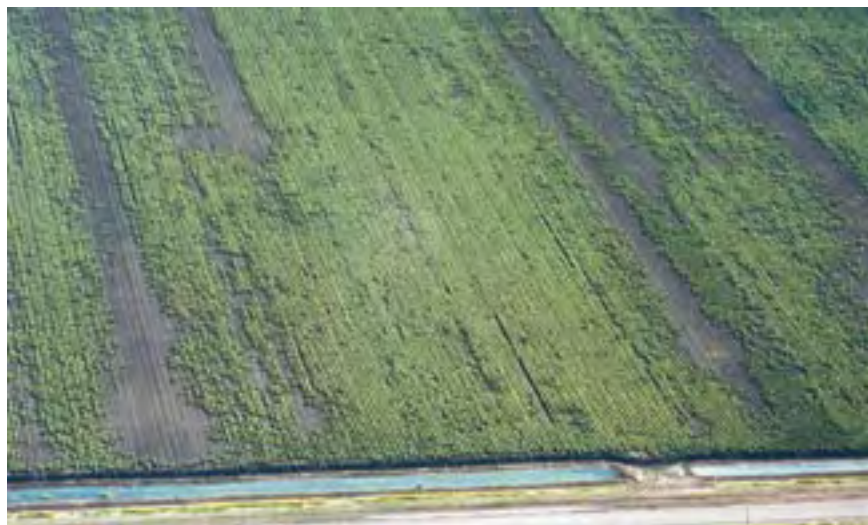
Dispersal of the pathogen within the field

Dispersal from field to field, that is, introducing the pathogen to new fields

Water moving down a furrow and into and along a tail drain carries soil particles and crop residues. Significant numbers of pathogen spores may be dispersed in this manner.

Dr David Nehl studied the distribution of spores of the black root rot pathogen in tailwater from an infested field and found 175 spores/litre of tailwater and 11,750 spores/kg of trash carried in tailwater at the tailwater drop-box. Trash carried in tailwater and sampled 2 km from the tailwater drop-box was found to be still carrying 2671 spores/kg trash.

Figure 3.6.1. Aerial photo of Fusarium wilt showing spread of the pathogen down the furrows



Aerial photographs of the field distribution of Fusarium wilt also show the significance of spore dispersal in irrigation water. The pathogen that causes Verticillium wilt can be easily isolated from crop residues floating in tailwater return systems.

Repeated wetting and drying cycles reduce pathogen survival

Pathogens survive best in dry soil. Frequent wetting and drying cycles allow for rapid breakdown of crop residues and consequently reduced survival of spores of the pathogen. Many cotton pathogens are favoured by a dry winter period between subsequent cotton crops.

Figure 3.6.2. Large amounts of crop residue are moved about in tailwater return systems.



Various types of 'trashlifter' have been developed to remove a significant proportion of the crop residues from the tailwater return system.

Minimising the impact of irrigation practices on the pathogen

Minimise tailwater and tailwater recirculation by pulling siphons earlier. It is not easy or convenient but it can be done! Less tailwater recirculation means less pathogen redistribution. It is impossible to eliminate stormwater run-off.

Trevor Brownlie of 'Mahnal' Gibber Gunyah via Theodore writes: 'Our irrigation strategy is to irrigate the whole field at once. We operate a two-metre permanent bed system in our Fusarium affected field and therefore only irrigate every second row across the field. However in the 50 to 60 metres of rows surrounding the diseased area we ensure that the siphons are pulled from the head ditch early so that no excess irrigation water reaches the tail drain. This practice has prevented the dispersal of soil particles and infected plant material via the tailwater system. Disease surveys conducted by the QDPI's Dr Joe Kochman have indicated to date that the disease has not spread outside the initial affected area. In addition – any field operation, such as planting, spraying or picking, start at either end of the field and work inwards to the affected area. The rows of the affected area are worked last, and machinery cleaned down before moving on to another part of the farm.'

(Note: When applying this strategy it is essential that the full distribution of the pathogen is known. It may be wiser to minimise tailwater across the whole farm!)

Minimise tailwater backing up into field. This may be achieved by modifying the depth and slope of tail drains.

Remove crop residues from tailwater return systems. Floating 'booms' may be used to hold back rafts of crop residues. Various designs of 'trashlifter' can be installed in the tailwater return system (Figure 3.6.2). The use of natural wetland areas to provide 'biological strainers' is being evaluated.

Flood infested fields for 30-60 days in summer (summer flooding). If water is available and field topography is suitable, then summer flooding is an option for reducing, but not eliminating, the pathogen spore population. This has been shown to be effective against black root rot and Fusarium wilt in Australia and is recommended for the control of seedling diseases, black root rot and Verticillium wilt in parts of California. The soil (and crop residues) must be completely submerged.

Consider buried drip instead of furrow irrigation. With buried drip there is no movement of pathogen spores down the furrow and no tailwater or tailwater recirculation, apart from that resulting from run-off associated with rainfall events.

Beware of contaminated water sources. Run-off from a gin yard may introduce new pathogens. An outbreak of Phytophthora boll rot in California was attributed to the overhead application of water from an infested water storage. Water storages may become contaminated when used to store tailwater from fields where a disease is present.

Impact of irrigation practices on the host

Diminished host plant resistance due to waterlogging-induced nutrient imbalances

Natural host plant resistance mechanisms are dependent on adequate host plant nutrition. Potassium is particularly important and potassium deficiency in cotton has been associated with increased susceptibility to Fusarium wilt, Verticillium wilt and Alternaria leaf spot.

Minimising the impact of irrigation practices on the host

Avoid or minimise waterlogging. Fields should have adequate slope and be well drained. Tail drains should be efficient and not allow adjacent areas of the crop to be inundated unnecessarily. For some soil types, the use of wide (2 metre) beds may provide an alternative system to minimise or reduce waterlogging.

Impact of irrigation practices on the crop environment

Irrigations drop soil temperatures

The pathogens that cause seedling diseases, black root rot, Fusarium wilt and Verticillium wilt are all favoured by cooler soil temperatures and adequate soil moisture.

High humidity and periods of leaf wetness favour infection

Foliar pathogens such as those responsible for bacterial blight and Alternaria leaf spot require either very high humidity or periods of leaf wetness for spore germination and completion of the infection process. In the dry Californian climate, the change from overhead sprinkler irrigation (which wet the leaves) to furrow irrigation (where leaves remained dry) provided complete control of bacterial blight.

Late season irrigations contribute to later harvests

Later maturing crops are exposed to cooler autumn weather which is more favourable for disease development. Withholding the final irrigation to cotton fields in California resulted in a lower incidence of Verticillium wilt and a higher yield than in control fields that did receive the final irrigation.

Minimising the impact of irrigation practices on the crop environment

- Plant into moisture in preference to watering-up.
- Avoid late irrigations.
- Avoid irrigation systems that wet the foliage.

Conclusions

Irrigation strategies have contributed, and are still contributing, to the emergence of significant cotton disease problems that threaten the economic viability of cotton farming. Cotton plant breeders may eventually provide solutions to these disease problems in the form of resistant varieties but it could be a long time before that solution is forthcoming. In the meantime it is essential that growers do all they can to slow the rate of epidemic development by reducing the spread of pathogens, providing for the adequate nutrition of the host and by manipulating the crop environment so that it is less favourable for disease development.

Further reading

For further reading, see *Integrated disease management*, compiled by SJ Allen, DB Nehl, and N Moore, Australian Cotton Cooperative Research Centre with support from the Cotton Research and Development Corporation, Narrabri, NSW. Available at

<http://www.cotton.pi.csiro.au/Assets/PDFFiles/Disease/IDMGL021.pdf>



3.7 Measuring plant water status

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Key points

Plant-based measurements

- are effective at monitoring the water status of a crop;
- are not practical to schedule irrigations due to the high frequency of clouds at solar noon in most cotton areas in Australia;
- work best in sunny conditions, when the air is dry (that is, relative humidity is low);
- may be useful for on-farm trials where researchers are involved.

Measuring the water status of cotton using plant-based measurements has proven challenging in Australia. This is because clouds are common at solar noon, which interferes with regular measurements that are needed for irrigation scheduling purposes. When combined with the irregular hours of consulting agronomists and the humid climate, many of these tools have not been successful in the commercial environment in Australia for irrigation scheduling. (They have been effective in arid and sunny climates like Arizona and Israel.)

However, these tools are used by researchers to accurately determine the plant water status in their experiments, and questions often arise about their use, which is why this topic has been included in WATERpak.

Remote sensing and crop water status

Satellites, airborne imaging systems and hand-held instruments are frequently proposed as indicators of crop stress caused by water, soil compaction, lack of nutrients, diseases and mites. Studies have been conducted to investigate how crop reflectance and temperature changes with the onset of water stress in the green, red, near infrared and thermal infrared wavelengths of the electromagnetic spectrum. These wavelengths are the most commonly used by remote sensing tools.

Pre-visual detection of water stress using hand-held radiometers, airborne or satellite imagery has been proposed as a more accurate way to time irrigations. Unfortunately, this is easier said than done. It has turned out the instruments have been more successful for other applications such as measuring leaf area, detecting diseases and measuring the spatial variability in fields.

Crop canopy temperatures and irrigation scheduling

As water becomes limiting, crop temperatures rise because they cannot transpire enough water to keep themselves cool. Plant leaves open their stomata to admit carbon dioxide for photosynthesis and at the same time water vapour flows out of the leaf, which cools the leaf surface. When soil water becomes limiting, transpiration decreases, thus reducing the leaf cooling effect and causing the crop temperature to rise. This is why when you touch the leaves of a well-watered crop in sunlight on a hot sunny day they are cool, whereas a piece of green cardboard would feel hot.

All objects emit energy or radiation that is measured as their temperature. For crop canopies the temperature is usually measured with a thermal infrared thermometer.

Stress degree day method

Wiegand and Namken (1966) proposed that the difference between leaf temperature and air temperature ($T_l - T_a$) could be used for irrigation scheduling. This idea was adopted by Idso et al. (1977) and Jackson et al. (1977), who suggested the difference between canopy temperature (T_c) and air temperature (T_a) obtained about an hour after solar noon could be used for irrigation scheduling. This method is known as the 'stress degree day' concept and assumes environmental factors such as vapour pressure deficit, net radiation and wind would be manifested in the canopy temperature.

Roth (1993) found that typical values of well-watered cotton crop temperatures in Australia are about 4°C below the ambient air temperature. That is, if the air temperature is 32°C, then a well-watered crop will have a temperature around 28°C degrees. Malouf et al. (1998) found that well-watered cotton crop temperatures are typically around 26°C to 30°C degrees when measured around solar noon. As a crop becomes water stressed the difference between the air temperature and crop temperature narrows from 4°C to 1°C below ambient air temperatures. Crops with temperatures above the ambient air temperature are usually stressed.

Crop water stress index

It is known that vapour pressure deficit (a measure of humidity) and net radiation influence crop temperature. As air becomes drier the vapour pressure deficit increases and the evaporative process becomes more efficient at cooling the plant, which is similar to an evaporative cooler cooling a house.

The crop water stress index (CWSI) was proposed as a more quantitative and repeatable method for determining crop water status than the stress degree day method. The CWSI is determined by subtracting the air temperature from the crop canopy temperature and comparing the resultant value with that of a well-watered crop at the same vapour pressure deficit (VPD). The crop temperature is measured using an infra-red thermometer, while

the air temperature and vapour pressure deficit are measured using dry and wet bulb thermometers, or using formulae to convert relative humidity measurements. Idso et al. (1981) describes an empirical method for determining the CWSI while Jackson et al. (1981) gives a theoretical explanation of the index. The CWSI value is a measurement of the reduction in transpiration, expressed as a decimal in CWSI units. The CWSI has values ranging from 0 (no stress) up to 1 (maximum stress). A CWSI value between 0.25–0.35 would occur when the irrigation is due.

The CWSI is characterised by a lower limit or a 'non-water stress baseline', at which the plant is experiencing no stress, and an upper limit where the plant is experiencing severe stress. A baseline of no water stress with an intercept of 2.0 and a slope of -2.24 has been commonly used for cotton (Idso et al. 1982). To determine a base line of no water stress, measure a non-stressed crop canopy temperature over a range of VPDs. This can be done by monitoring it as it changes over one day or by taking measurements on different days when the VPD is different around solar noon.

The CWSI is calculated by using the following formula: where

A is the upper limit of $T_{crop} - T_{air}$

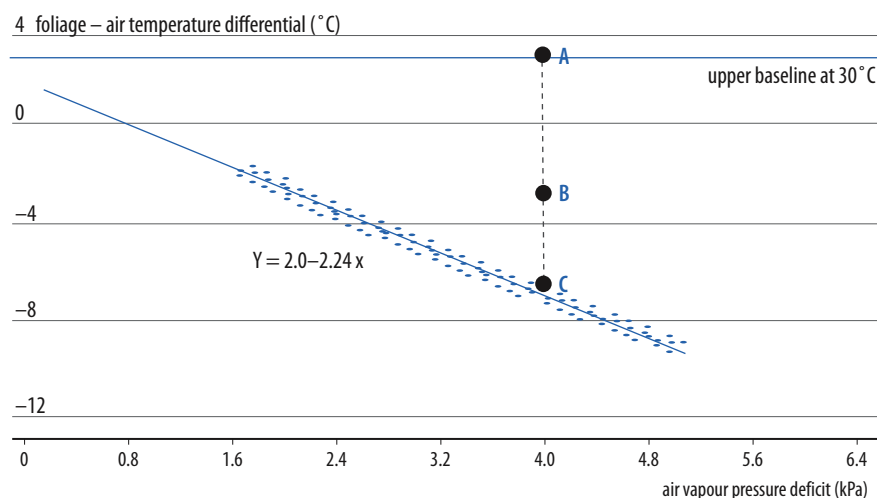
B is the actual measured value of $T_{crop} - T_{air}$ and

C is the value of $T_{crop} - T_{air}$ if the crop were not stressed (Figure 3.7.1).

$$CWSI = \frac{B - C}{A - C}$$



Figure 3.7.1. Theoretical relationship between the canopy air-temperature difference and the vapour-pressure deficit



Source: Jackson 1982

While in theory this method is very sound and has worked well in irrigation experiments in dry, sunny climates like Arizona, it has not been adopted in Australia. This is because in Australia the climate is more humid and the VPD range is much less. When combined with cloudy weather this means it is more difficult to collect the data on a routine basis. The Australian summer of 2002/03 would have been ideal summer as it was hot, dry and sunny most days. However, patchy clouds normally build up after midday in Australia and create problems when applying plant-based measurement techniques for irrigation scheduling.

Relative temperature differences

Canopy temperature variations due to stress are only small (1° to 3°C) and difficult to separate from variations caused by diurnal and daily changes in radiation. An alternative way to use crop temperatures for irrigation scheduling is, on any one day, to measure the canopy temperature of a well-watered crop and use that as a base temperature to compare with other crops on the same day. Crops with warmer temperatures are likely to be more stressed. Thus, water stress can be assessed by examining differences in canopy temperature between the field in question and a well-watered area of the same crop in the near vicinity. This assumes environmental effects are common to all areas on a farm at the measurement time. Another option, for those growers interested in precision water management techniques, is to use a cropped field as its own reference point and examine the temperature variability within the field.

Practical tips for measuring crop temperatures

The optimum time for measuring crop temperatures is around solar noon when the crop is experiencing maximum diurnal stress levels: no earlier than 11.00 am (Eastern Summer Time), unless it is a really hot day. Usually, between 11.30 am and 3.00 pm (Eastern Summer Time) is best.

Clouds are the biggest headache, so avoid cloudy days or when patchy clouds are about. The crop needs to be in the sunlight for a few minutes before the temperature is taken.

Make sure you only measure crop canopy temperatures. Soil background will ruin results. Crop temperatures should be around 28°C, while the grey clays soils will be about 50°C at the same time in the middle of the day. If you record temperatures above 35–40°C it is likely soil background is influencing the data.

Canopy temperature can be influenced by the soil thermal environment when the plants are small. Canopy temperature measurements may not be valid when the crop height is less than 0.5 metres.

Air temperatures and relative humidity can be obtained from a suitable local weather station. Otherwise, you need a wet and dry bulb thermometer.

Much of the research on crop temperatures was done in the hot and very dry air climates of Arizona, so care should be taken when extrapolating the results of this research to the more humid and cloudy (patchy) Australian conditions.

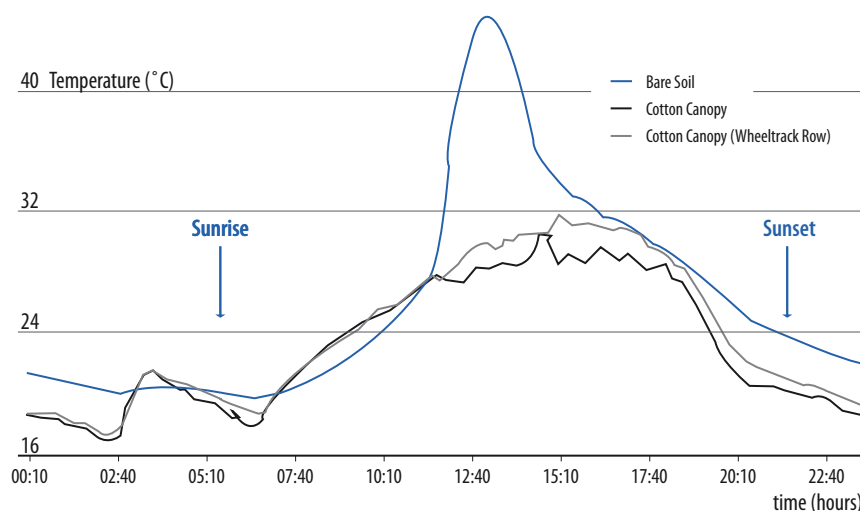
Many factors can affect crop canopy temperatures: air temperature, solar radiation, the dryness of the air, wind, waterlogging, soil compaction and soil background temperatures.

Changes in solar radiation intensity are likely to be a complication when using measurements of canopy temperature for irrigation scheduling. Variations in solar radiation intensity will cause canopy temperatures to fluctuate across a range three times larger than the variation attributed to changes in soil moisture depletion. Roth (2003) showed that crop canopy and soil surface temperatures change considerably during the day (Figure 3.7.2). During the night, soil surface temperatures were warmer than the crop canopy.

At 7.40 am soil and canopy temperatures were similar. As the morning elapsed, the crop canopy was exposed to more sunlight and its temperature rose above the soil surface that remained shaded underneath the canopy. By 11.30 am the sun's elevation in the sky was high and soil temperatures rose above the crop, as the soil surface was now in direct sunlight. One day, for example, the soil temperature peaked at 44°C, while the crop canopy temperature was 30°C. Soil surface temperatures up to 50°C were common in the middle of the day, while canopy temperatures of non-stressed crops were usually around 28° to 30°C. Figure 3.7.2 shows that the row with the highest afternoon canopy temperature was a tractor wheeltrack row: in this row, the soil was more compacted, and so soil moisture was less available for crop transpiration, resulting in a canopy temperature rise.



Figure 3.7.2. Diurnal change in canopy temperature



Infra red photography

Infra red photography is often used to record plant stress visually. It is possible to use a normal camera with infrared film and an infrared filter for the lens. Any good camera shop will have this material or know where to get it. The images are highly correlated to leaf area index/ biomass/ groundcover. The Kodak™ website has useful information.

Airborne thermal infrared imagery

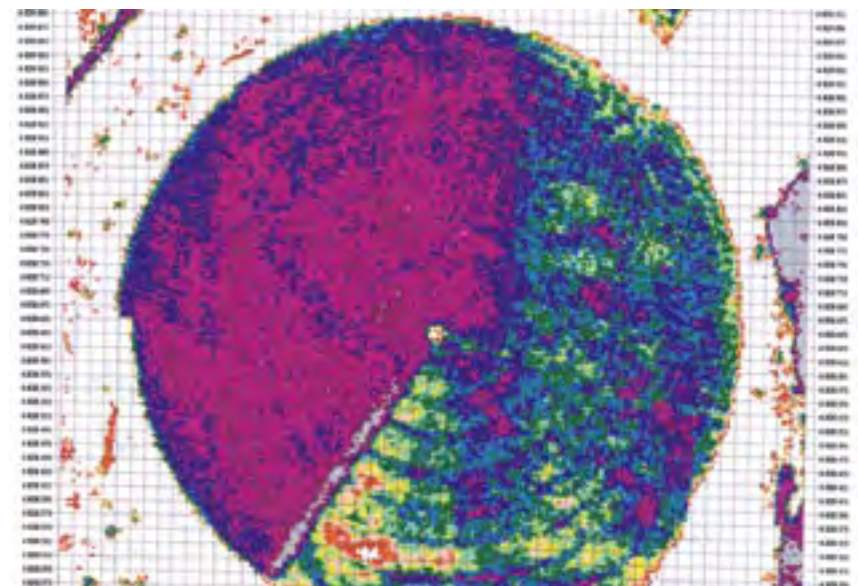
It is possible to 'photograph' the crop temperature to examine the spatial variation of crop health within and between fields on farms. This can be done from an aircraft or satellite. Problems with satellite imagery in the thermal infrared band include poor spatial resolution (120 metre pixels), and image capture at the wrong time of day (early in the morning – 10.00 am, which is not good for stress detection). The infrequency of satellite passes creates problems obtaining images. Airborne imagery can be collected any time and is usually done about 6000 to 9000 feet above ground level, which results in a pixel resolution of about 3 metres.

In addition to scheduling irrigations, thermal imaging has other potential applications including:

- improving grower and consultant knowledge of the variability in their fields
- detecting low spots and waterlogging problems
- early 'cut out' detection of highly loaded crops
- early detection of Fusarium wilt disease
- insect monitoring such as mite hotspots, and high LAI
- accurate potential yield variation maps
- defoliation information with rank and late maturing crop areas identified for variable rate and product selection
- hail damage assessment
- agronomist overview and precision mapping overlay with EM surveys
- farm maps
- examination of drip and spray irrigation system distribution.

Figure 3.7.3 is a thermal infrared image and shows the variation in several cotton fields. Fields 24, 25, and 20 have been watered and have cool temperatures and less spatial variation in the amount of stress exhibited in a field. In fields 19, 21, and 26 you see exactly where the water is flowing and how much more spatial variation is evident in the crops.

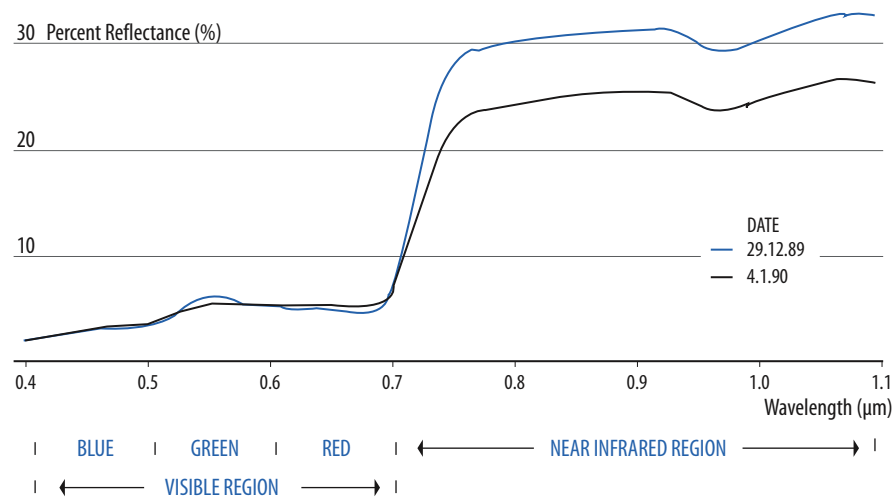
Figure 3.7.3. Airborne thermal infrared image of a cotton crop



Cotton canopy spectral reflectance

Figure 3.7.4 shows the spectral reflectance of a cotton crop near Wee Waa as measured by a portable spectro-radiometer.

Figure 3.7.4. The spectral reflectance of a cotton crop



Source: Roth 2002

Canopy reflectance of the mid-season cotton canopies was low in the visible region (0.4–0.7 μm) with a small peak in the green band at 0.55 μm. This peak is why plants are green to the human eye. Radiation absorption by chlorophyll and other plant pigments causes low reflectance values in the visible region, while internal leaf reflection of incident radiation that is dominated by leaf structure causes canopy reflectance to increase considerably in the near infrared region (0.7–1.1 μm). This is why near infrared images and instruments are proposed to monitor crop stress, as reflectance levels are much greater than those of the visible wavelengths observed by the human eye.

Water stress influences canopy reflectance. During the five-day period prior to the irrigation date or refill point, reflectance decreased in the near infrared and green bands. Red reflectance increased only after the soil moisture status fell below the refill point. The greatest change in reflectance was in the near infrared region, which was attributed to a decrease in groundcover caused by canopy architectural changes including leaf wilting. Red and green band reflectance changes were very small and would not be practical for irrigation scheduling purposes under commercial operational conditions (Roth 2002). Other experiments showed that the crop reflectance was more strongly influenced by groundcover and plant height than the soil moisture status (Roth and Button 1994).

Relative water content

Relative water content (RWC) estimates the water content of sampled leaf tissue relative to the maximum water content that it can hold at full turgidity. It is a measure of water deficit in the leaf. Normal values of RWC range between 98% in turgid and transpiring leaves to about 40% in severely desiccated and dying leaves. In most crop species the typical RWC at about wilting is around 60% to 70%.

Discs are cut from the leaves, to obtain about 5-10 cm²/sample, for no more than two hours at and after solar noon. Each sample is placed in a pre-weighed airtight container and kept cool until it reaches the lab. In the lab containers are weighed to obtain leaf sample weight (W), after which the sample is immediately hydrated by floating on de-ionised water to full turgidity under normal room light and temperature. After 4 hours the samples are taken out of water and dried of any surface moisture and immediately weighed to obtain fully turgid weight (TW). Samples are then oven dried at 80°C for 24 h and weighed to determine dry weight (DW).

$$\text{RWC (\%)} = [(W - DW) \div (TW - DW)] \times 100$$

Where,

W = sample fresh weight

TW = sample turgid weight

DW = sample dry weight.

Pressure chamber (pressure bomb)

The pressure chamber technique for measuring plant water potential has been a standard research technique since the 1960s. It was tried in the Australian cotton industry in the early days, but is no longer used for commercial irrigation scheduling because of problems getting repeatable data due to cloudy weather. It is still used in countries that do not experience clouds, such as Israel and California.

Stem parts, leaves, branches or whole plants are placed into the chamber so the cut end protrudes through the specimen holder. Pressure (nitrogen) is applied to the plant part until a drop of sap is observed at the cut end. The pressure required to force a drop of sap from the sample is equivalent to the force with which water is held to plant tissues by forces of adsorption and capillarity. In order to use the pressure bomb as a tool for irrigation scheduling, pressure bomb data have to be correlated with soil water potential data using a neutron moisture meter and potential evapotranspiration. With this relationship, it is possible to characterise the irrigation scheduling for a specific crop.

Sampling should be done under full sunlight in cloud-free conditions. Under milder or cloudy conditions, readings will be less negative and won't give a useful soil moisture measurement. Morning measurements are difficult to interpret, and some researchers like to examine pre-dawn data to see whether plants are completely recovering from moisture stress overnight. Sampling is easy, and generally the uppermost fully expanded leaf petiole is used.

Delays between petiole removal and measurement can introduce serious errors in the readings obtained due to moisture loss before measurement. This is readily minimised by wrapping the leaf in clear plastic 'cling wrap' before excision and placing the leaf still wrapped into the chamber for measurement. Much more consistent results are obtained this way. The best method is to take the readings in the field.

In the *Australian Cotton Grower* magazine, Nov. 1986, Rod Brown published extracts from his paper presented to the 'Irrigation 86' symposium in Toowoomba where he reviewed the Pressure Bomb. This article explains the use of the pressure bomb as it relates to cotton irrigation. The following leaf water potentials measured using the Bomb in the early afternoon and in full sunlight are suggested:

Maximum photosynthesis and leaf growth above -1.4 MPa

Optimum growth -1.6 to -1.7 MPa

Irrigation required -1.8 to -2.4 MPa

The article concludes with the statement: 'With a little experience the Pressure Bomb can be a handy tool to pinpoint water stress in cotton. Because it must be used in mid afternoon on clear sunny days it has limitations for reliable scheduling over a season. However it is an excellent tool for calibrating or fine tuning other scheduling systems and is useful for spot checks at critical stages of the growing season.'

Thermocouple psychrometer

Measuring water potential by thermocouple psychrometry refers to the measurements of the difference in temperature between an atmosphere and a freely evaporating moist surface. In that atmosphere the psychrometer measures small differences in vapour pressure. A thermocouple is formed where wires of two different metals are joined.

If the two junctions are held at different temperatures, an electric current will flow through the circuit. The magnitude of the current is a measure of the difference in temperature between the two junctions. Thermocouple psychrometry depends on the principle that water vapour at equilibrium with plant tissue will have the same water potential as the tissue. Water potential of tissue can be measured by measuring the vapour pressure of the chamber in which plant material is sealed.

The plant material is sealed in a small chamber with a thermocouple junction and a drop of water. The chamber quickly saturates with water vapour. Since the water potential of the tissue is more negative than the water potential of the pure drop of water, water vapour moves from the drop into the tissue. As the water evaporates from the junction, the temperature drops. This drop in temperature is compared with a known ambient temperature and vapour pressure calculated.

Porometer

The loss of water (evaporation) by plant leaves is regulated by the stomata (pores) of the leaves, as absorption of CO₂ takes place for photosynthesis. It is an important indicator for the physiological condition of the plant. The opening of the stomata can be interpreted as the resistance against gas diffusion and is measured using the **porometer**. Measurements of diffusion conductance are therefore important indicators of plant water status and provide a valuable insight into plant growth and adaptation to environmental variables.

Sap flow sensors

There are three types of sap flow sensors: heat balance, heat pulse and thermal diffusion. The heat balance sensor is placed around the stem and the others require probes to be inserted into the plant stems. The resulting measurements can be related to plant water status and ultimately irrigation scheduling. These instruments have been mainly restricted to scientific investigations.

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3a.1 Scheduling canola irrigation with GBugs

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Information sourced from IREC Farmers' Newsletter, No. 175, Autumn 2007

Key points

- Stem elongation and flowering are the two most critical stages for moisture in canola.
- With the aid of moisture monitoring devices the amount of moisture in the soil can be measured to assist in irrigation scheduling to ensure maximum crop yields.
- In 2006, in a canola variety trial, the use of GBugs at estimated rooting depths was essential to accurately match up crop water requirements with critical growth stages.

The irrigation of canola provides adequate soil moisture for the crop to use at critical growth stages. A trial in 2006 at the Victorian DPI Kerang research site showed that moisture monitoring devices can be used to avoid moisture stress at these critical times.

For canola crops, adequate soil moisture at stem elongation and flowering promotes:

- root growth
- large leaf area and assists the plants to retain their leaves longer, thereby lengthening the flowering period
- the number of branches per plant, the number of flowers forming pods, the number of seeds per pod, seed weight and ultimately, yield.

Effect of moisture stress

Canola plants under early season moisture stress may recover to near normal growth with rainfall or irrigation. Stressed plants have the ability to partially recover leaf area, form flowers, set pods and fill seeds with the availability of water. However, canola crops generally cannot fully compensate for early moisture stress as the hastened development and earlier maturity leads to lower yields.

The worst times for canola to experience moisture stress are during stem elongation and flowering, so the use of moisture monitoring devices at the estimated rooting depths of the crop has been essential to match up irrigation timing and plant moisture needs.

Grain filling will continue for about 25 days after flowering. The end of flowering is defined as the stage when only 10% of plants have flowers. With flowering extending up to 30 days, there is easily over two months where in theory, moisture should be readily available and maintained in the soil.

Canola does not tolerate waterlogging, especially during flowering, but in a flood irrigated environment it is almost impossible to avoid the occasional excess water stress where the water holding capacity of the soil is exceeded through irrigation.

Waterlogging for three days or more during flowering reduces the number of pods per branch as well as seeds per pod. It is critical to have good drainage and slopes on the layout and use reliable weather-predicting tools to reduce the chances/impact of waterlogging.

Soil moisture measurements with G Bugs

In 2006, the use of G Bugs for moisture monitoring in canola crops was investigated at the Kerang research site.

The G Bug is a mini data logger to which up to four gypsum blocks at different rooting depths can be attached. The G Bug logs the sensor readings every two hours so everything is measured (rainfall, irrigation, hot weather and peak plant water use demand times) and up to 20 days of readings can be stored at one time. The data stored in the G Bug is then collected using a wireless connection. Readings can be reviewed on the MEARetriever or downloaded into the supplied software for analysis.

G Bugs were selected for the trial because once installed they are easy to use and determine soil moisture. Correct installation is critical to ensure accurate readings. Once installed, the logger connected to the G Bug will record valuable soil moisture information. A portable retriever transfers data from the logger in the field to a computer. Costs are \$80 for each GBLite block, a G Bug data logger is \$1000 and the portable retriever is \$550.

Two different moisture monitoring devices (a 'GBHeavy' and a 'GBLite') were installed at the site at a depth of 15 cm. Two GBLites blocks were installed at 30 cm and 45 cm. The GBLite blocks can be used in most soil types if the root zone of the crop is going to be in the 'readily available water' zone and operates over a tension range of 10 to 200 kPa.

If the crop is going to be pushed into water deficit in clay soils, the GBHeavy should be used as they operate over a tension range of 60 to 600 kPa.

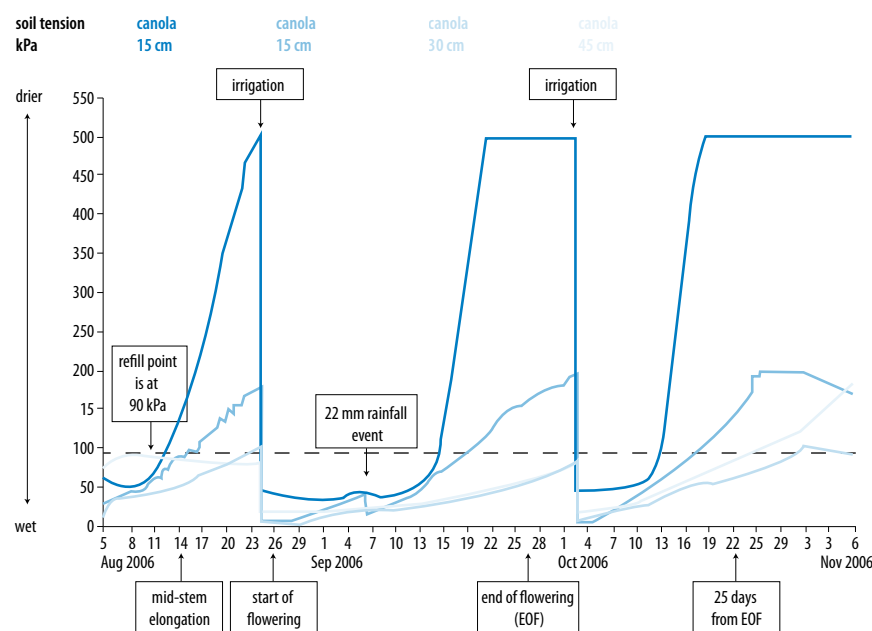
Decisions to irrigate in 2006

Figure 3a.1.1 shows the soil moisture levels and critical growth stages of canola in the variety trial site at Kerang, in 2006. At this stage we estimate that the refill point on the Kerang heavy clay vertosols is around the 80–95 soil tension kPa at a rooting depth of 30–40 cm.

First irrigation

In 2006, the first irrigation took place in late August near the end of stem elongation, just before flowering commenced. The canola roots at 30 cm depth had begun to rapidly deplete the soil moisture levels, and soil moisture levels had reached the soil refill point (dotted horizontal black line on Figure 3a.1.1). This line could be further refined with field observations and ground-truthing the soil. Each soil type and crop type will have slightly different refill lines and root depths but ground-truthing can be performed to determine this.

Figure 3a.1.1. G Bug graph of soil moisture under the 2006 DPI irrigated canola trial. The — line is the soil tension at 15 cm measured by the GBLite; the — line represents the soil tension with the GBHeavy at 15 cm, the — line at 30 cm and the — line at 45 cm depth. The dashed line indicates the suggested refill point.



The decision to irrigate at this time was based on both the patchy emergence from lack of rainfall in May and June, and the crop growth stage. The aim was to promote the opportunity for the crop to compensate for the low plant density by increasing branching.

In addition, this irrigation event was going to be the first opportunity since sowing to topdress with nitrogen. It provided the ideal situation for the nitrogen to be applied to the crop. Only starter fertiliser had been applied at sowing, as it was preferred to apply nitrogen through topdressing when significant rainfall or an irrigation event is able to wash the nitrogen into the soil.

Second irrigation

Despite 22 mm of rainfall during mid September, the moisture levels did not change at the rooting depth of 30 cm. At the end of September the canola had finished flowering but moisture levels were critically low with the canola roots estimated to be 45 cm deep. Soil moisture depletion was the same at 30 cm and 45 cm.

The grain filling period for canola is around 25 days from the end of flowering. With the plant still being able to use moisture for a further 25 days to contribute to yield and oil content, combined with a forecast of well-below average October rainfall, the second irrigation was applied.

Trial yields

Variety yields varied considerably and ranged from 1.5 to 3.0 t/ha on the trial site in 2006. Lower yields could be attributed to the low plant densities at establishment, moisture stress through winter and lack of spring rain where the irrigation events attempted to compensate the deficit. Incidents of wind that blew petals off the canola and hot weather limited flowering.

Conclusion

G Bugs are another tool to investigate soil moisture levels at depth so that irrigation events can be better planned and matched to critical growth stages of canola. The experience at the Kerang trial site shows that soil moisture monitoring can help to make more timely decisions about irrigating canola.

Acknowledgement

Thanks to Felicity Pritchard, Oilseeds Industry Development Officer, for instigating and reviewing this article.

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Figure 3a.1.2. A G Bug data logger and wireless retriever (in a maize crop).





3a.2 Challenges for irrigated canola in 2007

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Information sourced from IREC Farmers' Newsletter, No. 175, Autumn 2007

Key points

- Canola is a key ingredient in a sound winter crop rotation.
- The price outlook is positive in the short, medium and longer term.
- The keys to lower risk and more profitable irrigated canola in 2007 will be timely sowing and correct variety choice to match sowing time, irrigation at critical times if allocations permit, close crop monitoring and managing production costs while maximising yields.
- Cutting the crop for hay in spring can be very profitable if there is high market demand.

Crop rotations have been pushed to the limit in some regions and canola can be a valuable option in the rotations on irrigated and dryland farms.

Extensive surveys and trials of dryland crops across Australia have found that wheat yields are on average around 20% higher after canola than after wheat. Experienced irrigated canola growers have reported similar responses. Other benefits of canola are:

- higher two year gross margins.
- cleaner paddocks to sow a cereal into
- less build up of grass weeds and associated problems
- herbicide resistance management, particularly when growing the triazine tolerant (TT) varieties which allow growers to leave out a group A herbicide
- reduced root diseases after canola including Rhizoctonia.

The price of canola (Jan 2007) is \$455/t delivered Geelong, and is likely to stay strong due to global demand for oilseeds. The long-term average price (1995 to present) is between \$365–370/t delivered port (based on industry sources).

Benchmarking

Close crop monitoring will be critical to make the most of 2007.

Benchmarking agronomic and financial information allows advisers to compare the management of the top-performing crops with the average and the poorer performing crops, and use this as a basis to develop improved recommendations.

A number of private companies along with the NSW Department of Primary Industries are involved in benchmarking, however the information gathered and methods used for benchmarking vary.

Time of sowing

Optimum sowing time and flexibility

The optimum sowing time for irrigated canola in the irrigation areas of southern NSW is mid to late April to early May, and by mid May for northern Victoria, although sowing can start from mid-April.

In low rainfall areas (< 350 mm) with no water allocation, canola should be considered as an opportunity crop to take advantage of a good early break and a forecast for a favourable season. It should be sown before the end of May if there is available subsoil moisture.

In medium rainfall areas (350–500 mm) with no spring allocation, canola should ideally be sown by mid-May, although sowing into mid-June is possible in northern Victoria. If there is a late break, start to assess other crop options, particularly if there is no subsoil moisture.

Sowing canola late is costly – especially in hot and dry seasons

In 2007, many irrigators will have enough water for one irrigation only or may have no water at all for canola – so make the most of it by sowing on time. Late-sown canola crops generally have lower oil and yields, and require more irrigations to finish. They also emerge more slowly and are more susceptible to insect attack and waterlogging in winter. The ‘rule of thumb’ is a 5% yield penalty per week delay in sowing.

A database of 197 crops grown in the Riverina and northern Victoria shows that Anzac Day was the median sowing date for the top 20% yielding irrigated canola crops, for the period 1991–2003. In contrast, the median

sowing date for the remaining crops was 9 to 10 days later (Table 3a.2.1).

Late-sown crops experience more hot and dry conditions during the critical flowering and pod-filling periods than crops sown on time. Very hot weather during flowering can cause flowers to abort (‘heat blast’) and reduce potential yield. Hence, irrigated canola crops in the Riverina and northern Victoria have not consistently achieved yields similar to crops in the cooler regions of the high-rainfall zone.

In dryland trials, average temperatures did not correlate with yields, but had a bigger effect on oil content: the oil content rose by 0.8% for each 1°C drop in average temperatures from flowering to maturity, but only by 0.2% per 10 mm of in-crop rainfall.

Calculating potential yields using sowing date and subsoil moisture

Recently, a modified simple potential yield calculation was developed based on southern NSW data,

which factors in time of sowing and available stored moisture. Using the model, APSIM, this calculation has potential for use in irrigated canola crops, so long as the combined in-crop rainfall plus irrigation does not exceed the equivalent of 450 mm. Target yields using this calculation are at 85% of potential yield, but may be higher depending on the soil type and grower experience.

Sowing very early

Very early sowing can cause excessive growth and lead to early spring moisture stress and sometimes lodging. For each month of earlier sowing, the crop will mature around 10 days earlier.

Stored subsoil moisture

Stored subsoil moisture is like insurance for canola yields. Every 10 mm of stored water translates into at least 0.15 t/ha of canola grain if in-crop rainfall is between 160–270 mm, according to APSIM modelling for dryland crops at Forbes, NSW. However, the relationship is weaker in drier or wetter years.

Table 3a.2.1: Median sowing date and yield for 197 irrigated canola crops in the Riverina and northern Victoria from 1991–2003, based on maturity type. The data are benchmarked for the top 20% crops (highest yielding), average crops and the bottom 20% crops (lowest yielding).

Variety maturity	top 20%		middle 20%		bottom 20%		All crops
	Sowing date	Yield (t/ha)	Sowing date	Yield (t/ha)	Sowing date	Yield (t/ha)	
Early	17 April	3.0 (20%) ^a	24 April	2.4 (5%)	1 May ^b	1.2 (1%)	2.8
Early-mid	na	na (0%)	16 April	2.4 (5%)	18 April	0.9 (10%)	2.0
Mid	25 April	3.0 (68%)	7 May	2.3 (66%)	6 May	1.1 (65%)	2.3
Mid-late	22 April	3.0 (8%)	28 April	2.2 (16%)	20 April	1.4 (18%)	2.2
Late	na	na (0%)	20 April ^b	2.3 (1%)	na	na (0%)	2.3
All crops	25 April	3.0 (100%)	5 May	2.2 (100%)	4 May (100%)	1.2 (100%)	2 May, 2.3

^a The figure in brackets after each yield value indicates the percentage of crops within the category.

^b Indicates small dataset, so view these figures with caution. Source of raw data: NSW DPI Cropcheck.

The number of crops in the database: Finley (127), Coleambally (35), un-named (13), Yanco (8), Kerang (5), Cobram (3), Deniliquin (2), Griffith (2), Hay (1).



Variety selection

Trials in south-east Australia showed that 8%–19% of variation in yield came from variety choice. The best approach for selecting a canola variety is to stick to proven varieties, and try new varieties on a smaller scale. Go to <http://www.nvtonline.com.au/home.htm> for national variety trial data for dryland canola.

Matching maturity type to irrigation timing and sowing date

Mid-season varieties are generally the best option in a normal year in northern Victoria. In regions which experience more hot days post-flowering (e.g. Murrumbidgee Valley), early-mid and mid-season varieties are normally preferred. This year, early maturing varieties are probably a better option in lower rainfall areas (< 350 mm), if water allocation is not assured for spring.

Figure 3a.2.1. The old message to grow canola in the best wheat paddock still holds true. Also particularly this year, consider herbicide residues following the drought, and strictly adhere to minimum re-cropping periods as there will be no room for error.



Maturity type needs to be matched to sowing date. For example, earlier maturing varieties cope better with late sowing than late maturing varieties. If timely sowing is not possible this year, choose an early-mid variety if sowing in early May, or an early variety if sowing beyond early May in southern NSW.

TT yield penalty and hybrid vigour

Triazine tolerant varieties are inherently lower yielding than CLEARFIELD® or conventional varieties with yields only 77%–89% of the non TT types (Table 3a.2.2). These varieties should only be used when the weed population necessitates their use, or when triazine residues from the previous year (e.g. sometimes after maize) limits the cropping options.

Lodging

Some varieties are more prone to lodging under irrigation than others. Lodging is influenced by sowing date, establishment rate and up-front nitrogen levels. High plant populations, sown early with lots of nitrogen result in huge biomass, which often leads to lodging.

Disease resistance

The risk of blackleg is still an issue this year. All varieties have a blackleg resistance rating of four or more this year, which is the minimum for low rainfall areas. The minimum is six for other areas. Refer to the Australian Blackleg Management Guide. Go to http://www.australianoilseeds.com/commodity_groups/canola_association_of_australia/pests_and_disease

Figure 3a.2.2. This year, consider reducing nitrogen inputs at the start of the season to levels required for a dryland crop, and then topdress between the six-leaf stage and stem elongation if the crop is going to finish well. (photo: John Lacy).



Table 3a.2.2. Summary of canola yields at the Victorian DPI Kerang irrigated trial site, with estimated mean yields from 2003 to 2006.

Variety	Year of release	Maturity	Type	Years of data	Overall yield	% yield AVSapphire	Lodging 2003	Lodging 2005
RT125	2007	Mid	Conventional	2	3.10	102		
Pioneer® 44C11	2004	Early	Conventional	1	3.06	101		
^{AV} Sapphire	2003	Mid	Conventional	4	3.03	100	9	
Hyola 75	2006	Mid-late	Conventional hybrid		1	3.02	99	
^{AG} Drover	2004	Mid	Conventional	2	2.97	98		8
Skipton	2004	Mid	Conventional	4	2.92	96	3	6
^{AV} Ruby	2006	Mid	Conventional	4	2.90	96	2	8
Pioneer® 46C04	2003	Mid	Conventional	4	2.89	95		
Warrior CL	2006	Mid	Clearfield	1	2.88	95		
Hyola 60	2001	Mid	Conventional hybrid	3	2.88	95	7	8
Rainbow	1993	Mid	Conventional	2	2.88	95	5	
Pioneer® 45Y77	2006	Early	Clearfield	1	2.83	93		
Pioneer® 46C76	2004	Mid-late	Clearfield	3	2.83	93		3
^{AG} Spectrum	2004	Early-mid	Conventional	3	2.80	92	7	9
Lantern	2002	Mid	Conventional	2	2.78	92	4	
^{AV} Jade	2006	Early-mid	Conventional	4	2.77	91	6	9
^{AG} Castle	2002	Mid-late	Conventional	2	2.76	91	8	
Hyola 61	2004	Mid	Conventional hybrid	1	2.75	91	5	9
NMC 131	2007	Mid	Specialty	1	2.74	90		
Thunder TT	2005	Mid-late	Triazine tolerant	2	2.70	89		7
^{ATR} Summitt	2006	Mid	Triazine tolerant	1	2.64	87		
Pioneer® 45C05	2003	Early-mid	Conventional	2	2.64	87	4	
Charlton	1998	Mid-late	Conventional	2	2.61	86	3	
MC202	2004	Mid-late	Specialty	2	2.59	85	3	
Surpass 603 CL	2001	Mid	Clearfield	4	2.59	85		
^{ATR} Grace	2001	Mid-late	Triazine tolerant	2	2.55	84	7	9
Rocket CL	2005	Mid-late	Clearfield	1	2.51	83		
^{ATR} 409	2007	Early	Triazine tolerant	2	2.45	80		
Bravo TT	2005	Early-mid	Triazine tolerant	2	2.40	79	7	
Tornado TT	2004	Mid	Triazine tolerant	2	2.38	79	6	
^{ATR} Beacon	2002	Early-mid	Triazine tolerant	2	2.35	77		

* Lodging is scored subjectively: 0 = horizontal, 9 = vertical. Minimal lodging in 2002 and 2006, Data unavailable for 2004.



Dry sowing

Dry sowing has its risks, but experience from growers in Victoria in recent years has shown that with late breaks dry-sown crops have generally performed much better than crops sown later on cultivated soil. However, dry sowing with no subsoil moisture is a very risky proposition if irrigation water is not assured for spring.

Dry sowing is not recommended in NSW irrigation areas.

Paddock selection

The old message to grow canola in the best wheat paddock still holds true. Also consider herbicide residues following the drought, and strictly adhere to minimum re-cropping periods as there will be no room for error this year.

Figure 3a.2.3. Water deficit stress during flowering can halve canola yields. Where only one watering is possible in 2007, an option is to sow canola if there is a good, early autumn break and irrigate at early flowering.



Irrigation management

For irrigators with no water allocation in low rainfall areas, canola can be an opportunistic dryland crop. This should only be considered if a good, early autumn break takes place and there is good subsoil moisture at sowing.

Drought stress

Water deficit stress during flowering can halve canola yields.

Where only one watering is possible this year, one option is to sow canola if there is a good, early autumn break and irrigate by early flowering or as soon as water becomes available. If it is another dry season, it may be cost effective to use the water on other crops and cut the canola crop for hay.

In areas with more reliable spring rainfall, the other option is to pre-irrigate or water-up (on soils that do not crust), sow on time, and treat the crop as a dryland crop. It has been suggested that pre-irrigation is only cost effective if water is less than \$100/ML.

Waterlogging

One of the main limitations to high yields on irrigation is waterlogging in winter and early spring. Further information on irrigation layout and management can be found in the article 'Is there a place for canola on irrigation?' in the IREC Farmers' Newsletter, No. 172, Autumn 2006, pp 12–15; or on the IREC website www.irec.org.au/farmer_f/pdf_172/Canola%20on%20irrigation.pdf

Reducing the up-front costs of canola

Managing costs without compromising profitability is important. Benchmarking of 29 canola crops by consulting firm Holmes and Sackett (mainly in NSW, but also Victoria and Tasmania) found that the most profitable and water-use efficient canola crops actually had lower variable costs (but higher fixed costs), and vice-versa.

Nutrition

Nutrient inputs need to be tailored to target yield.

Fertiliser, particularly nitrogen, is the biggest single variable cost for canola and carries with it financial risk if the season shapes up poorly.

Roughly 40 kg/ha of nitrogen is removed per tonne of grain, and the rough 'rule of thumb' is that the crop needs 80 kg N/ha to produce one tonne of grain.

This year, nitrogen inputs at the start of the season can be reduced to levels required for a dryland crop. Dryland trials in NSW and Bendigo have shown that delaying or splitting nitrogen fertiliser applications usually has no yield penalty associated with it when there is at least 40 kg N/ha in the top 50 cm at sowing time.

One strategy for irrigation is to apply starter nitrogen (e.g. 22 kg N/ha as 125 kg/ha DAP), if there is a reasonable soil nitrogen level (e.g. 60–70 kg N/ha). The crop can be topdressed to make up the required amount of nitrogen (assuming 80 kg of nitrogen per tonne of grain targeted).

A realistic target yield is needed, and deep soil tests should be undertaken as close as possible to sowing time. Splitting the nitrogen applications allows growers to re-assess target yields throughout the growing season and removes some of the risk involved in growing canola.

Topdressing is best conducted between the six-leaf stage and stem elongation.

Unlike nitrogen, there is no room for error with phosphorus, as it needs to be applied up-front. But there may be certain situations where phosphorus rates may be reduced this year.

Gypsum applications can be deferred this year, unless it is the only source of sulfur.

Fungicide seed treatments

Responses to fungicides are much less likely with blackleg resistant varieties. In southern NSW, responses to fungicides are more common than in Victoria, but are far less marked in resistant varieties.

Figure 3a.2.4. Seed from 2006 should be germination tested. Dryland trials have shown an average 12% yield decline with poor-quality retained seed when the crop suffered from a dry finish. Yields of crops sown with certified seed are more consistent.



Sowing rates – are we throwing away money?

Plant densities of 40–50 plants/m² are considered ideal for irrigated canola to prevent lodging. However, plants densities of late-sown crops can be up to 75 plants/m² without yield loss. Early sown crops can compensate better for low plant populations than late-sown crops.

Twenty per cent of irrigated canola crops in the Cropcheck database had more than 75 plants/m². (As a general rule 1 kg/ha of seed produces 25 plants/m²). More than half of these growers sowed canola at 5 kg/ha or more, but 3–4 kg/ha is now considered sufficient. The better the paddock preparation, the lower the required sowing rate. For example, where there is a good seedbed and ample moisture, 3 kg/ha is possible. On cloddy soils with marginal moisture, a sowing rate of 5 kg/ha may be necessary. Some dryland no-till farmers in the Victorian Wimmera have successfully reduced sowing rates to 1–2 kg/ha, apparently without penalty.

Retaining seed may be false economy

Seed from 2006 should be germination tested before sowing. Sowing retained seed is not generally recommended. Dryland trials have shown an average 12% yield decline with poor-quality retained seed (and in one case, complete crop failure) when the crop suffered from a dry finish. Yields of crops sown with certified seed are more consistent.

Price outlook

The price outlook for Australian canola is strong in the short-term due to the drought (\$90/t above average). The price will remain buoyant in the medium to long term due to strong demand for biofuels which is resulting in an increased area of corn at the expense of soybeans in the US.

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3a.3 Is there a place for canola on irrigation?

Don McCaffery

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Information sourced from IREC Farmers' Newsletter, No. 172, Autumn 2006

Key points

- Canola is a viable winter rotation crop option under irrigation but yield and profitability must improve for it to have a regular place in the rotation.
- Consistent high canola yields depend on a package approach to the agronomy of the crop – the key agronomy steps must be 'done right'.
- Paddock selection, nutrition management and water management are the most important management factors.

It is fair to say that irrigators do not value canola as a rotation crop as much as dryland farmers do, and the reasons are obvious – irrigators have more rotation break crop options including a variety of summer crops such as rice, maize and soybeans.

Currently there are about 8000 ha of irrigated canola in southern NSW, yet there is potential to increase this area to between 16 000 and 20 000 ha, if the crop can be grown profitably and can demonstrate a clear benefit to following wheat crops.

Benefits of canola in irrigated rotations

An analysis of all dryland research trials in southern NSW shows an average benefit of 20% higher yield in the following wheat crop, and in some cases, a 12% higher yield in the second year of wheat. This benefit was mainly due to canola providing a break crop, reducing the incidence of cereal root diseases such as take-all, crown rot and common root rot.

Similar wheat yield increases, whilst not measured in research plots, have been recorded by experienced irrigated canola growers. In addition, canola makes the soil 'softer' and easier to cultivate or direct sow a subsequent wheat crop, and improves soil structure when grown as the first crop after landforming, more so on the better structured

selfmulching soils. Be aware that disappointing results may occur on poorly structured red soils after landforming, especially without deep tillage, and the use of additives such as poultry manure, and gypsum where soils are sodic.

There may be other situations where canola could be the best winter crop option, depending on the weed spectrum and possible herbicide residue issues, e.g. high rates of atrazine used in maize. Weeds such as wild radish (spreading on irrigation), Paterson's curse and shepherds purse can be controlled by selecting a triazine tolerant (TT) canola variety and applying the appropriate herbicide. The use of Primextra® Gold (active ingredients atrazine and S-metolachlor) in maize allows wheat to be double-cropped, but in some weed circumstances high rates of atrazine may be needed, restricting the following double crop to TT canola.

2005 season in review

Last season was good for canola, with mild spring temperatures during flowering and pod-fill enhancing yield potential and oil contents. Timely rain also reduced irrigation requirements, and any potential waterlogging on flood irrigated layouts that cannot be drained in less than 12 hours.

A Coleambally crop grown on a border check layout achieved a yield of 345 t/ha in 2005, whilst a Carrothool crop yielded 3–9 t/ha on raised beds, using the agronomic recipe for high yields, outlined at the Griffith GRDC Update in July 2004. This proves again that canola can achieve high yields under irrigated conditions if the correct agronomy is applied to the crop. In saying this, canola is helped to big yields when spring temperatures are below average and there are no high temperature spikes during flowering to early pod-fill. Canola is not as tough as wheat under hot spring temperatures.

Bottom line

Despite claiming a net financial benefit to a following wheat crop in the order of 20% higher yield or 1.2 t/ha for a 6 t/ha wheat crop, or in dollar terms \$180/ha (wheat valued at \$150/t), can canola be profitable in its own right? Figure 3a.3.1 uses canola yields from the mid 1990s Murrumbidgee Valley *Canolacheck* data, but puts into the gross margin calculation the 2005 season growing costs of \$600/ha and price of canola of \$320/t on-farm. The 1994 data set was selected as being representative of a period when high yields were consistently achieved over a three year period, 1994–96.

For a yield of 3.5 t/ha, the gross margin last year was about \$500/ha (based on a \$320/t) and still profitable. In 1994 the gross margin for a 3.5 t/ha crop was \$700–850/ha. The average price of canola in 1994 was \$355/t on-farm, with growing costs of \$433/ha. Add \$180/ha to the \$500/ha for the additional wheat yield due to a preceding canola crop, and the figures make canola even more important to the farm rotation gross margin.

Gross margins need to be developed for each specific paddock as costs will vary. In 1994 the growing costs ranged from \$278–580/ha.

When developing individual paddock gross margins a realistic yield target should be set no higher than 10% above the average yield of the last three canola crops or 50% of achievable wheat yield for the paddock.

Management for consistent high yields

To achieve consistent high canola yields, agronomy has to be implemented as a package. Following is a discussion of some of the key agronomy issues that must be 'got right' to make canola profitable.

Paddock selection

This is one of the most crucial of all decisions to get right. Select your best wheat paddock for canola. As a guide canola should yield 50–55% of wheat, i.e. paddocks yielding

7 t/ha of wheat should be able to grow a 3.5 t/ha crop of canola. If this cannot be achieved, investigations need to find out why.

Ensure that soil structure is good. Self-mulching soils perform the best. Eliminate any subsoil constraints such as plough pans with deep tillage. Soil pH preferably should be above 5.0 (CaCl_2) and any liming carried out the season before the crop is grown.

Crop nutrition

Canola has a higher nitrogen (N), phosphorus (P) and sulfur (S) requirement compared with wheat. Canola needs 40–50 kg N, 10 kg P and 10 kg S to produce each tonne of grain. It is important to note that these are the nutrient requirements of the crop, not the amount of nutrient removed in the grain. Table 3a.3.1 shows the nutrient demand for different yield targets. Only apply micronutrients if soil tests are backed up by field experimentation.

Figure 3a.3.1. Yield/gross margin comparison for the Murrumbidgee Valley – mid 1990s yields with 2005 growing costs and grain prices

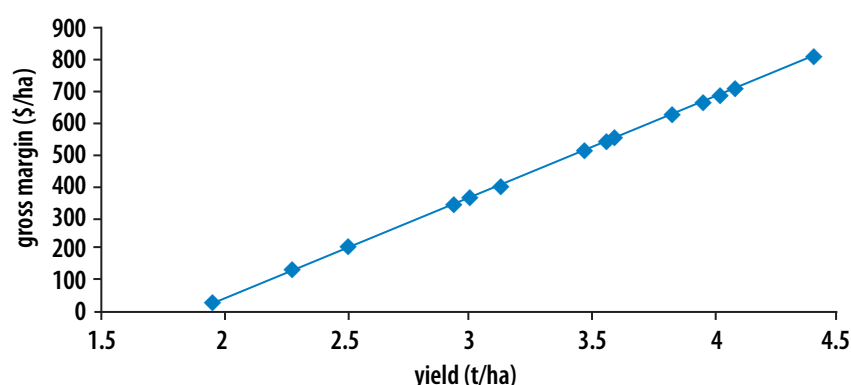


Table 3a.3.1. Canola nutrient requirement for four yield targets

Target Yield	2.5 t/ha	3.0 t/ha	3.5 t/ha	4.0 t/ha
Nitrogen kg N/ha	100–125	120–150	140–175	160–200
Phosphorus kg P/ha	25	30	35	40
Sulfur kg S/ha	25	30	35	40



Nutritional requirements are met by a combination of applied fertiliser and supply from the soil itself. Murrumbidgee Valley *Canolacheck* data 1994–1996, showed the highest yielding crops (3.5–4.2 t/ha) received about 140–160 kg N/ha, 35–50 kg P/ha. and 40–50 kg S/ha.

Nitrogen timing is always a subject of debate and needs to allow for the characteristics of the variety (crop height and lodging propensity), sowing time and the underlying fertility of the paddock. A Deep Soil Nitrogen Test is a useful tool in determining background nitrogen fertility. It is more accurate than paddock history 'guesstimates' but is probably best used in conjunction with paddock history to determine nitrogen rates and timing strategies.

Banding all the nitrogen requirements as anhydrous ammonia has been used successfully in the past as nitrogen is released slower than it is from solid fertilisers such as urea, which theoretically produces less cabbage growth by budding. Topdressing is still very economic in most situations. To balance risk, a general rule of thumb is to apply about 60% of total nitrogen requirements before or at sowing. This will ensure adequate cabbage

growth by budding, when the yield potential can be better assessed and the remainder of the nitrogen can be topdressed at an appropriate rate.

Nitrogen test strips applied at or before sowing can assist topdressing decisions as well help refine future timing strategies.

Irrigation layout and management

Farmer results show that canola grown on beds will yield on average about 20% better than on border check and terraced contour layouts. Top irrigators who are in tune with crop requirements have been able to reduce this difference to about 10–15% (Figure 3a.3.2). Overhead sprinkler irrigation offers a number of advantages over flood systems including timely sowing because 25 mm can be applied to the seedbed and the crop sown within a few days. As water is applied like a normal rain event, there is no deep drainage loss {below the root zone} as there is when flood irrigating.

Water can be applied closer to when it is actually needed. This improves water use efficiency by reducing waterlogging potential, and maintaining yield using less water.

Spring irrigation of canola is needed earlier than for wheat, so unless there has been substantial rainfall to fill the root zone, irrigate as soon as water becomes available. The crop uses water at a faster rate than wheat during August because of its more advanced development (i.e. earlier flowering). Any waterlogging at this time has less effect on yield compared with during pod-fill, when temperatures are much warmer, increasing the risk of 'cooking' the crop.

Be prepared to irrigate to the target yield. This first spring irrigation is the most important as growth achieved at this time has the biggest influence on yield. It is important to get water on and off the bay within 12 hours. On flat layouts, high flow rates (15–20 ML per day) may be required. Crops grown on raised beds will not lose yield potential with slower watering times, with 12–18 hours being acceptable because drainage is better.

For very high yielding crops, spring water use could be as high as 4 ML/ha. An achievable Water Use Efficiency target for canola is 8–10 kg/ha/mm, i.e. for each mm of growing season water (rain and irrigation). This calculation uses an irrigation efficiency factor of about 80% which is a fair figure for a good flood irrigated layout.

Figure 3a.3.2. Canola grown on border check (left) can yield 85%–90% of canola grown on raised beds (right) with good irrigation layout and careful management.



Other key management points to consider

Varieties

The three major issues in selecting a canola variety for irrigation are:

- the planned sowing time
- the maturity of the variety
- the lodging risk during spring irrigation.

Mid-maturing or mid- to late-maturing varieties are best suited to late April sowings. Early- to mid-maturing varieties are best suited to early May sowing. Early-maturing varieties are best suited to sowing from early to mid May. This order of maturities reduces the risk of flowering and pod-fill taking place in high temperatures and also manages the risk of possible frost damage during pod-fill (Figure 3a.3.3).

There are other factors such as yield, oil content, blackleg resistance and herbicide tolerance that should be considered.

Establishment

Target a plant population of 40–75 plants/m² by sowing 3–4 kg/ha in late April/early May.

Figure 3a.3.3. Early-maturing varieties (left) suit later sowings (early to mid-May) and mid-maturing varieties are suited to earlier sowings (late April to early May), to ensure flowering and pod-fill occur at the most suitable times of the season.



Higher seeding rates are not needed unless establishment losses are anticipated.

Sow at a shallow depth into a firm seedbed and water up the crop with high flow rates. If sowing into dry soil, rolling before sowing will firm the seedbed. Do not chase moisture when sowing canola, especially where there is a risk of the soil slaking, dispersing, setting hard or slumping if heavy rain falls within 10 to 14 days of sowing.

Pest management

Earth mites are the major establishment pest of canola but the risk is often less in the irrigation areas than in dryland areas as most canola does not follow a pasture phase. However, preventative measures are recommended and are cheap insurance. Ensure seed is treated with Gaucho® (active ingredient imidacloprid) to protect the seedling crop from aphids as the warm, dry conditions of the southern irrigation areas is conducive to high aphid pressure. Gaucho is also registered for earth mite control but should not be relied on as the sole control method.

Canola's place in irrigation

Canola is a viable winter rotation crop option under irrigation, but yield and profitability must improve for it to have a recognised place in farmers' rotation planning. In northern NSW, canola has been described by some as a 'fair weather friend'. Whilst this may have an element of truth for the irrigation areas, how many irrigators are making money out of irrigated wheat and barley, and especially when springs are tough?

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Further information

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3a.4 Soybean trials in northern Victoria and the Riverina

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Irrigated Cropping Forum, Horsham

Luke Gaynor
NSW DPI, Wagga Wagga

Dale Grey
Vic DPI, Cobram

Information sourced from IREC Farmers' Newsletter,
No. 173, Spring 2006

Key points

- Trial results in 2005–06 and averages over the last five years show Djakal to be the top-performing soybean variety in northern Victoria and the Riverina
- The variety Snowy released in 2005 also performed well, and together with Djakal these varieties are proving to be higher yielding and have better end-use quality than older varieties, and their quicker maturity means they use less water
- Another trial in 2005–06 showed that row spacing and choice of variety can have a major effect on irrigated soybean yields, with the research indicating that significant yield gains can be achieved through the use of narrow rows.

The area planted to soybeans in southern NSW more than doubled from 1570 ha in 2004–05 to 3650 ha in 2005–06, averaging an estimated 3.3 t/ha, with top yields of 4.6 t/ha.

The main varieties grown in 2005–06 were Djakal and Snowy, which are higher yielding and of better end-use quality than older varieties due to their larger seed size, higher protein and tofu-making qualities. These varieties are also faster maturing, making them more suitable to double-cropping programs. In addition, many growers have found that due to the earlier maturity of Djakal and Snowy, these varieties generally require one less watering and are therefore more water use efficient. Snowy is considered premium quality for export markets, in particular the tofu market.

The following information summarises some of the results from the research into soybean breeding and agronomy in northern Victoria and the Riverina.

field trials up to the advanced replicated regional trials and newly-released varieties from the National Soybean Improvement Program. All varieties/lines included in the trials were culinary types, except Stephens, which is a black-hilum crushing variety.

Trial details

In northern Victoria, breeding lines were replicated three times in randomised complete blocks at sites at Katandra and Corop. In southern NSW at Leeton and Coleambally, lines were replicated four times in randomised complete block designs. Advanced lines were also tested across a range of sowing dates, from early, ideal and late planting dates.

Details of the trial site and the management at each site are given in Table 3a.4.1.

Figure 3a.4.1: Luke Gaynor, NSW DPI and Jim Maskus, Whitton, harvesting Djakal soybeans near Leeton in April 2006.



Soybean evaluation trials

A range of varieties and advanced breeding lines of soybeans was evaluated in four trials across northern Victoria and the Riverina in the 2005–06 season. The trials were conducted to evaluate newly-crossed breeding lines from first generation

Table 3a.4.1. 2005–06 trial site details

Coordinator Site Cooperator	Luke Gaynor, NSW DPI		Dale Grey, Vic DPI	
	Coleambally Bellato	Leeton NSW DPI	Katandra Tige Gardner	Corop Geoff Spencer
Sowing date	14 November	25 November 23 December	15 November	1 December
Soil type	Gregy self-mulching clay	Grey self-mulching clay	Red loam	Grey self-mulching clay
In-crop rainfall (mm)	NA	42 mm	118 mm	96 mm
Irrigation (ML)	8	8	7	6.5
Method	Raised beds (1.83 m)	Raised beds (1.83 m)	Border check	Drip irrigated beds
No. irrigations		10	9	10
Harvest	27 March	12 April	12 April	20 April
Fertiliser		250 kg legume starter	40 kg P/ha as single super	25 kg P/ha as single super
Previous winter crop	Fallow	Fallow	Oaten-vetch Hay	Fallow
Previous summer crop	Soybeans	Fallow	Maize	Tomatoes

Table 3a.4.2. Off-header yields (t/ha) for Victoria, and seed-graded yields (t/ha) for southern NSW of soybean varieties and selected advanced breeding lines for 2005–06 harvest

Variety/ line	Katandra	Coleambally	Leeton Nov sown	Leeton Dec sown	Variety mean	Corop*
Djakal	5.04	3.35	3.99	3.95	4.08	3.21
Snowy	4.46	2.72	3.44	3.68	3.58	2.60
99091A-4	4.55	2.95	3.50	3.39	3.60	3.29
F190-6	4.30	2.84	3.55	3.69	3.60	*
F148-3	4.58	2.95	3.42	3.64	3.65	*
Stephens	4.97	2.90	3.32	3.65	3.71	*
F147-5	4.52	2.90	3.43	3.74	3.65	*
Empyle	4.04	2.91	3.57	3.81	3.58	3.13
F148-4	4.65	2.75	3.34	3.80	3.64	3.46
Curringa	3.85	2.52	3.17	3.52	3.27	3.29
96248-23	4.13	2.47	3.06	3.21	3.22	3.16
Bowyer	3.17	2.35	2.97	3.67	3.04	*
Site mean	4.36	2.80	3.40	3.65	3.55	

*Corop data analysed separately, using ANOVA. All other data analysed with AS-REML.

Table 3a.4.3. Number of days from sowing to physiological maturity (P95) at Leeton (two sowing dates), Coleambally and Katandra in 2005–06

Variety/line	Leeton Nov sown	Leeton Dec sown	Coleambally	Katandra
Bowyer	127	121	128	*
Curringa	126	118	127	134
Snowy	123	103	120	134
Empyle	121	103	118	132
96248-23	118	99	114	128
Djakal	117	99	112	129
Site mean	122	107	120	132

2005–06 yields

The yield results for the trials are given in Table 3a.4.2 and maturity (days from sowing to physiological maturity) for each of the tested varieties/lines is given in Table 3a.4.3.

Long-term yields for both regions

Long-term data (Table 3a.4.4) were based on trial results from the northern Victorian sites for five trials from 2001–02 until 2005–06 at Congupna and Katamatite. In the Riverina, long-term data were derived from 12 trials from Leeton (two sowing dates) and Coleambally from 2003–04 until 2005–06.

The long-term data show that Djakal is the highest yielding variety, followed by Empyle and Snowy. The newer varieties such as Snowy and Djakal, which tend to be faster maturing, have consistently and significantly out yielded older varieties such as Stephens, Curringa and Bowyer, especially in the Riverina.



What does the long-term data mean?

Djakal remains the top-performing variety, with very robust yields across all conditions and a range of sowing dates over a number of years (Table 3a.4.2). It is very well suited to double cropping because of its fast maturity, high yields and very quick dry-down finish.

Djakal and the recent new release Snowy, have lifted the yield potential of the culinary-type soybeans. Generally Djakal and Snowy's yields are very similar and not significantly different. Further, the varieties are more water use efficient as they produce higher yields and may require one less watering than the older, later maturing varieties. However, Snowy is slightly later maturing than Djakal (Table 3a.4.3).

Snowy and Djakal have the potential to fit into both the premium culinary and the crushing markets. Snowy is the first clear hilum variety, and is highly desirable for export markets.

The two new varieties have different genetic backgrounds for resistance to the disease *Phytophthora* root rot. Where two soybean crops are grown in succession and there is a history of *phytophthora* present in the farm/area, Snowy and Djakal can be rotated as a disease management strategy.

Table 3a.4.4. Long-term mean yields of soybean varieties and advanced breeding lines for Victoria (2001–02 to 2005–06) (off-header yields) and Riverina (2003–04 to 2005–06) (seed graded yields)

Variety	Year of release	Northern Victoria	Riverina	Variety mean
Djakal	2001	3.91	3.97	3.95
Snowy	2005	3.39	3.52	3.48
Empyle	2001	3.56	3.54	3.55
96248-23	To be released	3.01	3.08	3.06
Stephens	1987	3.15	3.44	3.35
Curringa	1999	2.84	3.28	3.15
Bowyer	1982	2.81	3.00	2.94
Site	mean	3.24	3.40	3.36
No. trials		5	12	

Figure 3a.4.2. (a) Djakal (buff hilum), (b) Snowy soybeans (clear hilum) and (c) an older variety, Banjelong (dark hilum).



Soybean row spacing by plant density trial

In the Riverina, soybeans are commonly sown in wide rows, with two rows per 1.8 m raised bed. However, in northern Victoria, soybeans are usually sown in more narrow rows (17–20 cm) on border check layout. Both methods allow growers in each district to use conventional winter cropping equipment for sowing.

Past research has found that row spacing can have a major impact on yields of irrigated soybeans, while the effect of plant density has been inconsistent. Narrower row spacing can be used as a part of an integrated weed management strategy.

The trial was conducted to see which row spacings and plant densities produce the highest yields and optimum grain size on irrigated border check soybeans in northern Victoria.

Trial description

The varieties Djakal and Snowy and the advanced breeding line 96248-23 were sown at rates to give targeted plant densities of 40 plants/m² and 60 plants/m², at 35 cm and 70 cm row spacing at the Katandra site (see Table 3a.4.1 for site details). The actual

average plant densities achieved were 33 and 49 plants/m² for Djakal, 31 and 45 plants/m² for Snowy, and 39 and 59 plants/m² for 96246-23, and are cited as approximately 35 and 50 plants/m². Variations in water use were not measured.

Results

Wider row spacing reduced yields by 12% in the trial. Highest yields were achieved with narrower row spacings for all varieties. In addition, the narrower row spacings were observed to have fewer weeds and faster canopy closure.

On average across all treatments, Djakal yielded 10% more than Snowy and 20% more than 96246-23. Plant density did not affect yields (Table 3a.4.5).

What do the results mean?

This trial shows that row spacing and the choice of variety can have a major effect on irrigated soybean yields.

This research has indicated that significant yield gains can be achieved through the use of narrow rows. Wider rows are used in southern NSW to allow for row cropping techniques and the use of existing machinery. This includes

precision planters (which help guarantee correct plant densities), and the use of inter-row cultivators and sprayers for weed control, which are used for other crops such as cotton and maize. Soybean growers in the Riverina should seriously consider the benefits and disadvantages of changing their sowing methods.

Row spacing has a considerable effect on yields because it is related to the crop's ability to capture sunlight and accumulate leaf area (biomass), which in turn, leads to grain production (when other factors like water are not limiting).

Previous research in Australia and the United States of America has shown that in the early growth stages, of a soybean crop, light interception is related to the proportion of ground covered by the crop's leaf canopy. Closer row spacing improves the crop's light interception. The results of this trial are consistent with past research in Queensland which showed that closer spacing of soybeans led to faster development of leaf area/biomass, but higher water use. In an irrigated situation, this has led to higher yields.

Table 3a.4.5. Effect of row spacings and approximate plant density on yields (t/ha) of three soybean varieties/lines

Row spacing	35 cm		35 cm row mean	70 cm		70 cm row mean	Variety mean
Plant density (plants/m ²)	35	50		35	50		
Djakal	5.09	5.25		3.98	3.96		4.57
Snowy	4.58	4.72		3.51	3.57		4.10
96246-23	4.09	4.29		2.97	3.33		3.67
Treatment mean	4.59	4.75	4.67	3.49	3.62	3.55	4.11

LSD (comparing widths) = 0.24; LSD (comparing varieties) = 0.29; LSD for plant density and all interactions were not significant. Data analysed by ANOVA.



Although row spacing affected yields in this trial, plant density did not. Similarly, other research has also shown that although higher plant densities of grain legumes increased crop growth rates and water use, this did not result in better yields. This was probably due to competition between plants within a row for, nutrients and light, and possibly water. However, it appears more local research is needed on the topic, as other work in the USA has found that soybean yields could be lifted by increasing plant populations when sowing in narrow rows in both irrigated and rain-fed crops (except where lodging occurs).

Further research is currently being undertaken to study the effect of the spatial arrangement of soybeans on biomass and yields, using a range of sowing dates. This may help overcome yield penalties associated with late sowing. However, at this stage, it is advised to sow soybeans on time in the ideal window for the region to achieve maximum yields. This work is currently in progress in southern NSW at NSW DPI Leeton

Figure 3a.4.3: Whitton grower Wayne Williams in crop of Snowy soybeans, April 2006



Field Station, in collaboration with CSIRO and James Cook University. Results are unavailable at time of writing.

One of the trial's aims was to determine the effects of plant density and row spacing on grain size, but at the time of writing, quality data from the trial are unavailable. In a similar trial undertaken by the Victorian DPI in 2003–04, grain size was unaffected by row spacing. Similarly, Queensland research has found that wider plant spacing reduces the number of pods per plant of irrigated soybeans, more than increasing the grain size.

Soybean outlook – markets and research

As export markets develop, and if the Japanese yen strengthens, growers are likely to benefit from the greater demand and prices for the light hilum varieties Djakal and Snowy. In addition, a return to normal levels of production this season will further improve the price of soybeans in the Riverina and northern Victoria.

The soybean breeding program will continue in 2006–07 in the Riverina through the NSW DPI, and variety demonstrations will also be undertaken in northern Victoria.

The trial to evaluate the effects of variety, plant density, row spacing, sowing date, and their interactions will also continue this season at Leeton Field Station.

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3a.5 Irrigated soybeans: maximising yields and whole farm profitability

Luke Gaynor

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Information sourced from 2005, Grains Research & Development Corporation, Research Update for Growers, Griffith

Key points

- Achieving a good, solid and even plant stand with the correct plant population is the cornerstone of a high yielding crop.
- Timing irrigations to meet plant moisture needs is critical for high yields.
- Newer, shorter season, high yielding varieties suited to the culinary market produced by National Soybean Improvement Program (funded by Grains Research & Development Corporation) offer new opportunities to increase returns per megalitre and improve the competitiveness of soybeans against other summer crops.
- Shorter season soybean varieties can potentially increase overall returns when incorporated into a double cropping system which fully uses sub-soil moisture and nutrients left by the previous crop.

Introduction

Soybeans have been grown in southern NSW and northern Victoria since the late 1960s and early 1970s. They have been a profitable crop for irrigated farming systems in the Riverina, particularly where the crop attains quality standards for human consumption markets. Significant premiums are paid for soybeans suitable for these markets making the crop more attractive when high yields are achieved.

The planting area in the Riverina (Murrumbidgee and Murray Valleys) has fluctuated from 11 700 ha in 1993–94 to as little as 2000 ha in recent years. The decline is primarily the result of reduced availability of irrigation water. Although soybeans can be a water use efficient and profitable crop, water is in strong demand and competing with other crops such as rice, maize and wheat. This makes the profitability and gross margins of the irrigation water high on the priority list for all growers and potential growers.

Soybeans can be used as a single cropping rotation or in an intensive double-cropping system with winter cereals. New, shorter season, high-yielding varieties suited to the culinary market produced by Grains Research & Development Corporation (GRDC) funded National Soybean Improvement Program

(NSIP) offer new opportunities to increase returns per megalitre (ML) and the competitiveness of soybeans against other summer crops. Shorter season soybean varieties can potentially increase overall returns when incorporated into a double-cropping system which fully uses sub-soil moisture and nutrients left by the previous crop.

Profitability and returns per megalitre of water in a double-cropping system are very attractive and favourable to the grower. Human consumption varieties such as Djakal and Snowy are excellent examples of high-yielding, shorter season, culinary soybeans. Rotations such as soybean-barley-soybean-biscuit wheat, can lift water use efficiencies (WUE) and gross margins per megalitre (Gross Margin/ML) by hundreds of dollars a hectare and out-compete most other summer crop rotations.

Several key strategies and techniques are necessary to set up the crop for maximum yield, WUE and profitability. Thorough planning cannot be over emphasised prior to the planting of any seed or the running of any water.

Varietal selection

A preferred variety should be selected according to location, disease resistance, maturity, yield potential and suitability for the target market. Recommendations (Table 3a.5.1) are based on extensive and on-going testing (updated yearly in NSW DPI Planting Guides – available www.dpi.nsw.gov.au or from NSW DPI Offices) of new and existing varieties.

New short-season varieties such as Djakal and Snowy are high yielding, culinary types that are well adapted to southern NSW. New light-hilum varieties have equal or more yield than older existing black-hilum varieties (e.g. Arunta and Stephens). Growers have two options for the soybean markets, human consumption and/or crushing markets. Black-hilum varieties are only suited to the lower priced crushing market, while light hilums are suitable to both. However, human consumption markets attract a premium price compared to crushing markets.

Table 3a.5.1. Southern NSW and northern Victoria adapted varieties (yield t/ha)

Location	Preferred varieties		Suitable varieties	
Murrumbidgee and Murray Valleys	Djakal ¹ (4.0)	Curringa ¹ (3.2)	Empyle ¹ (3.59)	Stephens ²
	Snowy ¹ (3.8)	Arunta ²	Bowyer ¹ (3.06)	
Lachlan Valley	Snowy ¹	Valiant ²	Hale ²	Banjalong ²
	Djakal ¹	Curringa ¹	Bowyer ¹	

¹ Light hilum varieties preferred for human consumption (samples are assessed from trials and commercial paddocks)

² Black hilum varieties, crushing only (not suitable for premium priced markets)

Seed quality

Seed germination and seed quality should be reviewed prior to sowing. Low-quality planting seed should be replaced as it is likely to result in sub-optimal establishment. Soybean seeds are relatively short-lived and even when produced under optimum conditions can have reduced germination potential and vigour after a few months in storage. Seeds have a thin seedcoat, making them more susceptible to damage than other crop species. Soybean types with larger seeds, and are grown for human consumption markets, are at greater risk of mechanical damage (harvesting and handling) than the smaller-seeded crushing types. Excessive auguring should be avoided.

Obtain a reliable germination test after harvest to ensure seed is worth keeping and test again before sowing to check it has not deteriorated. Germination tests of planting seed should be carried out every year within 4–8 weeks of planting. The germination test results of harvested seed can vary greatly depending upon storage conditions over winter and costs \$30–\$50 per sample. Seed testing information is available from your local NSW DPI office. Often a simple germination test can be completed at home with cotton wool or paper towel.

Irrigation layout

Soybeans grown on raised beds produce higher and more consistent yields than soybeans planted on a border-check layout. In the Riverina, soybeans are typically grown on raised beds using furrow irrigation on slopes of 1:1500 or flatter with run lengths of 400–800m. This allows better drainage around the root zone, less water-logging problems (i.e. potential disease build-up) and minimal establishment difficulties. Raised beds facilitate the sowing of soybeans into a moist seedbed for successful and critical plant establishment. Border-check layouts often have establishment problems, due to difficulties sowing into a moist soil that is not too wet to drive on. Often the soil surface dries out too quickly before, during and after sowing resulting in uneven and low plant establishment.

On raised beds, paddocks ideally should be pre-watered one to three weeks before planting and sown as soon as soil is dry enough to work. This strategy is best used when sowing into fallow. Watering-up (double-cropping strategy) once soybeans are planted on raised beds is possible if the soils are uniform,



and beds are high and well consolidated. Seed must be lightly covered with soil and the seed line must remain above the furrow water level. Watering-up on border check is not recommended as the seed will drown and/or burst. Watering-up is also not recommended for first time soybean paddocks, as rhizobia will die in the hot, dry soil before water can be applied. Achieving a good, solid, even plant stand with the correct plant population is the cornerstone of a high yielding crop.

Irrigation scheduling should be done according to the plant's moisture needs and stage of growth. To achieve high yields, the grower must predict with reasonable accuracy the timing of the next irrigation. Timing irrigations to meet plant moisture needs is critical for high yields. NSW DPI and CSIRO have a Water Watch scheduling service which provides Evapotranspiration (ET_o) rates on a daily basis for four locations in southern NSW. They have also developed crop coefficients (K_c) that can be applied to different crops to reflect their water use and demand at certain periods of the season (Table 3a.5.2). Soybeans should be watered at between 60–90 mm of accumulated ET_o adjusted for soil type, K_c and rainfall during the peak water-use period of the season (rainfall of less than 20 mm is often ignored in the heat of mid summer). The use of soil moisture probes (e.g. gypsum blocks, neutron probes or similar) are useful tools to monitor soil moisture movements and plant extraction.

Table 3a.5.2. Crop coefficient figures, Wayne Meyer CSIRO

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Soybean	0.75	1.05	1.0	–	–	–	–	–	–	–	0.3	0.45
Barley	–	–	–	0.3	0.35	0.5	0.8	1.2	1.0	0.9	0.5	–
Wheat	–	–	–	0.4	0.4	0.6	0.9	1.05	1.05	1.0	0.5	–
Rice	1.1	1.1	0.3	0.3	–	–	–	–	–	0.8	1.1	1.1

Planting timing

Soybeans start flowering in response to shortening daylight hours after the summer solstice on December 22. Current varieties are all photoperiod sensitive and therefore the later they are sown, the fewer days they have to maximise vegetative biomass before flowering. Late-sown crops produce smaller, shorter and less vegetated plants with fewer pods, which reduce seed yield potential per plant. On the other hand, if varieties are sown too early they will become over vegetative, grow too tall and lodge which results in lower yields

Soybeans should be sown from mid-November to the second week in December. Planting after this time reduces the probability of achieving high yields. Soybeans sown into fallow paddocks ideally should be pre-watered one to three weeks before planting and sown as soon as soil is dry enough to work. Seed should be sown into moisture to ensure even germination, full emergence and also the survival of applied inoculum (Group H inoculum). Seed should always be inoculated at planting, either with a seed dressing or by injecting liquid inoculant onto the seed. This is cheap insurance for free

nitrogen fixing and nitrogen (N) supply for the crop. Watering-up techniques can be used in double-cropping situations to speed up planting and establishment time. Beds need to be uniform, well consolidated and with no soil compaction problems (refer to irrigation layout section).

Seeding rates, plant populations and row spacings

Two crucial factors in achieving maximum soybean yields are to plant on time and achieve the correct plant population. High potential yield is determined by the ability to obtain and maintain a uniform plant stand. The desirable plant density is:

- 35–40 plants/m² for crops sown on time (mid-November to second week of December)
- 40–45 plants/m² from mid-December to late December

Growers planting tofu types such as Djakal, Snowy, Currunga and Bowyer need to take into account the larger seed size of these varieties, in order to achieve the desired plant density. This will often result in an increase in sowing rates compared to older smaller seeded varieties. Current practice for row spacing is two rows per bed (1.8 m beds), with each row positioned on the outer edge of the bed. Research has found 75 cm to be optimum row spacing, however 90 cm is still acceptable provided the crop is planted on time and an adequate plant population is achieved.

More research is currently taking place on the subject. Soybean plant growth must achieve full ground cover by mid flowering for southern

NSW indeterminate varieties. Flowering should commence approximately 40–55 days after sowing in the Murrumbidgee Valley and southwards to achieve full ground cover by mid-flowering.

Double cropping

As a grain legume, soybeans are well suited to rotations which include winter cereals, canola, rice and maize. The most common double-cropping system uses soybeans and winter cereals, and offers growers opportunities to:

- increase water use efficiencies
- increase gross margins per ML of water used
- create a break crop in the rotation
- provide all the benefits of a legume crop.

The varieties Djakal and Snowy are ideally suited to the double-cropping system. These shorter growing period varieties (122 and 126 days respectively to pod maturity) offer

higher water use efficiencies by requiring less irrigations compared with the longer-season varieties. High-yielding soybeans typically use 6–8 ML of irrigation water per ha depending upon soil type, variety, paddock, irrigation layout and seasonal conditions. The water use of double-crop soybeans will be closer to 6 ML/ha on average. These shorter-maturity varieties also allow soybeans to be harvested before the autumn break and allow the following winter cereal to be planted on time into some stored moisture. This stored moisture within the soil profile can be completely used by the following crop and not wasted.

Double-cropping practices are typically on permanent beds or under travelling irrigators. With careful selection of a short-season cereal crop (i.e. barley or wheat), soybeans can be planted back into the same paddock after harvesting winter cereal. The rotation can consist of several years of alternate crops of cereals (wheat and barley) and soybeans (see Table 3a.5.3). It is recommended due to the possible disease build up of phytophthora root rot that no more than 2–3 soybean crops should be grown in successive years. Alternatively, a summer crop rotation of soybeans and maize could be implemented.

Table 3a.5.3 shows a yield penalty can usually occur in soybeans in a double-crop situation which is offset by the income from the previous cereal and lower growing costs. This yield penalty could be due to a number of factors including soil compaction from the previous harvest or a slighter later than desirable planting date. Good management can reduce the yield penalty. However, impressive and profitable yields can still be achieved in a double-crop situation. Detailed planning, good time management and planting are the keys to a successful double crop. A complete range of pre-emergent and post-emergent chemicals are available to control almost all weeds, which is necessary to maintain seed quality and obtain premium prices.

Table 3a.5.3. Cropping rotation with gross margins (GM) and crop management

Crop	Period		Summary of production figures per hectare					Irrigation and sowing methods
	Sow	Harvest	Yield (t/ha)	Cost of production (\$)	Water use (ML)	Profit (\$/ha)	GM (\$/ML)	
Soybean	3rd wk Nov 05	1st wk April 06	4.25	785	8.0	1 425	178	Pre-water and sow into fallow
Barley	1st wk May 06	2nd wk Nov 06	5	470	2.0	155	78	Direct drill in soybean stubble
Soybean	4th wk Nov 06	2nd wk April 07	3.25	735	6.0	955	160	Burn barley stubble, sow and water up
Wheat	1st wk May 07	2nd wk Dec 07	6.5	495	3.5	545	156	Direct drill in soybean stubble
Rotation totals				2 485	19.5	3 080	572	
Average per calendar year				1 242	9.75	1 540	286	

Notes: Soybeans @ \$520/tonne (Djakal or Snowy), Barley @ \$125/tonne (Gairdner, Baudin or Schooner), and Wheat @ \$160 (Biscuit or Bread wheats).



Overall the GM per ML for a soybean/barley and soybean/wheat rotation is \$256 and \$316 respectively. As a two year cropping rotation, this example returns an average of \$286. In a single rotation of soybeans followed by wheat, a GM of \$334 can be expected. The soybean figures and yields here are achievable and realistic, with growers in the Coleambally Irrigation Area (CIA) and Murrumbidgee Irrigation Area (MIA) achieving in excess of 4.5 tonne/ha in the last two seasons. Older varieties such as Curringa and Bowyer, are slightly longer in maturity (10 and 14 days respectively), and do not have as high a yield potential as Djakal and Snowy.

Nutrition

As a high yielding crop, soybeans have a high demand for nutrients. Table 3a.5.4 provides approximate quantities of nutrients used by a soybean crop. A soil test is the best way to determine soil nutrient status and requirements to achieve maximum yields.

Table 3a.5.4. Approximate nutrient use in a 2.5t/ha soybean crop

	Plant nutrient (kg/ha)			
	Nitrogen	Phosphorus	Potassium	Sulfur
Total plant uptake	230	28	70	14
Seed removal only	167	18	40	11

Insect monitoring and control

Monitoring for insects throughout the season is highly recommended. It should initially take place weekly then twice a week from flowering. The crop should be checked between 7 and 9 am when the insects are most active on top of the plant's canopy. Soybeans can tolerate up to 35% loss of leaf area before flowering without any yield penalties. However, once flowering commences soybeans are less tolerant to leaf loss and damage can occur to growing points, flowers and pods. Loss of growing points can dramatically impede plant growth and reduce yield potential. This can often occur well before visual damage can be seen. Leaf-feeding pests such as heliothis, soybean moth, looper caterpillar and grass blue butterfly are most likely to cause this damage. The spray threshold for heliothis and grass blue butterfly is six larvae per square metre pre flowering, and lowers as the season progresses. Sucking pests such as green vegetable bug, red-banded shield bug, brown stick bug and brown bean bug occur commonly in soybeans. The green vegetable bug (GVB) is the worst of the sucking pests, severely reducing yields and quality by feeding on young pods and developing seed. Sucking pests cause damage from very early pod development to right through to harvest.

Table 3a.5.5. Insect thresholds per metre² (courtesy of H Brier, QDPI&F)

Pest	Threshold (human consumption)	Threshold (crushing)
Green vegetable bug	0.33	1.0
Brown bean bugs	0.5	1.5
Red-banded shield bug	1.0	3.0
Brown stink bug	1.7	5.7

Growers targeting the high quality tofu and milk markets should be aware of lower insect-damage thresholds in seed for these markets. More detailed information on insect pests and their control is available in the second edition of *Soybeans* (Agfact P5.2.6), the Queensland Department of Primary Industries and Fisheries' publication, *What insect is that?* and the guide, *Insect and Mite Control in Field Crops 2005*. The latter publication is available from district agronomists or can be found on the NSW Department of Primary Industries' website at www.dpi.nsw.gov.au.

Summary

Whole farm profitability and high soybean yields are very achievable if good planning and time management techniques are used. New high-yielding, human consumption soybean varieties, Djakal and Snowy, provide growers with a shorter and manageable growing season, better water-use efficiencies and higher returns per ML, resulting in an extra 2–3 weeks to fit better into a double-cropping rotation. Annual gross margin returns in excess of \$285/ML are achievable with soybeans in rotation with winter cereals. There are growers currently achieving this in the Murrumbidgee Irrigation Area and Coleambally Irrigation Area. With soybeans as a stand alone crop, GM can be in excess of \$195/ML with current prices. Good planning and management can result in these yields on a yearly basis.



3a.6 Irrigation scheduling wheat under centre pivots

Lindsay Evans

NSW DPI, Deniliquin

Information sourced from 2006, Grains Research and Development Corporation, Research Update for Growers, Moama

Key points

- Manage crops to meet daily water requirements.
- Where pre-sowing moisture is inadequate, centre pivots can pre-water without filling the profile.
- Wheat needs almost continual readily available water (RAW) in September and October.
- Soil water during the 10 days after flowering determines the grain size.
- Wheat needs water for at least six weeks after flowering has finished.
- Do not schedule by crop appearance – use soil moisture and weather.

Water use by wheat

Wheat yield is influenced by water availability, along with other factors such as varietal characteristics, time of sowing, soil fertility (chemical and physical), weeds and disease.

If most of the above factors are adequate to favourable, our wheat varieties are expected to produce 15–20 kg/ha for each mm of water used by the crop. Water use by any crop is directly related to potential evapotranspiration (ET_p).

Crop water requirements change during a season. To obtain maximum yield, manage crops to meet daily water requirements. To determine the daily water use of a vigorously growing crop, multiply daily potential evaporation (ET_p) by a crop co-efficient (K_c).

For an average cropping situation, (assuming a wheat crop sown in late May, has a good plant stand, is adequately fertilised, is relatively free of weeds and disease, and there are no major soil constraints) the K_c factors to use with the daily ET_p readings from the two CSIRO weather stations in our area are shown in the tables below.

Soil moisture prior to sowing

Good pre-sowing moisture ensures an adequate plant stand and reduces the likelihood of crop growth slowing and stressing for moisture (losing yield potential) prior to the start of the irrigation season.

Every season is different. In some years there will be sufficient soil moisture to sow on time and for germination without the need for a watering. This was not the case in 2005 and 2006, when pre-sowing and post-sowing waterings were needed. A late pre-sowing irrigation of around 25 mm is a safe option with a centre pivot, and if needed another 12 mm can be applied to assist emergence. On-farm storage may be needed in irrigation districts where water is not supplied during winter.

Pre-watering with a centre pivot need not fill the soil profile, but it is still useful to know how much water is in the soil if it is full. Our average cropping soils can hold up to about 130 mm to 0.9 m, however about 88 mm of plant available water (PAW) is in the top 0.6 m (effective rootzone) and about 42 mm of this is readily available water (RAW).

Winter water use

Table 3a.6.1 shows average monthly ETo and estimated crop water use for Finley in NSW plus the mean monthly rainfall in the winter months at three sites in the region.

Table 3a.6.1 Average expected water use by wheat in winter

Month	Av. ETo Finley (mm)	Kc	Crop Water Use (mm)	Mean monthly rainfall (mm)		
				Finley	Echuca	Moulamein
June	36	0.5	18	43	44	34
July	38	0.7	27	40	40	32
August	68	0.8	55	41	43	34
Total	142	–	100	124	127	100

If 100 mm of effective rain falls through the winter, optimum crop growth should occur with no moisture setbacks. In practice this seldom occurs as rainfall is seldom evenly spaced, and dry spells and frosty or windy weather reduce the effectiveness of the rain. Weeds also compete for soil water, and some soil water may move below the developing roots if the subsoil is dry.

Spring water use

Wheat needs almost continual RAW in the effective rootzone in September and October to produce high yields. Soil water prior to head emergence helps determine head size and the number of florets to be fertilised (number of grains). Soil water during the 10 days after flowering determines the size of the grains.

Wheat needs water for at least six weeks after flowering has finished. It uses water at the same rate as pre-flowering for about 25 days after full flowering, and then the rate of use declines during the next 17 days or so.

Spring irrigation scheduling

Judging when to irrigate by crop appearance is a poor guide. If the crop is showing signs of moisture stress, then much of the yield potential has already been lost.

Assessing soil moisture is a better guide. When assessing soils, auger down to at least 0.5 m, not just to shovel depth. If you can make a ball of soil from clay or clay loam but it will not ribbon, then RAW has already run out.

Soil moisture monitoring instruments are the most accurate guides. Weather based scheduling is a satisfactory alternative and a back-up. Make use of the ETo readings from the CSIRO or other weather stations.

As a late May sown wheat crop should finish flowering in the first week of October, Table 3a.6.2 shows average expected water use for moderately good wheat crops (around 5 t/ha) if the crop has RAW throughout the spring.



Table 3a.6.2. Potential water use by wheat in spring

Month	Av. ETo Finley (mm)	Kc	Crop Water Use (mm)	Mean Monthly Rainfall (mm)		
				Finley	Echuca	Moulamein
September	105	0.8	84	39	39	32
October	165	0.8	132	42	45	35
November 1-15	100	0.6	60	33 (whole month)	32	26
November 16- *	130	0.4	?	—	—	—
Total	500		276	114	116	93

* Moisture extracted from deep in the rootzone is usually sufficient to finish the crop.

Note that the Kc should be increased by 0.1 for crops with well over 5 t/ha yield potential, and by 0.2 if aiming for an 8 t/ha crop. Daily potential evaporation at Finley from September to mid November 2005 was about 10 mm below the average. Tullakool ETo readings are usually about 5% higher than at Finley from October onwards.

In 2005 eight spring waterings of 12 mm each should have been sufficient for a 5–6 t/ha crop. Ideally irrigations should have commenced by 6 September and finished in late October. Another watering around mid November would have been needed for higher yielding crops. The attached irrigation scheduling sheet gives an indication of how scheduling under a centre pivot would have worked in September 2005.

Three case studies are briefly discussed, all from NSW DPI 'Centre Pivot Irrigation in the Murray Irrigation Districts' project, a monitoring project funded from the Murray Land & Water Management Plan Research and Development budget.

Another scheduling sheet is provided for surface irrigation, which indicates that at Finley the first spring watering should have commenced by 15 September in 2005. A blank scheduling sheet is included for grower use.

Irrigation Scheduling Sheet (Centre Pivot)

Month:	September 2005	Crop:	Wheat	Block:	Berriquin	RAW:	42	mm	Irrigation Interval: Overhead	30	mm

Surface		max		mm	RAW deficit from previous month	20	mm

Date	A Evapotranspiration (E_{To} –mm) Finley	B Crop co-efficient (K_c)	C Crop water use (ET_{crop}) (A x B)	D Rainfall (mm)	E Effective Rain or Irrigation (mm)	F Daily water used ($E - C$)	G Cumulative total water use ($\pm$ in F)
1	2.7	0.8	2.2	–	–	2.2	22.2
2	2.9	0.8	2.3	–	–	2.3	24.5
3	2.1	0.8	1.7	3.0	1.0	0.7	25.2
4	3.8	0.8	3.0	–	–	3.0	28.2
5	3.3	0.8	2.6	–	–	2.6	30.8
6	3.3	0.8	2.6	–	12.0	–9.4	21.4
7	3.9	0.8	3.1	–	–	3.1	24.5
8	3.6	0.8	2.9	–	–	2.9	27.4
9	3.8	0.8	3.0	10.0	7.0	–4.0	23.4
10	3.8	0.8	3.0	3.0	3.0	0	23.4
11	2.7	0.8	2.2	–	–	2.2	25.6
12	3.6	0.8	2.9	–	–	2.9	28.5
13	2.4	0.8	1.9	–	–	1.9	30.4
14	3.3	0.8	2.6	–	12.0	–9.4	21.0
15	3.6	0.8	2.9	1.0	0	2.9	23.9
16	2.6	0.8	2.1	–	–	2.1	26.0
17	2.9	0.8	2.3	–	–	2.3	28.3
18	3.8	0.8	3.0	2.0	0	3.0	31.3
19	4.2	0.8	3.4	–	12.0	–8.6	22.7
20	3.3	0.8	2.6	–	–	2.6	25.3
21	3.8	0.8	3.0	–	–	3.0	28.3
22	3.4	0.8	2.7	–	–	2.7	31.0
23	4.7	0.8	3.8	–	12.0	–8.2	22.8
24	4.0	0.8	3.2	–	–	3.2	26.0
25	2.2	0.8	1.8	–	–	1.8	27.8
26	2.5	0.8	2.0	12.0	10.0	–8.0	19.8
27	4.8	0.8	3.8	–	–	3.8	23.6
28	2.5	0.8	2.0	19.0	17.0	–5.0	8.6
29	4.8	0.8	3.8	–	–	3.8	12.4
30	5.5	0.8	4.4	–	–	4.4	16.8
31	–	–	–	–	–	–	–
				50	48 irrig		

Daily E_{To} figures for Finley and Tullakool can be obtained from the CSIRO website www.clw.csiro.au/services/weather/#Data.

Note that the first 2–5 mm of a rainfall event is ignored.



Irrigation Scheduling Sheet (Border Check)

Month:	September 2005	Crop:	Wheat	Block:	Berriquin	RAW:	42	mm	Irrigation Interval: Overhead		mm

Surface		max	45	mm	RAW deficit from previous month	20	mm

Date	A Evapotranspiration (ETo –mm) Finley	B Crop co-efficient (Kc)	C Crop water use (ET crop) (A x B)	D Rainfall (mm)	E Effective Rain or Irrigation (mm)	F Daily water used (E – C)	G Cumulative total water use (± in F)
1	2.7	0.8	2.2	–	–	2.2	22.2
2	2.9	0.8	2.3	–	–	2.3	24.5
3	2.1	0.8	1.7	3.0	1.0	0.7	25.2
4	3.8	0.8	3.0	–	–	3.0	28.2
5	3.3	0.8	2.6	–	–	2.6	30.8
6	3.3	0.8	2.6	–	–	2.6	33.4
7	3.9	0.8	3.1	–	–	3.1	36.5
8	3.6	0.8	2.9	–	–	2.9	39.4
9	3.8	0.8	3.0	10.0	7.0	- 4.0	35.4
10	3.8	0.8	3.0	3.0	3.0	0	35.4
11	2.7	0.8	2.2	–	–	2.2	37.6
12	3.6	0.8	2.9	–	–	2.9	40.5
13	2.4	0.8	1.9	–	–	1.9	42.4
14	3.3	0.8	2.6	–	–	2.6	45.0
15	3.6	0.8	0	1.0	Irrig.	0	0
16	2.6	0.8	2.1	–	–	2.1	2.1
17	2.9	0.8	2.3	–	–	2.3	4.4
18	3.8	0.8	3.0	2.0	0	3.0	7.4
19	4.2	0.8	3.4	–	–	3.4	10.8
20	3.3	0.8	2.6	–	–	2.6	13.4
21	3.8	0.8	3.0	–	–	3.0	16.4
22	3.4	0.8	2.7	–	–	2.7	19.1
23	4.7	0.8	3.8	–	–	3.8	22.9
24	4.0	0.8	3.2	–	–	3.2	26.1
25	2.2	0.8	1.8	–	–	1.8	27.9
26	2.5	0.8	2.0	12.0	8.0	- 6.0	21.9
27	4.8	0.8	3.8	–	–	3.8	25.7
28	2.5	0.8	2.0	19.0	17.0	-15.0	10.7
29	4.8	0.8	3.8	–	–	3.8	14.5
30	5.5	0.8	4.4	–	–	4.4	18.9
31	–	–	–	–	–	–	–
				50	45 irrig		

Daily ETo figures for Finley and Tullakool can be obtained from the CSIRO website www.clw.csiro.au/services/weather/#Data.

Note that the first 2–5 mm of a rainfall event is ignored.

Irrigation Scheduling Sheet

Month:		Crop:		Block:		RAW:		mm	Irrigation Interval: Overhead		mm

Surface	max	mm	RAW deficit from previous month	mm

Date	A Evapotranspiration (ETo – mm)	B Crop co-efficient (Kc)	C Crop water use (ET crop) (A x B)	D Rainfall (mm)	E Effective Rain or Irrigation (mm)	F Daily water used (E – C)	G Cumulative total water use (± in F)
1							
2							
3							
4							
5							
6							
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3a.7 Barley – does it have a place in irrigated farming systems?

Dr Neil Fettel

NSW DPI, Condobolin

Information sourced from 2005, Grains Research & Development Corporation, Research Update for Growers, Southern Region (Irrigation)

Key points

- The demand for both malt and feed barley grain is expected to remain strong in the short to medium term.
- The deregulation of the NSW malt barley market may present new opportunities, and malting quality is easier to achieve following easing of the colour requirements.
- Barley is not a traditional irrigation crop, probably because of its susceptibility to waterlogging and the lack of suitable varieties.
- Better layouts and the use of beds can overcome the waterlogging problems.
- Improved varieties are now available.
- Barley is a valuable rotation crop as it is not susceptible to many wheat foliar diseases (yellow spot, stripe rust, septoria), suffers less yield loss from root diseases, and competes well with weeds.
- Barley often matures earlier than wheat, an advantage in double cropping situations.
- Gairdner[Ⓢ] has proved to be the highest yielding malting variety, but is prone to high screenings if not managed correctly.
- Gairdner has inherently low grain protein concentration, particularly at high yield levels, and inadequate nitrogen nutrition will result in grain too low in protein for acceptance into malting grades.
- Baudin[Ⓢ], from Western Australia, is a potential alternative to Gairdner with better grain size and lower screenings, but is more susceptible to leaf rust and mildew.
- Tantangara and Tilga are high yielding feed lines with Tantangara better suited to irrigation. Tilga can grow too tall and suffer from weak straw.

Why consider barley?

Barley is not a traditional irrigation crop, probably because of its susceptibility to waterlogging on older irrigation layouts and the lack of suitable varieties. These constraints have been reduced by the widespread improvements in irrigation layouts and the release of new varieties. Improved structures, laser-levelling, permanent beds and better drainage systems allow faster water application and drainage rates resulting in less waterlogging. Newer, semi-dwarf varieties have higher yield potential and are less susceptible to lodging and head loss. The earlier maturity of barley compared with other winter crops can be advantageous in a double cropping system.

In recent years, both the malt and feed markets have given good returns. New varieties with higher yield potential are being released and the colour standards for malting have been eased. Barley can be valuable as a rotation crop with wheat particularly in no-till and stubble-retention systems as it is not a host for most wheat foliar diseases. Its vigorous early growth allows it to compete well with weeds, needing lower herbicide rates and restricting weed seed set. It often needs fewer inputs than wheat.

Markets for barley

The NSW malting barley market consists of two classes:

- Demand for unprocessed malting barley in Australia's grain export markets, principally China. The very price sensitive Chinese market continues to grow. Demand for Schooner[Ⓛ] in China remains strong, with increasing acceptance of both Gairdner and Sloop[Ⓛ]. This is the major market for NSW grain
- Demand by domestic maltsters to supply malt to domestic brewing customers. This market is relatively static. Schooner is the preferred variety in this market.

Schooner and Gairdner remain the preferred malting varieties for 2005 in southern NSW. There are smaller markets for varieties such as Franklin[Ⓛ] and Baudin, which are usually filled by direct contract.

Domestic feed barley demand is likely to remain steady with record numbers of cattle on feed and the continued requirements of the dairy and intensive livestock industries.

Long-term results indicate Gairdner will often fail to meet grain size specifications for malting quality, particularly in stressed environments (Table 3a.7.1). Retention values for Gairdner average 69% while screenings average 4.9%, compared to 78% and 2.8% for Schooner.

Gairdner does have inherently 0.5%–1.0% lower grain protein content than Schooner, and this can be magnified by its higher yield potential. Some eastern farmers failed to achieve malting quality due to excessively low grain protein content in 2001.

Tilga and Tantangara remain as high yielding feed varieties. Tilga is best suited to dryland areas.

Baudin is a malting quality variety from Western Australia. It is seen as a Gairdner alternative with better grain size, lower screenings, quicker maturity and shorter straw. It is very susceptible to leaf rust and powdery mildew and growers need to plan a disease strategy and organise a market outlet.

Cowabbie[Ⓛ] is another possible Gairdner alternative. Released as feed but has the possibility of upgrading to malt quality and is aimed at the southern part of the State. It also has better grain size than Gairdner and good straw strength. Flowering time falls between Gairdner and Baudin and it is less susceptible than Baudin to leaf rust, leaf scald and powdery mildew.

Tulla[Ⓛ] is an acid-soils-tolerant, semi-dwarf feed variety with good grain size, straw strength, and disease resistance and yields similar to Tantangara on non-acid soils.

The Victorian program is testing VB0105, a Franklin[Ⓛ] derived malting line we have tested widely in NSW agronomy trials as a potential Schooner replacement. South Australia is placing major emphasis on Cereal Cyst Nematode (CCN) resistance with the lines WI3804 and WI3586, neither of which look to have a major place in NSW.

Unicorn[Ⓛ] is a very quick maturing variety which may have a place for late sowing but is susceptible to shattering and requires careful management.

Variety performance

Few irrigated barley variety trials are conducted each year and so the following comments are based on dryland trials as well.

Gairdner has performed particularly well across the southern region with the long-term data (Table 3a.7.1) showing a yield advantage of about 8% over Schooner. It has excellent malting quality, and although a semi-dwarf variety it can grow quite tall. It is slower to flower than Schooner and so best suited to early and main season planting and to favourable conditions.

Table 3a.7.1. Across sites and years analysis for yield and screenings for main season trials (sown after 15 May).

Variety	Yield as % Schooner [Ⓛ] (no. trials)	Retention (% > 2.5 mm)	Screenings (% < 2.2 mm)
Baudin [Ⓛ]	107 (6)	71	4.6
Binalong [Ⓛ]	110 (62)	–	–
Gairdner [Ⓛ]	108 (77)	69	4.9
Mackay [Ⓛ]	108 (39)	–	–
Schooner [Ⓛ]	100 (77)	78	2.8
Tantangara	106 (78)	68	4.5
Tilga	112 (78)	65	5.4
Tulla [Ⓛ]	107 (57)	68	4.5

Yields are for 1997–2003 and expressed as a percentage of Schooner. Screenings and retention are % by weight and are from 1999–2003 trials.



Phenology

Flowering time is the most important factor in adapting a crop to an environment. Many barley varieties respond to day length as well as to temperature, and so their maturity rankings can change with latitude. Development pattern also has a strong influence on grain number per ear in two-row barleys. Figures 3a.7.1 and 3a.7.2 show ear emergence dates and time from sowing to ear emergence for five barley varieties sown on four dates in 2003.

Figure 3a.7.1. Ear emergence dates for five barley varieties sown at four sowing dates, 2003

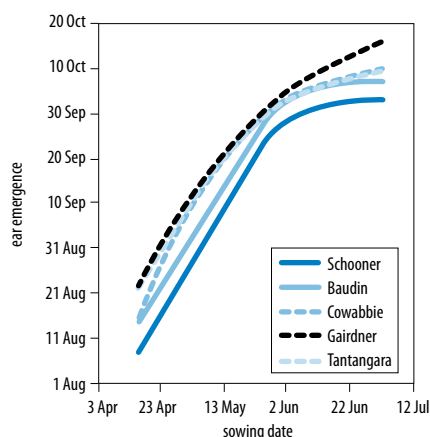
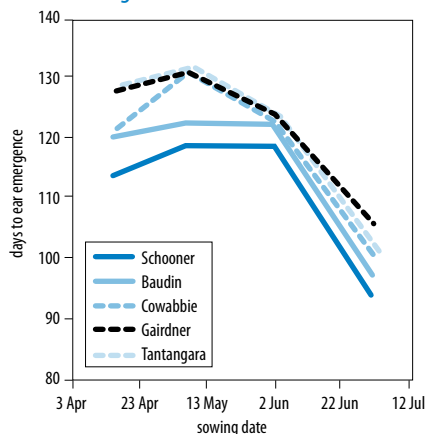


Figure 3a.7.2. Days from sowing to ear emergence for five barley varieties at four sowing dates

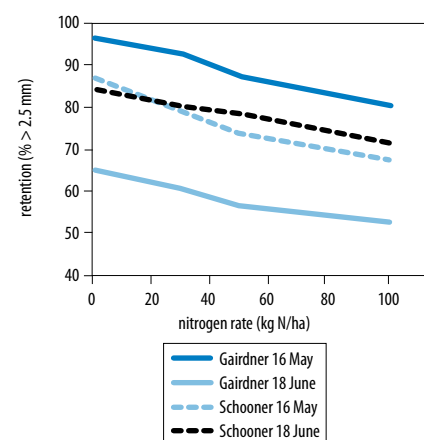


Schooner was the quickest to flower at all sowing dates; Baudin was generally next quickest followed by Cowabbie and Tantangara while Gairdner was the slowest. The ideal ear-emergence date will vary with season, being a balance between achieving sufficient biomass by flowering and the risk of frost. Based on frost risk, an acceptable ear-emergence period for western NSW might be between the 20 and 28 September. If so, Schooner should be sown in the last week of May or very early June whereas Gairdner should be sown at least two weeks earlier. If sowing is delayed until the end of June, Schooner is able to dramatically reduce the time to ear emergence whereas Gairdner is not.

Nitrogen nutrition

Protein content is a major determinant of malting quality. High protein concentrations reduce malt extract. In dryland areas, keeping below the 12% upper limit can be difficult, as the nitrogen (N) levels required to obtain maximum yield, result in grain proteins of about 11%. At low to moderate yield levels, only a small amount of additional nitrogen will rapidly increase grain protein and screenings. Figure 3a.7.3 shows the effect of nitrogen fertiliser on grain plumpness for Schooner and Gairdner sown on two dates at Condobolin. There is a steady decrease for each variety at each sowing time, and the slope of the lines is similar. However, retention was lower for Gairdner than Schooner for both sowing dates, and lower for the June than the May sowing. The allowable limit for malting is 70%.

Figure 3a.7.3. Effect of fertiliser nitrogen on retention (plump grain) in Gairdner and Schooner on two sowing dates at Condobolin.

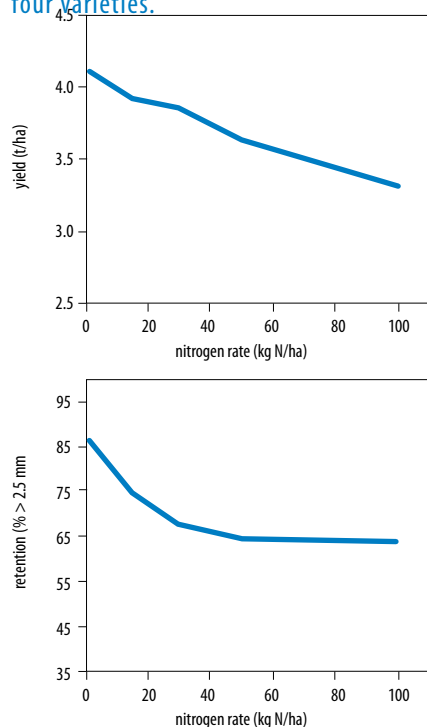


Negative yield and grain quality responses were also seen in 2004 which is hardly surprising given the dry conditions. Results from our highest yielding site, Alectown, are shown in Figure 3a.7.4. A deep nitrogen soil test at sowing showed there was 130 kg of mineral nitrogen in the top 60 cm and this was sufficient for an average yield across varieties of 4.2 t/ha. Additional nitrogen fertiliser, as little as 15 kg N/ha, decreased yield and plump grain and increased screenings in all varieties. However, even at the highest nitrogen rate, Schooner was above the 70% retention limit whereas any nitrogen pushed Gairdner below this level.

Low grain protein can also be a problem as most markets now require barley above 10%. Japanese malt markets have a preference for 11% protein. The minimum for malting grade has therefore been increased to 9.5%. Due to both the inherently low grain protein content of Gairdner and the higher yielding environments where Gairdner is being grown, appropriate N management for this variety is essential to avoid excessively low

grain protein levels. For dryland Schooner crops, if more than 100 kg nitrate N per ha is present at sowing, additional fertiliser N increases the risk of excessively-high, grain-protein levels. However, higher levels of nitrate N will be required for Gairdner production under irrigation.

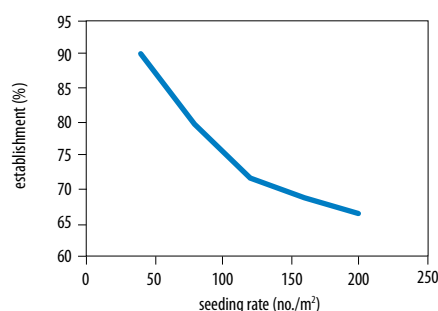
Figure 3a.7.4. Effect of nitrogen fertiliser on yield and retention at Alectown, 2004. Values are the mean of four varieties.



Seeding rate

Higher seeding rates have been advocated in wheat as a way of reducing the number of higher order tillers and hence maintaining grain size and reducing screenings. This can be dangerous in barley and particularly in Gairdner. In a series of trials across NSW, the yield and grain quality of existing varieties and lines close to release are being compared. Nominal seeding rates from 20 to 100 kg/ha are being used, equating to a range of 40 to 200 seeds/m². In 2004, there was a wide variation in establishment percentage, reflecting difficult planting conditions, with site averages ranging from 50% to 95% of seed producing a plant. Establishment percentage also decreased with seeding rate at most sites, and the average decline is shown in Figure 3a.7.5. Values declined from 90% at the lowest seeding rate to 65% at the highest.

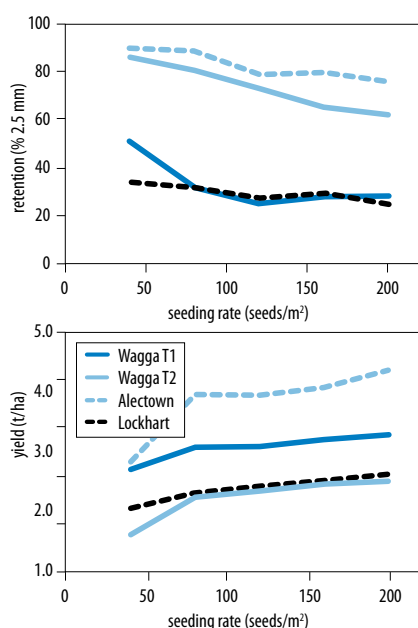
Figure 3a.7.5. The response of plant establishment (as a percentage of seeds sown) to seeding rate in 2004. Values are the mean of all varieties at 10 sites.



Yield and grain-plumpness data for four of the sites are shown in Figure 3a.7.6. Yield responses were similar across the sites, even though average yields varied from 2 to 4 t/ha. In all cases there was a big response, up to 80 seeds/m², and a small but continuing response to higher rates. This probably reflects the 2004 seasonal conditions at these sites, where stress around flowering was followed by milder conditions through grain-filling. At some more severely stressed sites, yield decreased at the highest rates. Grain size, as indicated by retention, decreased at most sites as seeding rate was increased. At Alectown, this was largely due to Gairdner. Schooner and Cowabbie were much more stable in grain size. Based on results over a number of years, populations of 70–110 plants/m² are likely to be a good compromise for yield and grain quality for dryland crops. For fully irrigated crops where the risk of screenings is less, an even stand of about 200 plants/m² is desirable.



Figure 3a.7.6. Effect of seeding rate on yield and retention (plump grain) at four sites in 2004. Values are the mean of four to six varieties at each site.



Irrigation management

For maximum yield and acceptable quality, barley should be grown on medium fertility paddocks, with layouts capable of being watered and drained in 8–12 hours maximum. The soil profile at sowing should be at about 70% of field capacity, which may require a pre-watering depending on the cropping sequence. A deep soil nitrogen test or early tissue tests should be used to determine the need for additional nitrogen and this should be applied before the end of tillering. Irrigation before flowering (ie before ear emergence) is desirable with the aim of ensuring grain set and the maintenance of green leaf area. Further irrigation during grain-filling should ensure that soil-water content is maintained above 60% of field capacity until the soft-dough stage. While barley often matures earlier than other cereals, premature drydown will limit grain yield and increase screenings.

With good management, target yield for a fully irrigated crop should be at least 6 t/ha. If limited water is available, the timing of irrigation and the levels of other inputs should be carefully considered or grain quality may be compromised.

ⓘ Varieties displaying this symbol beside them are protected under the *Plant Breeders Rights Act 1994*.



3a.8 Irrigated barley – a good rotation option?

Rob Fisher

Victoria (DPI), Kerang

Information sourced from 2004, Grains Research & Development Corporation, Research Update for Growers, Griffith

Key points

- There are no shortcuts in crop management.
- Use a plant variety suitable for irrigation.
- Understand plant nutritional needs.
- Aim for a yield of irrigated malting barley in excess of 5.5 t/ha as leading growers achieve this regularly on heavy soil types.
- Manage a barley crop as a money making exercise and use adequate inputs and irrigation.

Layout, soils and salinity

Develop excellent irrigation layouts as paddocks must be drained within 12 hours and barley is more susceptible to water logging than wheat. Like all crops, the better the soil conditions the better the yield potential.

Although barley has greater salinity tolerance than wheat, it should not be considered salt tolerant. Yields will be reduced in soils with salinity levels of 6 dS/m or greater and water salinity levels of 2.0 dS/M (1280 ppm) or more. When managing soil acidity, use lime if soils have a pH less than 5.0.

To improve soil structure, consider gypsum however a low Ca:Mg ratio will not always guarantee a response. Trial work indicates soil structure is as important as sodicity in some soils. Organic matter could be the key. Try test strips of gypsum.

Rotation and disease

Generally sow barley after wheat because the nitrogen environment is usually suitable. If soil nitrogen is unsuitable consider other rotations based on sowing times, potential weeds and market factors.

The critical disease factor is generally not root disease unless you have a Cereal Cyst Nematode issue. Select

disease resistant varieties and use a seed dressing for scald and powdery mildew. The spot form of net blotch is not a major concern so spraying is very rarely economical.

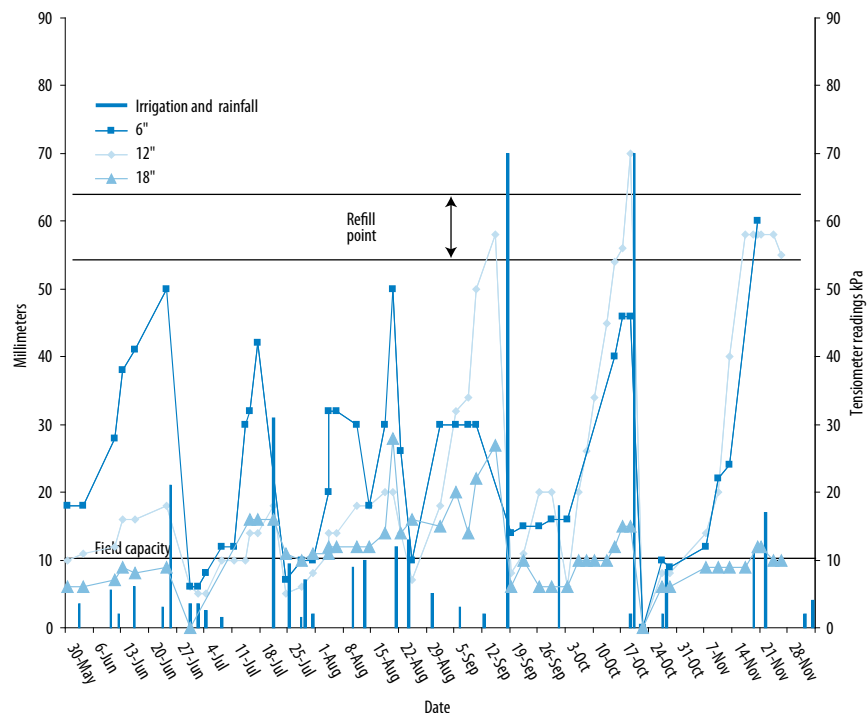
Irrigation

Around 4 t/ha is common at Kerang, on heavy clay soils in an average rainfall year with no pre irrigation and one spring irrigation. This can be greatly improved with better management.

In most years pre irrigation is essential for controlling soil moisture and time of sowing. Pre irrigation will add a tonne of yield on average however most growers pre irrigate too early. Figures for the Kerang area show that only three of the last 50 years would have been too wet for sowing if pre irrigation was completed by March 31.

Irrigate using tensiometer readings in the spring and irrigate either side of flowering (however barley flowers in the boot). So aim to irrigate around or even before head emergence and if the season requires it, during early milk development, being guided by the tensiometer.

Figure 3a.8.1. Barley variety trial 2003



Variety

Do not assume that dryland varieties are suitable. Look for varieties that handle lodging and have some degree of waterlogging tolerance. Table 3a.8.1 below is from the irrigated trial at Kerang. The 2002 trial suffered a degree of waterlogging whereas the 2003 trial was on a better layout. This may reflect the differences between the two years' results. Gairdner[Ⓛ] is reasonably consistent but Baudin[Ⓛ] had a large increase in 2003 which may be an indicator of its intolerance of waterlogging.

Table 3a.8.1

Year	Schooner	Franklin	Baudin [Ⓛ]	Gairdner [Ⓛ]	Yambla
2002/3 Ave	4.37	4.71	4.87	5.61	6.08
2002	3.81	3.50	3.44	5.52	5.52
2003	4.94	5.92	6.29	5.69	6.63

The best released varieties are Yambla for feed and Gairdner for malting (also because of its lower protein level).



Weeds

Another good reason for pre irrigation is to increase the opportunities to control weeds and volunteer cereals, especially if sowing barley after wheat. A double knockdown approach is cheap and effective. Use glyphosate post irrigation and sprayseed before sowing. Assess the crop for further grass and broadleaf control.

Nutrition

At sowing time, a phosphorus (P) 'bank' equivalent to the amount expected to be taken out in yield is required. If aiming at a 6 t/ha yield, about 24 kg/ha of P is removed so, start at around a Colwell P target of around 35 ppm. Slightly less is needed for sandy soil so add about 24 kg/ha of P, equivalent to 120 kg/ha of diammonium phopshate (DAP) at sowing. This rate will ensure adequate crop nutrition and prevent phosphorus mining by the crop.

Add zinc in the wheat stage of the rotation if there are deficiencies. The importance of copper is still under discussion. In the author's opinion, there is little evidence to suggest that many areas are deficient. A lot of symptoms of copper deficiency are actually environmental stresses like frost, but the good news is it is relatively inexpensive.

Nitrogen management

Determine paddock nitrogen (N) status using a deep nitrogen soil test, as a major reason for crop failure is growers using guess work when estimating nitrogen status. This results in missed malting grades because of protein being too high.

Try to limit paddock selection to those paddocks with less than 100 kg/ha N. If N levels are greater, then grow wheat or canola. Nitrogen calculations are simple and you can work with your agronomist to calculate paddock levels.

Table 3a.8.2 below is a worked example from the last two years of the Victorian Irrigated Cropping Council (VICC) trial block. Quantities are kg/ha of N.

Table 3a.8.2

Year	Soil N	Mineralised*	Pre-drilled	Starter N	Topdressed	Total	Yield (t/ha) [^]	Grain Protein (%)
2002	44	60	45	25	45	219	5.52	10.8
2003	41	60	—	25	60	191	5.79	9.75

* Estimated amount of N released from the breakdown of organic matter. ^ Gairdner barley

Topdressing

If aiming at 5.5 t/ha plus and the paddock is selected correctly, there is no need to pre drill urea.

The 2003 example in Table 3a.8.2 shows that not pre drilling urea, requires topdressing with 60 kg/ha of N or 130 kg/ha of urea but this allows you to assess the season and target N amounts to achieve malt grade. The combination of just 2.5 mm of rain and cool weather enables the crop to use at least 80% of the urea applied. You will also benefit from reduced lodging due to better canopy management.

Canopy management

Canopy management is about producing the necessary plant shoot numbers to efficiently intercept sunlight. Producing too dense a canopy makes the crop liable to lodging or water and nutrient inefficiencies. The aim is to have approximately 600 shoots per m² at flowering.

Earlier sowings have the potential for greater shoot production and development. Therefore lower sowing rates are required early in the season. Early N application encourages excessive early growth that contributes little towards final yield. Nitrogen applied during tillering maintains or promotes tiller production. Late N application supplies N to the developing stem, but if applied too late it can result in high grain protein.

If there are sufficient shoot numbers at late tillering (600–800 shoots/m²), topdressing can be delayed to the first node stage (Z31). If there are low or borderline shoot numbers, a light topdressing at that stage

will ensure shoot survival. Very low shoot numbers cannot be fixed with extra N.

Gross margins

Table 3a.8.3. Gross margins for Gairdner barley based on the trial results at Kerang

2002	
Income 5.5 t/ha @ \$280/t	\$1540
Costs	\$ 513
Gross margin \$/ha	\$1025
Gross margin \$/t	\$ 233
2003	
Income 5.7 t/ha @ \$175/t	\$ 998
Costs	\$ 477
Gross margin \$/ha	\$ 521
Gross margin \$/t	\$ 121

Summary

In summary, 5.5 t/ha crops can now be regularly grown on difficult sites. Further work on varieties and canopy management needs to be done which may make an 8 t/ha limit achievable. In 2003, 9 sites in south west Victoria averaged over 10 t/ha on raised beds which suggests we need to continue to invest time and money on this crop.

ⓘ Varieties displaying this symbol beside them are protected under the *Plant Breeders Rights Act 1994*.



3a.9 Faba Check in southern NSW – what have we learned?

Rachael Whitworth

NSW DPI, Griffith

Information sourced from 2005, Grains Research & Development Corporation, Research Update for Growers, Southern Region

Key Points

- The key to growing high yielding, good quality faba beans is to use best management practices that address paddock selection, layout selection, spring irrigation requirements and weed, insect and disease control.

Irrigated faba beans regained popularity due to improved disease-resistant varieties and the development of management packages for growers. In the Riverina a realistic and achievable yield for irrigated faba beans is 4–5 t/ha, making them a worthwhile component of irrigated crop rotations. Although often considered more risky and less profitable to grow than wheat, their high yield potential as well as the benefits they provide for the following wheat crop make them an attractive and viable option.

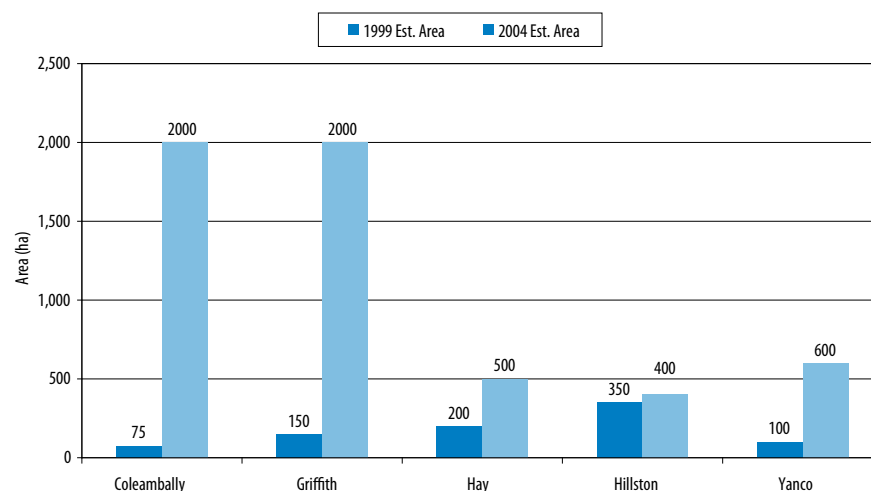
From 2000 to 2004 the NSW Department of Primary Industries' Faba Check program provided a benchmarking tool for district crops. It has also paved the way

for faba beans to lose the tag of 'failure beans' they were given in the mid 1990s when disease (mainly chocolate spot) devastated crops. The tag has now changed to 'failure in management'.

Faba beans and Faba Check 2000 to 2004

Although the area planted to faba beans has fluctuated due to water availability, faba bean prices, rotational constraints and the price of other commodities there has been a general increase in plantings throughout southern irrigation districts since 1999. This is shown in Figure 3a.9.1.

Figure 3a.9.1. NSW DPI district agronomist faba bean area estimates 1999 compared with 2004.



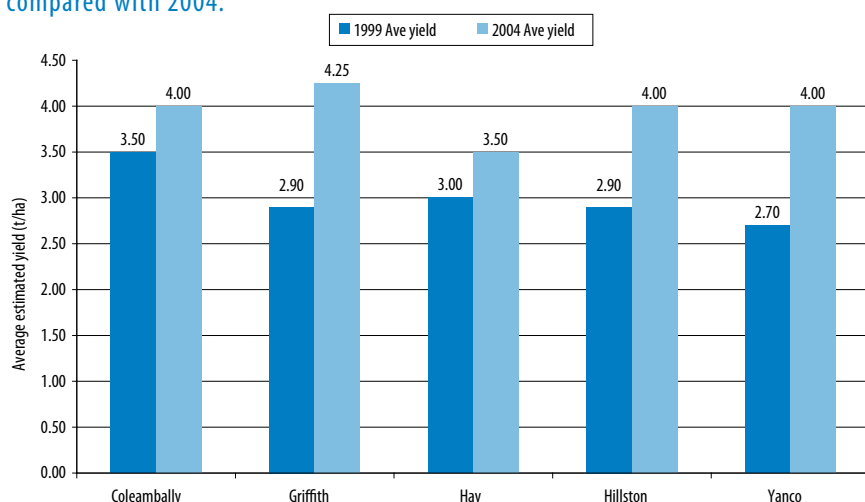
Source: NSW DPI Grains Reports, December 1999 and 2004.

The main reasons for this increase in area, as mentioned above, relate to better varieties, management strategies available for disease as well as a better understanding of overall best management practices.

Since the resurgence of faba beans in 2000, Faba Check enabled us to identify the key management practices in achieving high yielding, good quality, irrigated faba beans. Although seasonal conditions play a large part in determining the overall yield and quality of faba beans, growers who followed best management practices over the five year period (2000–2005) consistently achieved high yields and good quality. The keys to their success were good irrigation layout, commitment to frequent watering in the spring and developing a fungicide management strategy (even in dry years).

As well as the factors mentioned previously, Faba Check and best management practices have also played a part in the improvement of average districts yields. This is shown in Figure 3a.9.2 when comparing average district yields of 1999 with the average yields of 2004.

Figure 3a.9.2. NSW DPI district agronomist faba bean yield estimates 1999 compared with 2004.



Source: NSW DPI Grains Reports, December 1999 and 2004.

2000 Faba Check highlights

The year 2000 was the first year district crops were benchmarked and for many growers it was the first time they had ever grown faba beans. Yields ranged from 1.5 t/ha up to 5.5 t/ha, with average yields around 3.75 t/ha. Growers really tested the boundaries of faba bean farming, with many planting on the flat, instead of beds (on all sorts of slopes), and with rain after the first spring irrigation causing considerable damage. Therefore the two biggest factors in 2000 impacting on yields locally were water logging in the spring and lodging at harvest.

The main lessons learned from 2000 were:

- check soil pH as faba beans decline on acid soils with pH below 5.2 (CaCl_2)
- do not grow fabas on freshly land-formed paddocks, particularly if there are big cut and fill areas
- only grow on the best soil types
- calibrate seeders after inoculating for the correct plant population
- irrigation layout is one of the most important things for the final spring irrigation, consequently faba beans performed best on bed layouts with waterlogging a major issue on contour layouts
- be aware of potential damage from herbicide residue problems, particularly from boom spray contamination
- lodging proved to be an issue at harvest and was a bigger problem on beds as plants were harder to pick up from the furrows. Growers learned the importance of harvesting in one direction
- thrips were a problem at flowering in 2000 however growers who treated them were unsure if control measures were beneficial.



2001 Faba Check highlights

Seasonal conditions in 2001 contrasted with those of 2000. With below average rainfall throughout most winter months, crops showed signs of moisture stress towards the end of July and early August. Some crops actually lost yield potential at this critical time as they waited for the start of the irrigation season. The dry conditions and improved disease management strategies meant the incidence of disease was generally low. District yields ranged from 1.5 t/ha up to 6.2 t/ha, with average yields around 3.75–4.0 t/ha. These crops were grown with 5–6 fungicide sprays.

The main lessons learned from 2001 were:

- check seeder capabilities as seed size was an issue for some, often causing seeder blockages and/or resulting in sowing insufficient seeds per square metre. As seed size is a heritable trait it is not advisable to grade out the large seed, as the resultant crop may not meet market specifications
- sowing with a spreader (broadcasting) and then harrowing in 2001 gave variable results leading to poor establishment as there was no soil to seed contact, with seed often getting buried too deep or sitting on the surface
- growers became aware of the benefits that faba beans provide to following wheat crops.

2002 Faba Check highlights

The uncertainty of faba bean prices at the beginning of the 2002 season, rotational constraints and good wheat prices saw a decline in faba bean plantings across the Riverina. As a result, no Faba Check report was compiled in 2002.

Growers who kept to their rotation plan despite the outlook and planted faba beans and followed best management practice were rewarded with high-yielding, good-quality, faba bean crops. Yields of just under 6 t/ha were achieved around Griffith through good weed control in previous crops, good irrigation layouts, timely spring irrigations and the strategic use of fungicides.

2003 Faba Check highlights

The year 2003 saw the introduction of the Agrinational Marketing Pool for faba beans (now offered under the name of parent company Ecom Commodities). Crops which were committed to the Pool had the advantage of being an acreage commitment only, taking out the production risk of fixed-tonnage contracts. Growers were also given the benefits of dedicated receival facilities and attractive payment terms. This saw an increase in the area of faba beans grown locally in 2003.

The 2003 district yields ranged from 2.0 t/ha to just over 6.0 t/ha, with average yields around 3.75–4.0 t/ha. The district's top yielding crop, grown on raised beds on self-mulching black soil near Widgelli,

east of Griffith, yielded 6.2 t/ha. These crops were grown with 4–5 fungicide sprays. The season was exceptionally mild and hosted a number of frosts late in the season. Crop yields and grain quality were generally quite good, with the common comment being that grain size was smaller than usual, although still within delivery standards, due to the mild conditions.

The main lesson learned from 2003 was:

- not to sow too early as crops sown before May suffered from lodging. Sowing early to mid May helps to avoid the problem and maximises yield potential.

Growers who made every effort to achieve optimum plant populations, paid close attention to plant nutrition, kept up to date with disease prevention, were able to minimise moisture stress due to optimum irrigation layouts and managed to miss out on the hail storms in 2003 performed the best.

2004 Faba Check highlights

District yields showed mixed results with yields around 8%–10% down on previous years, possibly due to the hot conditions experienced in September and October. Due to the dry season, crops on beds generally received 2–3 spring irrigations, after being watered up.

One of the biggest issues in 2004 was the heliothis insect, with the majority of crops needing to be sprayed. Given 2004 was a dry year, 4–5 applications of fungicide spray were still required.

Faba Check trends

Whilst wheat remains the main winter crop grown in the area, faba beans have become an integral part of the irrigated cropping rotation locally since 2000. As water allocations tighten, growers are looking ahead and questioning how much ground to leave for summer crops, in particular rice. If the area of rice is decreased, concerns have been raised about the rotational constraints that may be encountered with growing consecutive wheat crops, so alternatives such as faba beans have been adopted.

Since 2000 there has been a move towards more suitable layouts for faba beans, with a higher proportion of crops now grown on beds compared with a flat field. Faba Check results support this trend. In 2000, 34% of Faba Check crops were on beds, 38% on border-check and 28% on contour. In 2003, 82% were on beds and 18% on border-check (although not represented in Faba Check, there were still a small percentage on contour in 2003).

These more suitable layouts have given growers flexibility in the spring and removed the waterlogging risk, particularly after the last spring irrigation. Table 3a.9.1 below shows the break-up of irrigation layout and yields from Faba Check data (2000 to 2003).

Table 3a.9.1. Irrigation layout and yield 2000 to 2003 – Faba Check

Year	Irrigation layout yields (t/ha)			
	Beds	Bordercheck	Contour	Other
2000	4.57	3.87	3.29	–
2001	4.37	4.04	3.72	3.7
2002	N/A	N/A	N/A	N/A
2003	5.16	3.77	–	–
Average	4.7	3.89	3.51	

Source: Faba Check Reports 2000, 2001 and 2003

Faba beans grown on beds have consistently out performed faba beans grown on any other layout. Given this, Faba Check results also show that the Water Use Efficiency (WUE) of faba beans grown on beds is higher than faba beans grown on border-check. The data since 2000 shows an average WUE of 12.50 kg grain/mm water for faba beans grown on beds compared to an average WUE of 9.88 kg grain/mm water for faba beans grown on border-check.

Growers since 2000 have also adopted a well-planned disease management strategy and are prepared to spray, four, five or even six times for disease, depending on seasonal conditions. This means the build-up of disease during winter is being effectively prevented and protection against disease in the spring is provided before each watering, whilst the canopy humidity and disease risk are high.

Strategic fungicide applications adopted by district growers are outlined below:

- an application of Mancozeb (mostly 1.5–2.0 kg/ha) four to six weeks after the crop has emerged and targeting mainly ascochyta
- applications (number will depend on the level of disease in the crop and seasonal conditions) of Mancozeb (mostly 1.5–2.0 kg/ha) and/or Carbendazim (500ml/ha) throughout the most active growth period for chocolate spot. Growers often substitute at least one Mancozeb spray with Carbendazim, it is usually the last spray before the final Mancozeb application
- a final application of Mancozeb (mostly 1.5–2.0 kg/ha) targets rust and ascochyta.

Over the past four years it has generally been the same growers consistently achieving high yields of 5–6 t/ha for faba beans. The key to their success has been their regular adoption of the key best management practices. These practices include paddock selection, layout selection; good weed, insect and disease control; and meeting the plant's spring irrigation requirements.



Summary

Faba Check has shown growers and their advisers the way forward in terms of crop management and identified the main factors for success of local irrigated crops. It has put faba beans in context with other winter crops as they require a higher level of management input. By benchmarking crops against others in the district, growers are able to see where improvements in their management systems can be made in order to achieve higher yields and better quality.

Through Faba Check, faba beans are now being grown on more suitable layouts. It has helped growers to realise the importance of adopting a well-planned disease management strategy and to look beyond the reputation that faba beans received in the mid 1990s.

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3a.10 Benefits of pulses in irrigation rotations

Trevor Bray
Pulse Australia, Griffith

Key points

- Pulses are a valuable part of the whole farming system.
- Pulses have a role in irrigation rotations not just for the traditional 'nitrogen fix' and 'disease break' but also as a cash crop in their own right.
- Growing new varieties to maximise their advantages will assist growers in producing a viable, quality pulse product to sustain their farming system and markets.
- Trials in irrigation regions are investigating the suitability of new pulse varieties under best management guidelines and assessing their value in the rotation.

There is potential for pulse expansion in the irrigation districts of southern New South Wales and Victoria. Already growers are achieving consistently high yields with faba beans, field peas and new chickpea varieties that fit into the various irrigation rotations and farming systems. Factors, such as disease, weeds and waterlogging, that limited yield have been identified and overcome through paddock selection, better layouts and management of the latest, improved varieties.

Rotations

Paddock rotations are extensively used on irrigation. While there appears to be no 'standard' rotation there is an awareness of not extending cereals (including rice) past two consecutive crops, and the need to include other crops such as pulses, canola or several years of legume-based pasture (if livestock are involved) in rotations.

Rice, which is grown on contour layout, continues to be a high priority for growers, taking up to 30% of the farm area. Cereals are commonly grown in rice rotations. However, bed layouts used for summer crops such as maize allow planting of a greater range of winter crops such as faba beans and canola as well as cereals. The ability to water

up crops and irrigate more often on beds with less risk of waterlogging is a decided advantage, but good border-check layouts and free draining soils can achieve similar results.

Determining the most suitable rotation requires careful planning with the dual aims of sustainability and highest overall profit. The rotation must be flexible enough to cope with key management strategies such as maintaining soil fertility and structure, controlling crop diseases, and controlling weeds. Commodity prices must also be considered however not as a key driver at the expense of other long-term benefits.

The nitrogen benefit

Pulses provide many benefits in cropping rotations, including the ability to fix atmospheric nitrogen (N_2), resulting in more soil nitrogen (N) for cereal crops. The amount of N fixed is determined by how well the crop grows. Crop growth reflects nodulation effectiveness, seasonal conditions, management, and the level of nitrate in the soil at planting.

Table 3a.10.1 below shows the total nitrogen fixed in both above-ground (shoots) and below-ground (roots and nodules), which in faba beans is about 30% of total biomass.

The nitrogen balance is the difference between the inputs (nitrogen fixation and nitrogen applied) and outputs (nitrogen harvested in grain or hay and nitrogen volatilized from the crop and soil). The nitrate-N benefit is the extra nitrate-N available at sowing in a soil that grew a pulse crop in the previous season compared with one that grew a cereal crop.

Table 3a.10.1. The nitrate-N benefit from faba beans, over a range of grain yields

Grain yield (t/ha)	Shoot dry matter (t/ha)	Low soil nitrate at sowing (50 kg N/ha)			Mod soil nitrate at sowing (100 kg N/ha)		
		N fixed (kg/ha)	N balance (kg/ha) [#]	Nitrate-N benefit (kg/ha)	N fixed (kg/ha)	N balance (kg/ha) [#]	Nitrate-N benefit (kg/ha)
1.0	2.8	49	12	15	39	2	3
1.5	4.2	83	25	26	68	10	11
2.0	5.6	120	40	41	100	21	22
2.5	6.9	158	58	45	133	33	36
3.0	8.3	196	75	49	167	45	49
3.5	9.7	234	92	53	202	60	60
4.0	11.1	274	111	57	237	74	64

[#] Grain proteins used in the calculations of N balance were 23.1% for faba beans.

Source: Herridge D, Manning, W and McCaffery, D, 2006.

Table 3a.10.1 was derived from extensive research in the northern grains region of New South Wales. Use the table as a guide when assessing the potential for faba beans to fix reasonable amounts of N even under high soil N situations. It is possible to assume that a 4 t/ha faba bean crop will have a nitrate benefit of around 60 kg/ha to the following cereal crop. This is equivalent to 130 kg/ha of urea and grower experience has shown this often occurs when assessing a crop's total nitrogen requirement after faba beans.



Disease management

Pulses play a vital role in controlling major cereal root diseases, particularly take-all, root lesion nematode, and crown rot, which are all prevalent in irrigation soils. Take-all must have a cereal or grass host to survive. As a non-host, pulses can be used very effectively as a one-year disease break-crop in a cereal rotation, provided other grasses and volunteer cereals are controlled. Root lesion nematodes *Pratylenchus neglectus* and *Pratylenchus thornei* in southern cropping regions can cause root damage and yield losses. They have a wide host range including cereals, grass weeds, pasture, forage legumes and oilseeds. With the exception of chickpeas, pulses have good resistance to both species and so reduce nematode populations in cropping rotations.

Crown rot is harder to control and is more prevalent in the north of the State. Control of this disease involves the strategic use of pulses and oilseeds as a break crop. Pulses and oilseeds with denser canopies, such as faba beans, can aid in the breakdown of infected cereal residue.

Cereal root diseases become more prevalent in years when cereal rotations are extended beyond two successive crops. Yield losses can be quite significant without careful attention to rotations involving break crops. The combination of higher soil N and reduced root diseases is cumulative and can result in a dramatic increase in subsequent cereal yields.

Stubble management

Improved stubble management reduces the need to burn, builds soil structure and reduces fuel and labour costs through direct drilling. Pulses such as faba beans can be sown on wide rows up to one metre and chickpeas up to 80 cm, enabling inter-row spraying with non-selective herbicides using hooded shields, and inter-row cultivation. Sowing pulses between standing rows of cereal stubble is now becoming possible with GPS guidance and autosteering systems enabling greater trash clearance through heavy stubbles.

New pulse varieties

New pulse varieties have been released in recent years with yield and disease resistance advantages for irrigation growers. 'Variety Management Packages' (VMP) are available for these new varieties of faba beans, field peas and chickpeas.

Faba beans

In 2005, many southern bean growers took on Farah[Ⓛ] as the new variety to replace Fiesta. The new variety Nura[Ⓛ] has been sown for seed increase with similar resistance to ascochyta and improved resistance to chocolate spot and rust.

The Nura VMP outlines how to place less emphasis on ascochyta control, without ignoring the risk, and concentrate more on chocolate spot control in high-risk situations.

The key points are:

- No foliar fungicide for ascochyta control at 6–8 weeks post-sowing is needed unless there is a severe ascochyta risk. Cercospora may however need controlling.
- At early flowering to podfill, concentrate on foliar chocolate spot control.
- Ascochyta control measures through rotation and isolation distances from bean stubble will still be required with Nura in high-risk situations.
- Nura is shorter than Fiesta and Farah and may be less inclined to lodge.

Nura seed increase blocks should be well isolated from other faba bean crops to ensure cross-pollination does not occur with older varieties.

Field peas

Interest in peas has been strong, particularly in the erect variety Kaska[Ⓛ] that can be grown on beds and has shown consistent yields of 3 t/ha or better with less input costs than most other crops.

The Kaska VMP suggests to growers that:

- using higher plant populations may be beneficial with Kaska
- downy mildew control is not needed
- closer management to avoid bacterial blight may be needed with Kaska
- monitor closely for insects during the short flowering and podding period
- crop topping is possible with Kaska despite its bulkiness

- Kasper can be easier to harvest, but avoid excessive harvest speeds, and harvest on time. Header modifications may be required.

Chickpeas

The new disease-resistant chickpea varieties for the southern region became available in 2005, starting with the desi Genesis™ 508. A new release last year has seen a small kabuli type called Genesis™ 90 distributed widely in southern regions including irrigation.

Through the VMP, growers of the new Genesis series of ascochyta-resistant chickpeas can be confident that:

- they only require one foliar fungicide to protect from ascochyta pod infection to ensure seed quality
- the new varieties are also being trialed and grown under irrigation this year
- the market will accept the new chickpeas but established varieties may be preferred
- the southern desi chickpea industry can re-establish and grow with these more reliable varieties.

Two new desi varieties from the NSW DPI at Tamworth have also been released. They are named Flipper[®] and Yorker[®], and have improved disease resistance bred initially for the northern chickpea region. Trials are now being conducted to look at their suitability in other regions and rainfall zones in NSW including irrigation areas. There is further research into kabuli types that can attract premiums, but size is very important in this limited and discerning market.

Conclusions

- evaluate the advantages of crops by determining rotations, and gross margins of each particular rotation
- wheat crops following break crops such as faba beans regularly show yield responses that are 20% above those of wheat following wheat
- use pulses in integrated weed management to help control resistant weeds
- diversity of crops in a rotation is important particularly for continuous-cropping systems that now prevail in most irrigation areas.

References

Herridge, D, Manning, W and McCaffery, D 2006, 'Nitrogen Benefits of Chickpea and Faba Bean', *Internal update for NSW Department of Primary Industries extension staff*, NSW DPI.



3a.11 What is Yield Prophet®?

James Hunt et al.

Birchip Group, Murray Irrigation, CSIRO Sustainable Ecosystems/APSRU
Information sourced from the Birchip Group web site, 2008

Key points

- Yield Prophet® is an on-line crop simulation service with great potential for irrigation scheduling and nitrogen management.
- Accuracy is currently limited by the quality of available soil characterisation data however this is improving with Grains Research & Development Corporation (GRDC) funding of a project to characterize soil types.
- Yield Prophet is 'data hungry' and requires an investment in time to set up and learn to use properly, but is incredibly powerful once this has been achieved.
- With current high grain and input prices, managing climate variability and production risk is more important than ever. Yield Prophet is the best tool available to assist with this.

Yield Prophet is a web interface for the crop production model APSIM (www.apsim.info). It simulates crop growth based on paddock-specific inputs of soil type, pre-sowing soil water and nitrogen, rainfall, irrigation and nitrogen fertiliser applications, and climate data.

Yield Prophet was developed by the Birchip Cropping Group (BCG) in collaboration with CSIRO as a risk management tool for dryland farming systems in the Victorian Wimmera and Mallee, with an emphasis on decision support for nitrogen fertiliser inputs. It was first used for wheat at BCG trial sites in 2002, and its early predictions of the failure of that season generated sufficient interest and credibility to allow a commercial release to BCG members in 2003 as a monthly fax-out service. Continuing demand resulted in the development of the Yield Prophet web-interface, which allowed a larger number of subscribers to receive up-to-date crop information and forecasts in 2004.

2005 was the first year of general commercial release of the service, and 338 paddocks were subscribed to the service from across Australia and over 6800 reports were generated during the season. Subscriptions grew in 2006 to include 540 paddocks, and over 9000 simulations were generated.

How does Yield Prophet work?

Subscription

Farmers or consultants subscribe to the service in late summer and autumn and provide the Yield Prophet team with their paddock names, locations (used to determine soil type and closest Bureau of Meteorology weather stations) and planned crops and varieties.

Subscribers are then given a user name and password allowing them to log onto the Yield Prophet website. Growers are also able to nominate a consultant with whom they wish to access Yield Prophet, and this consultant is also given access to the grower's paddock data.

Soil sampling

During autumn, subscribers sample their Yield Prophet paddocks' soil at different depth intervals down to the maximum rooting depth of their crop (e.g. 0–10, 10–40, 40–70, 70–100 cm). These samples are analysed for water content, nitrate concentration, organic carbon, electrical conductivity, chloride concentration and pH. These data are entered by growers into the Yield Prophet web interface, and are also used by the grower and Yield Prophet team to select a suitable soil characterisation.

Soil characterisation

An appropriately measured soil characterisation is an essential input for Yield Prophet to simulate crop growth, yield and protein accurately.

The plant available water capacity (PAWC) and bulk density of a specific soil type determine how much of the measured water and nitrogen is available to the crop for growth during the season. PAWC is determined by a soil's 'drained upper limit' (DUL, or field capacity) and its 'crop lower limit' (CLL, similar to permanent wilting point).

The Yield Prophet team have a 'library' of soil characterisations measured for many of the major cropping soil types found throughout Australia. However, many subscribers have soil types for which there are no available measured characterisation data. In these circumstances, a soil characterisation is estimated by the Yield Prophet team based on soil type and previous rainfall and crop yields provided by the growers, and any information available from existing soil surveys. An estimated characterisation is less likely to produce accurate results in comparison to a measured characterisation, and it is recommended that potential subscribers to Yield Prophet consider characterising their soil if no appropriate data exist. For more information, please contact Neal Dalglish on (07) 4688 1376, mobile 0427 725 955.

Crop growth simulation

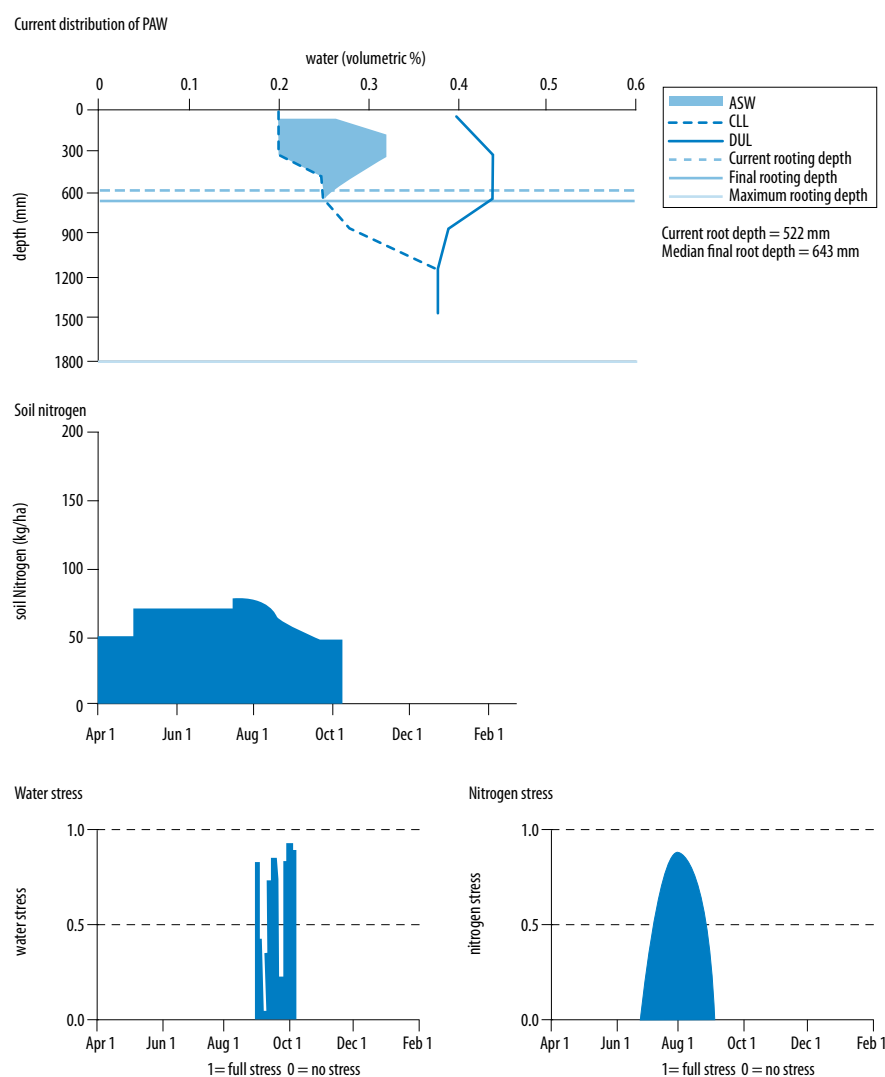
During the season, subscribers enter paddock management details (sowing date, crop type, variety, nitrogen fertiliser and irrigation) and rainfall. When growers wish to

find out how much water and nitrogen is currently available to a crop, the likely yield of their crop, or what the likely impact of management events will be, they generate a report.

When a report is generated, Yield Prophet simulates daily crop growth from sowing up to the present using the paddock specific rainfall and management data entered by the subscriber, and climate data (maximum and minimum temperature, radiation, evaporation and vapour pressure) from the nominated BOM weather station.

At every daily time step, Yield Prophet calculates the amount of water and nitrogen available to the crop, and the water and nitrogen demand of the crop. This is used to determine if the crop is suffering stress from lack of either of these resources, and any subsequent reduction in growth and yield potential. This information is then presented to subscribers in reports returned to the subscribers' account (Figure 3a.11.1).

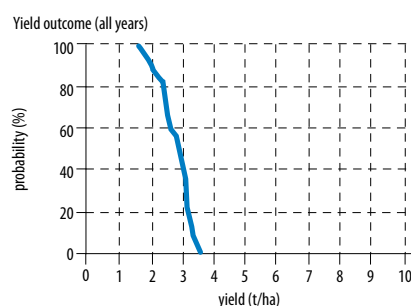
Figure 3a.11.1. Output from Yield Prophet indicating the amounts of water and nitrogen available to the crop during the season. The stress graphs indicate loss of potential growth and carbon fixation, i.e. on a day when the graph is at 0.5, the crop is growing and photosynthesising at half its potential rate.



Yield prediction

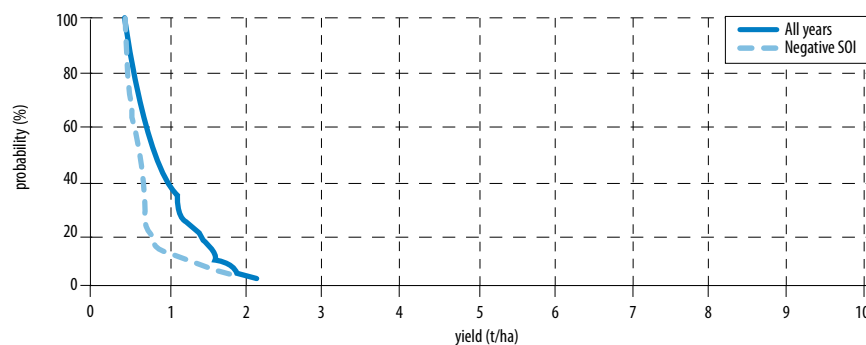
In order to make predictions about crop yield, Yield Prophet uses the last 100 years of climate data taken from the nearest BOM weather station to continue the simulation from the date of report generation to the end of the season. The model simulates 100 different crop yields and proteins, based on the current season up until the day the report is generated, and on the season finishes of the past one hundred years. These yields are then plotted as a probability curve (Figure 3a.11.2), which provides growers with an estimate of the probabilities of obtaining different yields. This range of probabilities narrows as the season progresses and components of yield become more certain.

Figure 3a.11.2. A yield probability curve, the main output from Yield Prophet.



This is the main output of Yield Prophet, and its value is increased by incorporating seasonal forecasts, such as the Southern Oscillation Index (SOI) phase system. In this case, instead of using season finishes for the last 100 years, Yield Prophet selects the years in which the SOI phase was the same as in the current year, and runs the future part of the simulation using only the finishes from those years. This creates another probability curve which growers can use if the SOI phase is strongly indicating wet or dry conditions (Figure 3a.11.3).

Figure 3a.11.3. Yield probability curve generated using season finishes for the last hundred years of climate data (solid blue line), and only those years in which the SOI phase was the same as the current phase at the time the report was generated. In the above example, this is the years with a negative SOI phase in July-August; the report was generated for a paddock near Birchip on 1 September 2006.



The 30 day mean SOI for August was -14.14, it was -8.57 in July.

Scenario predictions

The likely impact of different sowing dates, varieties and irrigation and nitrogen applications can then be determined by simulating different 'scenarios'. Yield Prophet calculates a probability curve for each scenario, and subscribers use this to determine the probability of achieving a yield or protein response from the addition of water or nitrogen (Figures 3a.11.4 and 3a.11.5), or from different sowing dates and varieties (Figure 3a.11.6). Yield Prophet can also calculate a nitrogen gross margin based on likely grain quality and price (Figure 3a.11.7).

Figure 3a.11.4. Yield probability curves for three different nitrogen top-dressing scenarios generated for a dryland wheat crop on 1 August 2005. Scenario 1 (dark blue line) is the yield probability adding no further nitrogen, Scenario 2 (blue line) is the yield probability with 35 kg/ha of nitrogen top-dressed on 15 August, Scenario 3 is the yield probability with 70 kg/ha of nitrogen top-dressed on 15 August 2005. There is an 80% chance of achieving a yield response with topdressing, and about a 50% chance of achieving a 1 t/ha yield response from 35 kg/ha of nitrogen.

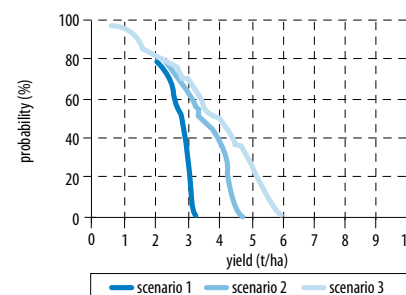


Figure 3a.11.5. Yield probability curves for three different nitrogen and irrigation scenarios generated for an irrigated wheat crop on 3 October 2005. Scenario 1 (dark blue line) is the yield probability adding no further water or nitrogen, Scenario 2 (blue line) is the yield probability with an additional 50 kg/ha of nitrogen top-dressed on 3 October, Scenario 3 is the yield probability with 50 kg/ha of nitrogen top-dressed on 3 October and two additional 25 mm irrigations on 3 and 17 October.

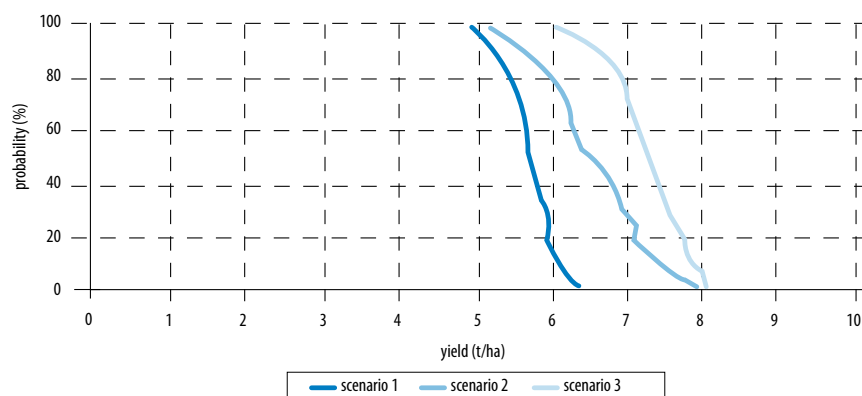


Figure 3a.11.6. Yield probability curves for three different sowing date scenarios (sowing dates are shown above the graph) generated for a wheat crop at Birchip crop on 21 June 2005.

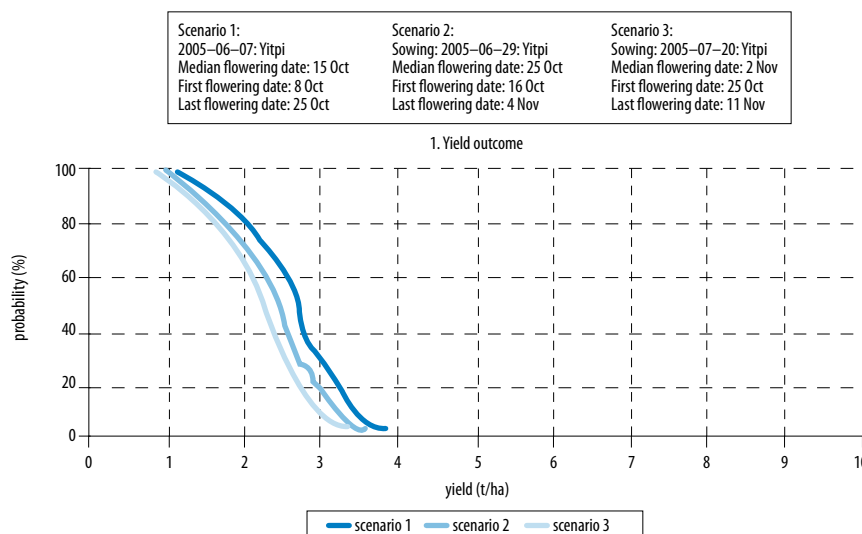
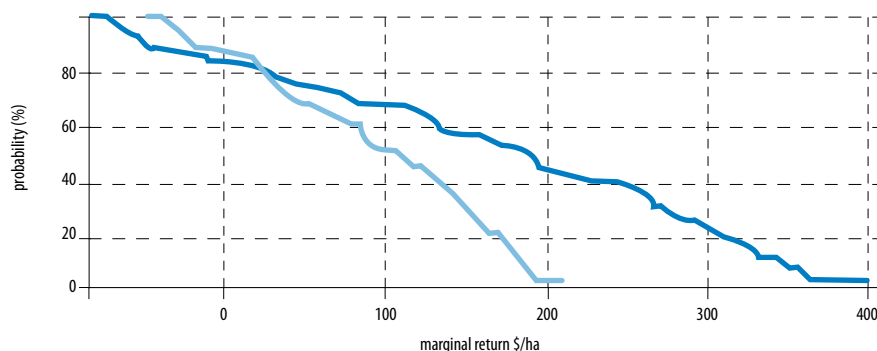


Figure 3a.11.7. Nitrogen profit curves for the same two nitrogen application scenarios shown in Figure 3a.11.4. Each line is calculated as the return from grain (determined by yield and protein minus cost of fertiliser and spreading) for Scenarios 2 (dark blue line, 35 kg/ha of nitrogen) and 3 (light blue line, 70 kg/ha of nitrogen) from Figure 3a.11.4, minus the return from Scenario 1 (adding no further nitrogen). This shows the difference in return between applying nitrogen of specified amounts, and not applying nitrogen. In this case it assumed the cost of fertiliser as \$0.95 per kg of nitrogen, cost of spreading as \$5 per ha and that the wheat price would be APW at \$160 per tonne, with a \$2 per 0.5% protein bonus.



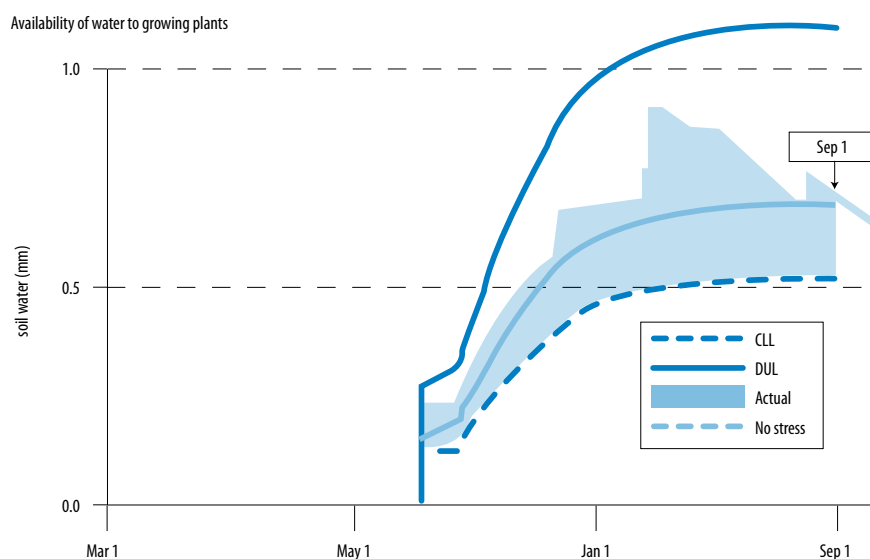
Irrigation scheduling

Because Yield Prophet calculates the amount of water available to a crop, and average evaporation and transpiration based on 100 years of data. It has the potential to be a very effective tool for irrigation scheduling.

Figure 3a.11.8 shows the Irrigation Scheduling Report from Yield Prophet. The graph shows the PAWC of the soil being accessed by the crop as roots grow, and the amount of PAW calculated from initial measured soil water plus rainfall and irrigation, minus evaporation and transpiration. The dotted line is a projection of PAW over the future two weeks assuming no rain, and growers can use this to determine when to water, and how much water to apply. The impact of any irrigation can be calculated from the probability curves in the irrigation comparison report described above (Figure 3a.11.5).

This output is also very useful for dryland crop management, as it provides an indication of the amount of water that is available to a crop at any point in the season.

Figure 3a.11.8. The graphic display of soil water from the Irrigation Scheduling Report in Yield Prophet.



You can visit the Yield Prophet website www.yieldprophet.com.au to view previously generated reports for the BCG trial site and access help files which will tell you more about operating Yield Prophet and how to interpret reports. Simply respond to Username and Password by typing in Visitor.

For further information contact: James Hunt – Yield Prophet Co-ordinator, BCG

Phone: (03) 9354 1654

Mobile: 0429 922 787

Email: james.hunt@aanet.com.au



3a.12 Diseases in irrigated wheat systems, stripe rust and septoria tritici blotch

Andrew Milgate

NSW DPI, Wagga Wagga

Information sourced from August 2005, Grains Research & Development Corporation, Research Update for Growers, Southern Region (Irrigation) Griffith

Key points

- Foliar disease management should be built around individual variety resistance make up.
- Choose varieties to minimise risks of major pathogens in your region.
- Industry wide choice of more resistant varieties when available has large positive effects on foliar disease management.

Varietal selection is the key platform on which foliar disease management strategies are based in any cropping system. Knowing the potential risks associated with a particular variety will help determine the appropriate response to any disease.

Irrigated wheat systems are high disease risk environments as they contain several ingredients which increase the risk of disease development. These ingredients include high plant densities, high humidity and high inputs of fertilisers.

Stripe rust

There are a number of publications available from NSW Department of Primary Industries (NSW DPI) and on the Grains Research & Development Corporation (GRDC) website that have clear messages about stripe rust management. All these publications present essentially the same message.

Delay the epidemic onset – How?

Control the green bridge

Stripe rust requires living wheat plants to survive. So eradicating volunteer wheat plants over summer reduces the risk of early infection in fields.

Varietal choice

The choice of sowing varieties with disease ratings of MR-MS or better has a three-fold effect on the management of the disease. Firstly, there is a reduction in the required fungicide management of the disease because of the ability of the plant to resist infection. Secondly, volunteers of more resistant varieties reduce the potential of stripe rust surviving over summer in high numbers. Thirdly, growing moderately resistant to resistant varieties reduces the risks of the pathogen rapidly mutating and new strains forming that are capable of overcoming other resistance genes.

Fungicide management

Consider three factors when deciding on fungicide management. Firstly, tailor the strategy to the resistance rating of the variety. For example, for varieties with a resistance rating of VS-S, a seed or fertiliser treatment in addition to one or more foliar applications, depending on the epidemic development, should be considered. Second, monitor the crop to decide if disease threatens economic returns. And finally, to be cost effective, timing of the application is critical.

Varietal choice for irrigation

In response to the new strain of stripe rust, breeding programs around Australia are moving quickly to release more resistant alternatives.

The highly resistant varieties are clear winners when the available varieties in southern NSW are compared on the basis of gross return, after the cost of stripe rust control on dryland systems is considered. However, on irrigation there is greater variation of yield potential in the available varieties and the achievement of maximum quality grades is less likely for the Australian Prime Hard (APH) and Australian Hard (AH) varieties.

Calculating the gross return of any variety is driven by the yield and price. Table 3a.12.1 gives an example of the type of comparison to consider when making varietal choices. Of the currently available varieties for sowing in 2005 and looking forward to 2006 Table 3a.12.1 shows that when yield and price differences are small the benefit of increased rust resistance is significant. The exception to this is Chara[Ⓛ] with a 6% ('Winter crop variety experiments', 2004, pp 212) yield advantage. However, the difference is only \$8.16/ha to Ventura[Ⓛ] which has the stripe rust rating of eight. The varieties with resistance ratings of MR-MS or above have the added benefit of control of the disease over summer and protecting the industry long term.

Table 3a.12.1. Example of an economic comparison of wheat varieties with expected stripe rust management to achieve maximum yield.

Variety	Chara	Ventura	Janz	Drysdale	H45	Rosella
Stripe rust management	Fert+fol	Nil	Seed+fol	Seed+fol	Fert+fol	Seed+fol
Across sites 1998–2004 (irrigation)	110	104	103	103	104	100
Across sites yield t/ha	6.42	6.07	6.02	6.02	6.07	5.84
Stripe rust rating**	MS-S	R-MR	MR-MS	MS-S	VS	MR-MS
Wheat price \$/t	\$142.14	\$142.14	\$142.14	\$142.14	\$142.14	\$129.70
Gross return \$/ha	\$912.54	\$862.79	\$855.68	\$855.68	\$862.79	\$757.45
Seed/in-furrow fungicide	\$21.60	\$0.00	\$6.20	\$6.20	\$21.60	\$6.20
Smut/bunt seed treatment	\$2.60	\$2.60	–	–	\$2.60	–
Foliar fungicide	\$7.00	\$0.00	\$7.00	\$7.00	\$7.00	\$7.00
Aerial application	\$12.00	\$0.00	\$12.00	\$12.00	\$12.00	\$12.00
End Point Royalty (EPR)	\$7.06	\$6.07	\$0.00	\$6.62	\$6.07	\$0.00
AWB bonus	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Gross return less stripe rust mgt costs and EPRs (\$/ha)	\$862.28	\$854.12	\$830.48	\$823.86	\$813.52	\$732.25
Difference between rank 1 and other varieties (\$/ha)	\$0.00	–\$8.16	–\$31.79	–\$38.42	–\$48.76	–\$130.03
Ranking on return	1	2	3	4	5	6

Please note: Several assumptions have been made to produce calculations. Maximum yield is achieved. No allowance for fertiliser input has been made to achieve specific quality grades. On irrigation APH varieties will achieve AH prices. Prices based on pool prices at Grong Grong on the 9/6/05.

* Calculation table courtesy of Mr. John Francis NSW DPI, District Agronomist Albury.

** Disease ratings based on 2005 data, updated ratings should be used for any analysis for subsequent years.



Septoria tritici blotch

Septoria tritici blotch (STB) is a social disease and is caused by *Mycosphaerella graminicola* (anamorph: *septoria tritici*). It is an important fungal disease of wheat worldwide. The disease can cause yield losses of up to 60% in susceptible cultivars in severe epidemics. In Australia, it is estimated that the disease costs the wheat industry \$28.3 million annually, with these losses concentrated in the southern and western cropping regions.

Genetic resistance

Genetic resistance is the best tool for ongoing control of this pathogen. During the 1970s and 1980s there was a shift away from highly susceptible cultivars to the wide-spread growing of moderately susceptible to moderately resistant varieties. This has contributed to the infrequency of the disease occurring in southern NSW (SNSW) at economically significant levels.

The pathogen is genetically diverse due to its heterothallic (sexual) mating system. This can lead to the evolution of new pathotypes emerging and spreading rapidly. The most recent information on the pathogen population in SNSW is that it is genetically distinct from the rest of the world and indeed distinct from the population in WA. What implications this has for the usefulness of overseas sources of resistance is under investigation.

There are currently 12 STB resistance genes which have had their chromosomal location identified in separate projects around the world. These genes are scattered

throughout the whole genome of wheat on different chromosomes. NSW DPI and the Value Added Wheat Cooperative Research Centre (VAWCRC) are about to begin a Grains Research & Development Corporation funded project focusing on bringing together many of these genes into several cultivars that have proven adaptation to Australian conditions. It is intended that this germplasm will help provide ongoing protection to the industry from this disease.

Management

The same basic principals apply to both STB and stripe rust control:

Control over summer survival of inoculum

Septoria tritici blotch does not require live wheat plants to survive over summer. Instead the fungus produces sexual spores which are capable of remaining viable during summer and autumn. These spores are found in the stubble of the previous susceptible wheat crops and are capable of travelling long distances in the wind. Thus an important part of management of STB is the removal of stubble prior to sowing the next season's crop.

Varietal choice

Genetic resistance has been very effective against this pathogen. It is important to avoid sowing susceptible and highly susceptible cultivars. This is particularly important in irrigated areas where high humidity levels are very conducive to epidemic development.

Timing of sowing

Early establishment of disease in a crop will lead to greater losses. This is very important for STB management as the spores which survive summer on the stubble are released early in autumn. Thus early sown crops experience greater disease pressure than those sown in the main season sowing window.

Fungicide management

Both fluquinconazole and triadimefon are registered for the control of STB. Foliar applications for the control of STB should only be considered in susceptible and highly susceptible varieties. Ensure the disease has been correctly identified prior to spraying because the symptoms are easily confused with other physiological damage or other pathogens.

Variety ratings for STB are available in the NSW DPI 'Winter Crop Variety Sowing Guide 2005'. This publication is updated and reprinted annually.

Maintaining resistance to social diseases

Breeding programs, through the release of resistant cultivars, save the agriculture industry millions of dollars every year across the spectrum of diseases. For example, in stripe rust prior to the most recent patho-type arrival, resistance breeding was estimated to be saving the industry \$161 million per annum (Brennan and Murray, 1998). The speed at which social diseases such as rusts or STB can overcome individual resistance genes and the devastating resulting costs have been clearly illustrated with the recent stripe rust incursion and subsequent epidemics.

To achieve greater durability of these genes the industry, breeding programs and growers, need to respond quickly to remove and replace susceptible varieties. This will help ensure that other effective genes are not placed under increasing pressure by rapid increases of the pathogen population. By working together in this fashion the industry can sustain effective genetic resistance and have minimal requirements of fungicides.

References

- Brennan, J P, and Murray, G M
1998, *Economic importance of wheat diseases in Australia*, NSW Agriculture, Wagga Wagga.
- McRae, FJ, McCaffery, DW, and Matthews, PW 2005, *Winter crop sowing guide 2005*, NSW Department of Primary Industries, Orange.



3a.13 Irrigation and grains disease interactions

Dr Damian Herde

Department of Primary Industries & Fisheries, Queensland

Key Points

- Irrigation is likely to exacerbate diseases of grains.
- Break crops may not give adequate control.
- Use resistant varieties where possible.
- Employ specific management activities for specific diseases.

Winter cereals are a useful and profitable rotation in a cotton system. However, the range and importance of potential diseases for irrigated winter cereals differs from dryland winter cereal farming. The impact of some diseases, such as crown rot (see *Root and Crown Diseases of Wheat and Barley in Northern NSW* in Section 3a Attachments) may be reduced with irrigation as they are more damaging when moisture stress occurs during grain-fill. Other diseases, such as yellow spot and stripe rust, where infection and disease progress is favoured by moist/humid conditions within the canopy, may be more serious under irrigation than under dryland farming practices. The increased biomass of irrigated winter cereal crops is likely to provide more favourable conditions for the development of a range of leaf diseases within the canopy of irrigated winter cereal crops.

Soil or stubble testing is available to inform the grower if any cereal diseases are present in the soil or remaining winter cereal stubble. A range of wheat varieties are available with a broad range of genetic resistances to many diseases, and knowing which diseases are present enables selection of the best choice of variety, providing the maximum disease protection as well as yield. An accredited agronomist can provide information on this testing.

If the cotton diseases black root rot (caused by *Thielaviopsis basicola*) or Fusarium wilt (caused by *Fusarium oxysporum* f.sp. *vasinfectum* (Fov)) are already present in a field, wheat will not be a useful break crop for their control. Further advice should be sought for control recommendations.

Crown rot

Crown rot is caused by the fungus *Fusarium pseudograminearum*. The crown rot fungus is stubble borne with initial infections favoured by good moisture availability early in the growing season. Crown rot infection is characterised by a brown discolouration of the base of infected tillers. However, severe yield loss through the production of whiteheads, which contain either no grain or is shrivelled and light weight, is related to moisture stress during grain-fill. Dry and hot conditions during grain-fill increase the formation of whiteheads in tillers infected with crown rot. Irrigation during flowering and grain-fill will minimise the potential damage.

Irrigation of cotton crops (a break crop for winter cereals) and pupae busting following cotton will increase the rate of decomposition of cereal stubble. This will help reduce crown rot inoculum levels carried into future seasons. Durum wheats are very susceptible to crown rot,

and additional care should be taken when growing these, or other highly susceptible wheat varieties. Barley is also susceptible to crown rot.

Common root rot

Common root rot (CRR) is caused by the fungus *Bipolaris sorokiniana*. The common root rot fungus survives primarily as thick-walled spores within the soil or on cereal residues. Soil moisture favours sporulation and infection by the CRR fungus. Common root rot infects the sub-crown internode causing a dark brown discolouration and reduced efficiency of the primary root system. Severely infected plants appear stunted and produce fewer tillers, although this disease has a minor impact on yield compared to crown rot. Partially resistant varieties are available. In irrigated crops it may be possible to reduce the sowing depth to limit the length of the sub-crown internode and hence infection by CRR.

Fusarium head blight

Fusarium head blight (FHB) is caused primarily by the fungus *Fusarium graminearum*. Fusarium head blight is favoured by wet/humid conditions during flowering and grain-fill. Climatic conditions mean that this disease is generally uncommon in Australia and has mainly occurred in limited areas such as the Liverpool Plains in northern NSW. However, warm weather (25° to 30°C) and overhead irrigation during flowering will provide a favourable environment for infection. Durum wheats are very susceptible to FHB, and additional care should be taken when growing

these, or other highly susceptible wheat varieties. Most Australian barley varieties are two-row which are generally more resistant to FHB infection. Maize and sorghum are both hosts of the causal fungus which must be considered if included in rotation with wheat.

Yellow spot

Yellow spot is caused by the fungus *Pyrenophora tritici-repentis*. This disease produces leaf lesions which are evident as tan spots surrounded by a yellow margin. The yellow spot fungus survives as small black fruiting bodies (pseudothecia) on wheat stubble. Infection is favoured by moist conditions during the growing season which stimulates the release of spores from the pseudothecia into the canopy. Yellow spot develops rapidly when leaves are wet for extended periods of time. The disease will spread up the plant with water splash of the fungal spores produced on infected lesions. Significant yield loss occurs if enough green leaf area is destroyed, particularly if the disease progresses to the flag leaf. Dense canopies, which are likely when growing wheat under irrigation, will provide a microclimate more conducive to the cycling of yellow spot within the crop. Chemical control is available, and should only be used after taking into consideration the risk of further damage and the economics (grain price, cost of spraying, potential yield, potential loss). Varietal resistance is available and susceptible varieties should be avoided in an irrigated system.

Stripe rust

Stripe rust is caused by the fungus *Puccinia striiformis*. Stripe rust is evident on leaves as yellow/orange pustules or blister-like swellings with powdery spores. Once past the seedling stage the pustules form in stripes which run parallel with the leaf veins. Stripe rust decreases yield and increases screenings by reducing the green leaf area of the plant. The stripe rust fungus requires a living host plant to survive between wheat crops. Spores are capable of moving great distances on the wind, which allows rapid disease spread over large areas. Following establishment of stripe rust in a crop, subsequent disease cycles will depend on climate (especially temperature and humidity in the canopy) and available host material that is vulnerable to infection. A new generation of spores will emerge in 10–15 days, depending on temperature, with the ideal temperature for stripe rust being 15° to 20°C. The denser canopies of irrigated wheat crops and maintenance of soil moisture under irrigation is likely to produce conditions more conducive to the cycling of stripe rust within the wheat canopy. Resistance is available in commercial varieties. If growing moderately susceptible varieties, a fungicide control program should be considered. Very susceptible varieties should be avoided.

Leaf rust and stem rust can also affect wheat, but current varieties have good levels of resistance to these two rusts.



Root lesion nematode

Root lesion nematode (RLN) is caused by the nematodes *Pratylenchus thornei* and *P. neglectus*. Root lesion nematode does not produce very obvious symptoms within infected crops. Infected plants may appear to be nutrient deficient and performing poorly, stunted and prone to wilting even when there is good soil moisture. Across a paddock RLN may cause an unevenness or waviness in a standing crop. Severely affected plants are yellow, have fewer lateral roots and may have indistinct brown lesions along the roots. The nematodes live within the roots and diagnosis can only be confirmed through laboratory testing. Non-host crops or tolerant wheat varieties should be grown where RLN is known to be high. Nematodes are spread by surface water, vehicles and farm machinery, so hygiene measures should be adopted to prevent introduction and spread within a property.

Black Point

Black point is believed to arise from the production of various enzymes within the grain under humid conditions during grain-fill. This results in the undesirable blackening of the germ end of the grain and results in the discounting of grain prices at receipt. High humidity with the warmer temperatures during grain-fill will contribute to greater black point discolouration. Irrigation and in particular overhead irrigation (depending on timing of watering) may provide an environment more

conducive to the development of black point. There are many wheat varieties with high genetic resistance to black point which should be considered when selecting varieties.

Damping-off

Damping-off or rotting of seedlings at the soil level or before they emerge, is not normally a problem in dryland farming systems. Excessive irrigation, waterlogging or irrigating poorly-drained soils could lead to seedling damage by a number of pathogens, such as species of *Pythium*. Dividend® seed treatment which contains the fungicide metalaxyl will help limit seedling damage from *Pythium*. However, careful management of soil moisture under irrigation during the seedling stage should avoid this problem. Damping-off fungi do not generally cause problems beyond the seedling stage.

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3a.14 Managing crown rot in irrigated farming

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Key points

- To be used in conjunction with the brochure, *Root and Crown Diseases of Wheat and Barley in Northern NSW* in Section 3a attachments.
- Major yield loss from crown rot arises when moisture stress occurs during grain fill which results in the formation of whiteheads in infected tillers.
- Under-irrigation moisture stress can be minimised during grain fill to reduce the impact of crown rot on final yield.

Crown rot and moisture stress risk

Irrigated cereal production faces a greater risk from crown rot and moisture stress as it targets higher yields, and has higher water and nutrition requirements. Crown rot can be effectively managed and the rewards for simple crown rot management far outweigh any yield reduction resulting from the disease.

Exposure to reduced yields from crown rot infection is dependant on the combination of two factors. Firstly, the level of crown rot inoculum and secondly, the degree of crop moisture stress later in the season. Non stressed crops will tolerate some crown rot with minor reductions in yield. However reductions in yield will occur if crops with any level of crown rot become moisture stressed. This effect is intensified if the plant is stressed at or after flowering, where infected tillers will produce a whitehead which either produce pinched or no grain.

Rotation management

Management of rotations to avoid a build up of crown rot inoculum in a paddock is the best way to avoid yield losses due to crown rot. This makes it vital that growers know the crown rot history of their paddocks.

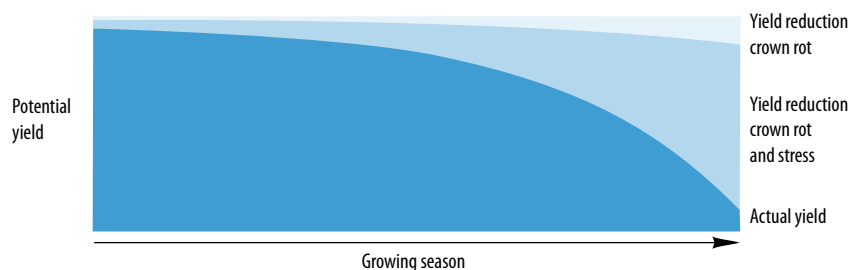
Paddock history

How many years since there has been a crown rot host in the paddock? All winter cereals (including barley), and many grasses (crops and weeds) are hosts for crown rot.

Rotational crops

Has there been a rotation to any non-host break crop, such as field peas, canola, faba beans, chickpeas or summer crops?

Figure 3a.14.1. Increased loss of yield due to crown rot and interaction with moisture stress



Quality of break

Crown rot requires cereal stubble as a host. Was the break crop and season effective in decomposing stubble? Is any cereal stubble still visible?

Partially resistant varieties

What was the level of resistance in the previous cereal varieties? Resistant varieties may not suffer significant yield loss while still building up crown rot inoculum. Information on resistant varieties is available in the *NSW DPI Winter Crop Variety Sowing Guide* and from district agronomists.

Test for crown rot

A commercial test for the level of crown rot inoculum in a paddock is available. Contact a district agronomist for further information and if in doubt, test paddocks for crown rot.

Crop choice

Your crop and rotation choice should take into account the risk associated with crown rot. Once the risk of crown rot is evaluated based on the level of crown rot in the paddock, three management options include:

1. If there is a **high level of crown rot**, rotate out of the crown rot cycle into a break crop. Any moisture stress in a non-resistant variety may impact on yield dramatically.
2. If there is a **low level of crown rot** in the paddock, choose resistant varieties and avoid any possible moisture or nutrient stress, especially around or after flowering. Resistant varieties will not totally eliminate the risk of reduced yield. Rotation out of any possible host is the best option.
3. If there is **no crown rot** in the paddock, choose according to other factors. Take advantage of high yielding varieties that are not resistant such as Durum.

Avoid moisture stress

If a crop is infected with crown rot, moisture must be managed to achieve maximum yield without increasing the risk of stress. Develop water management plans to avoid water stress to crops with crown rot especially at the critical times of during and after flowering. This will limit the formation of whiteheads in tillers infected with crown rot. Develop an accurate nitrogen budget that will make use of only the water that is available and not exacerbate moisture stress.

In Figure 3a.14.2, light blue indicates where moisture stress should be avoided and dark blue indicates where it must be avoided.

Further information

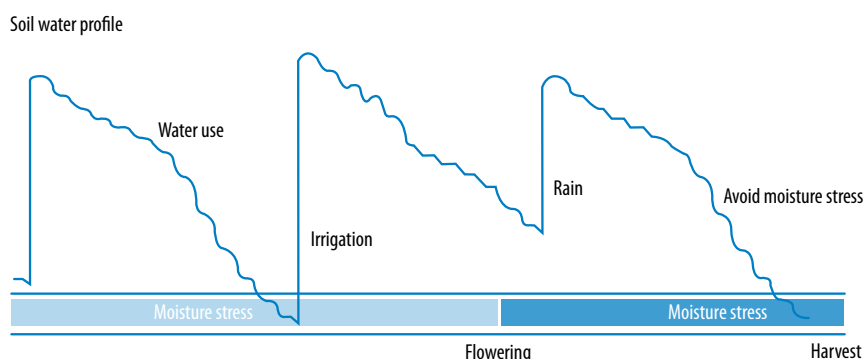
Moore, K, Manning B, Simpfendorfer S, and Verrell A 2005, *Root and Crown Diseases of Wheat and Barley in Northern NSW*, NSW Department of Primary Industries.

McRae, FJ, McCaffery, DW, and Matthews, PW (updated annually) *Winter Crop Variety Sowing Guide*, NSW DPI (available from all NSW DPI offices).

NSW Agriculture 1998, *Nitrogen Budgeting for Winter Cereals*, ISBN 0 7313 1480 8.

NSW DPI website,
www.dpi.nsw.gov.au

Figure 3a.14.2. Soil moisture probe trace showing moisture stress. Light blue indicates where moisture stress should be avoided and dark blue indicates where it must be avoided.





IRRIGATION RESEARCH & EXTENSION COMMITTEE

2004



FOR IRRIGATION CROPPERS

Achieving Higher Irrigated Wheat Yields

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Take home message

Results with the GRDC funded irrigated wheat project highlight some **important factors to build a crop structure for achieving high yields** in southern region irrigation areas with reduced lodging risk and with best use of nitrogen and available irrigation water:

- Soil conditions allowing good anchorage with roots
- Variety with stem and straw strength
- Sowing after Anzac Day
- Flowering in the last week of September
- Restricting tillering to attain 600 to 800 shoots per sqm
- Limited early growth with less than 70% ground cover at early stem elongation
- Avoiding water stress during stem elongation to maintain highest yield potential
- More than three green leaves per shoot at flowering to maintain highest yield potential.

Irrigation strategies with increasing water allocations for average soil capacity (80mm refill point) and rainfall:

- first a pre-sowing irrigation if subsoil moisture is inadequate, and
- one at heading for 3–4 t/ha, or
- two: at heading and after flowering for 5–6 t/ha, or
- avoiding water stress with three: at mid-stem elongation, before flowering and at early grain-filling for 7–8 t/ha.

Problems limiting wheat yields

Water allocations have recently been (very) low and uncertain in most irrigation areas of eastern Australia, making choice and areas of crops to grow very difficult. High returns per megalitre (ML) are now imperative. Some crops, like rice, need a set amount of water to be profitable, while others may have a more linear relationship between water supplied and yields harvested. Winter cereals are in the latter group and supplemental irrigation to augment winter rainfall and stored soil moisture is a highly effective use of irrigation water in the relatively mild conditions during winter and spring. Tactical irrigation management when water becomes available can be highly profitable when crop structure has been set up properly. Paddock choice, sowing time, variety choice, plant establishment and nitrogen management are important factors in building a crop responsive to water and yielding up to 7–8 t/ha as water becomes available. Guidelines for best management practices have been described in Wheat Check Recommendations (NSW Ag).

Paddocks with high fertility sown early will usually result in (lodged) crops with a low or very low harvest index, the fraction of total biomass as grain, and hence a heavy stubble and low water use efficiency (WUE), especially if more fertiliser is applied. Grain quality and screenings may be affected. Management to overcome these problems starts with the right combination of sowing date and variety to get the timings right and grow the best crop on a given paddock. A high fertility paddock sown early with a winter wheat can be grazed and still yield 5–6 t/ha, a proper target under such conditions. Pre-sowing nitrogen fertiliser needs always to be conservative for high yields and the crop then needs to be managed to achieve proper shoot density, green leaf area and duration, and reduced lodging risk. Efforts in canopy management can go to waste when managing a less than optimum variety-sowing date combination.

Lodging in winter cereals is a major problem in the southern irrigation areas as spring irrigations occur in the windiest months of the year. Saturated soils during irrigation greatly reduce the anchoring strength of plants in heavy crops. Lodging is a major risk when targeting high yields and may result in high screenings, low

test-weight, risk of weather damage and slowed harvesting. The project evaluates genetic and agronomic solutions to avoid yield losses of up to 3 t/ha caused by lodging.

The project

The GRDC Irrigated Wheat Evaluation Project (2001/05) for the irrigation areas in the southern region is described and 2002 research results are presented on the GRDC website under Research Updates – Irrigation. Progress reports for 2002 and 2003 have been presented in the IREC Farmers' Newsletter Large Area Editions no. 164 and 166, respectively.

Field trials have been conducted in 2002 and 2003, with 2004 in progress, at Griffith, Benerembah and Deniliquin with the evaluation of some 180 genotypes (ie varieties and breeding lines) from most breeding programs in Australia, Crop and Food Research in New Zealand and CIMMYT in Mexico. Additional experiments at Griffith involved sowing dates, sowing rates, nitrogen timing, growth regulators and fungicides, which are being conducted again in 2004.

All our current varieties depend on one of two dwarfing genes, neither particularly associated with straw strength. Griffith this season, in collaboration with CSIRO Plant Industry wheat breeders, has a large-scale evaluation of new types of dwarfing genes that seem to be associated with stronger stems. Over 4000 backcross-derived lines containing new dwarfing and reduced-tillering genes will be evaluated for straw strength, yield and grain quality.

Nitrogen test-strips on Chara crops were commercially applied and harvested (up to 9.4 t/ha) in the past two seasons at some 20 farms across the irrigation areas of the Lachlan, Murrumbidgee and Murray Valleys. Paddock records were kept and strips were sampled during early stem elongation (DC30), end of flowering (DC70) and maturity (DC90).

How to achieve high yields

Under irrigation or in years with adequate rain climatic conditions during autumn/winter in much of the Southern Region may result in abundant vegetative growth. However, this can't be backed up with grain production at a similar level, as average grain-filling temperatures are always sub-optimum (see below). Relatively warm winters with adequate solar energy keep wheat plants tillering and growing when nutrients and water are freely available. The "source" (green matter) becomes too big and competes with the developing "sink" (kernels in spike) during the critical 30-day period prior to flowering. After flowering, temperature and evaporative demand increase rapidly and, compared with cool-temperate climates, the source senesces quicker than grain development advances. Hence crops become source limited, that is, leaves senesce before physiological maturity (maximum grain weight) is reached. This source limitation is exacerbated when water becomes in short supply during grain-filling, especially following an increase of the sink by nitrogen fertiliser, that is, haying-off resulting in high screenings. In cool-temperate climates with adequate water there is usually green leaf area left at maturity (ie sink limited). Under high yielding conditions, therefore, source and sink need to be balanced through management to achieve maximum yield.

Variety with stem and straw strength – The leverage exerted by heavier spikes causes lodging when stem strength or anchorage is weak. Lodging risk is affected by soil management factors. Physical, chemical and biological soil conditions influence significantly the anchorage strength of plants through their impact on root growth. Good anchorage by strong roots will reduce lodging under saturated conditions during irrigation. Even varieties with strong stems will be at risk of lodging if grown on soils that inhibit root growth.

For example, in 2002 a breeding line with very strong stems was, under above 7 t/ha conditions, standing up on a grey cracking clay but lodged on a transitional red brown earth. A telephone pole needs a foundation! Provide therefore soil conditions that allow good anchorage. Good soil management is therefore important in achieving consistently high yields. Raised beds and biological agriculture are being evaluated in this respect.

Sowing after Anzac Day – Sowing date, sowing rate and variety choice determines the development of a proper foundation on which a high yielding crop can be built. Early flowering is important for efficient use of resources and inputs in achieving high yields. Across trials past and present maximum yields were attained with mid-flowering in the last week of September or first week of October. Frost risks seem acceptable for mid-flowering from September 22 in the irrigation areas of the plains in southeastern Australia. Flowering earlier in this optimum period increases WUE, important for irrigation and dryland. The later the flowering, the more irrigation required to produce a tonne of grain.

Flowering in last week of September – Flowering early is important as even with optimum inputs yields tend to decrease by 100 kg/ha per day delay in flowering between mid-October and mid-November (150 kg/ha/d in 2002). Temperature affects grain growth and yields decrease by 5% for every 1°C increase in average daily post-flowering temperature above 14°C. This average temperature is 14.9, 15.5, 16.4, 16.8 and 18.0°C for Tatura, Wagga, Kerang, Griffith and Condobolin, respectively, when flowering on October 1st.

The recommended sowing dates in the Winter Crop Variety Sowing Guide (NSW Ag) can be followed for flowering to occur in this critical period, whereby generally the ‘>’ marked sowing dates are the first ones flowering within the period and ‘<’ the first ones outside. A simple rule of thumb on the New South Wales plains is a 3-day delay in flowering for every week delay in sowing, which becomes a 4-day delay towards the eastern areas of the southeastern wheat belt. It’s always best to choose the quickest maturity recommended for a sowing date. That results in a couple of days earlier flowering and an impact through improved harvest index.

Limit early growth and tillering – High yielding crops had strong stems with dense canopy and 450 to 600 spikes/m², obtained from 560 to 850 shoots/m². These canopies were open at the stem base in contrast to the dense undergrowth (dead tillers) in, for example, very high sowing rates or April sowings that resulted in weak stems. Direct light on the plant base, with full canopy cover reached just before flag leaf stage, strengthens stem and anchorage, and allows maximum yields to be achieved. Tillering can be low as a variety characteristic, for example, H45 where tiller survival is high: 450 spikes from 560 shoots/m². Low tillering genotypes developed by CSIRO Plant Industry will be evaluated under irrigation in 2004.

It is therefore recommended to keep the shoot density (main stems plus tillers) between 600 and 800 per sqm. It is recommended to have a fairly even plant establishment between 150 and 200 plants/m² across the paddock, avoiding areas with poor establishment (eg. variation in sowing depth). This can generally be achieved with sowing rates between 80 and 100 kg/ha. Tillering for such sowing rates usually is four to six per plant for most varieties and therefore has to be restricted to three per plant to reach the target shoot density. This can be done through nitrogen fertiliser management (see below). High yields may also be achievable in fertile paddocks with lower sowing rates but risks increase due to weeds and poor establishment areas. In 2003 at Griffith, for example, yields of 7.5 t/ha were achieved from 35 kg/ha sowing rates that reached 750 shoots/m² and showed delayed and reduced lodging.

Importance of first spring irrigation – When aiming for a 7 to 8 t/ha crop, it is important to irrigate during the critical period of stem elongation to prevent water stress. Chara crops above 7 t/ha, including farms, had average crop heights above 83 cm (up to 92 cm) and the length of the peduncle, the part of the stem between spike and top node, was greater than 33 cm. Crop height is an indicator of yield potential, as important yield determining processes take place concurrently with stem elongation.

During that critical period, between the start of stem elongation (DC30) and the start of grain filling (DC70), tillers are becoming spike-bearing shoots followed by the formation of spike size through numbers and potential size of kernels. The latter process starts at full flag leaf emergence and takes place concurrently with peduncle elongation. A short peduncle may indicate water stress in that period and therefore will also have reduced spike size and thus attainable yield. Yields of Chara crops were also reduced if the peduncle had the right length but plant height was shorter than 83 cm. This occurs if early stresses of nitrogen or water shorten the lower stem internodes and reduce tiller survival.

This critical period of stem elongation usually coincides with water becoming available for the first spring irrigation, the need of which is often greatly underestimated as crops generally look good coming out of winter. However, the crop grows at full potential rates during this phase, uses stored soil water and can quickly run out of available water thereby reducing attainable yield. Therefore, be ready to irrigate the high yield potential paddocks first when water becomes available. This may be followed by two more irrigations to achieving the 7 to 8 t/ha.

Green leaves for grain-filling – A high yielding crop needs a healthy green leaf area and duration to keep fully intercepting solar energy for as long as possible. Hence, water use for such crops remains at potential rates longer, and more irrigation is required. To achieve the 7 to 8 t/ha, crops need an, for that variety, appropriate spike density (450–600/m²) with at least three green leaves per shoot at flowering. Leaf disease may cause a rapid decrease in green leaves per shoot during grain filling resulting in substantial yield loss. Fungicides may be used at flag leaf stage to protect the yield potential set when, for example, stripe rust is becoming present in the crop. In 2003 at Griffith, for example, one fungicide spray increased yield of Chara from 7.5 to 8.1 t/ha and of H45 from 6 to 7.5 t/ha.

Irrigation

Best results are achieved with adequate subsoil moisture at sowing through a pre-sowing irrigation if necessary. The number of irrigations depends on seasonal rainfall and the plant available water holding capacity of the soil. The examples given here are for an average soil with a 80mm refill point. Typical soils vary between 60mm (duplex clay) and 100mm (vertisol) and will therefore have more or fewer irrigations, respectively, than the standard used.

The importance of timing of first spring irrigation for 7–8 t/ha yields was raised above. The first irrigation can be delayed till heading stage when aiming for a 5–6 t/ha crop with another irrigation likely after flowering. A full profile at sowing may be sufficient for a 3–4 t/ha yield but in some years (eg 2002) would still require an irrigation at heading.

For the whole season irrigated wheat crops have a typical WUE of 15 kg/ha/mm. Average return of irrigation water would be 1 ton per ML supplied to the paddock, that is, 10 kg/ha/mm. Decisions on the requirement of a last irrigation involve the status of the crop, availability of irrigation water for the paddock, and soil moisture status in relation to recent and forecasted rainfall. To keep WUE high, don't irrigate when there is less than one green leaf left per shoot, that is, the flag. A water deficit towards maturity, hard dough stage, beyond the amount required at refill point will mean a yield loss, which may be up to 1 t/ha. However, this could be the best commercial outcome with least risk, best returns and highest WUE.

Nitrogen

Results of nitrogen treatments were variable for the contrasting seasons 2002 and 2003. Therefore, detailed results of nitrogen trials and resulting recommendations will be presented when 2004 season results have been obtained. Nitrogen budgets for the various treatments over three seasons will then be presented with total nitrogen uptake and fertiliser efficiencies in relation to grain protein, quality grade, irrigation management and rainfall.

Fertile soil or early application of nitrogen tends to promote tillering and early growth in all crops, similar to early sowing, and should be avoided if aiming for high yields. Sowing rate can be lowered when soil fertility goes up as to keeping shoot density low as shown above. The aim of nitrogen management is to restrict tillering and early growth as stem strength increases and lodging is reduced when ground cover during early stem elongation remains below 70%.

Tillering can be kept low by providing enough nitrogen up to sowing to reach the target of 600 to 800 shoots/m², ideally not more than 1000 shoots/m². Topdressing for yield is then required between early (DC30) to mid (DC32) stem elongation, depending on current nitrogen status and shoot density achieved. That is, the lower the shoot density, the earlier the topdressing. The recommended last topdressing around

booting-heading in the Eight Tonne Club (IREC Farmers' Newsletter no.163 and this Update) seems generally too late for wheat on the plains to achieve returns from increased yield.

Late topdressing up till flowering may be used to increase grain protein content to secure a quality grade. For example, at Griffith protein increased from 11.4 to 12.5 % and from 10.8 to 11.9 % for 8.3 t/ha Chara and 8.0 t/ha Arrivato, respectively, topdressed at flowering with 75 kg/ha of urea before irrigation.

Nitrogen test-strip trials with two to nine treatments were conducted on a commercial scale in 2002 and 2003 on Chara crops of thirteen and sixteen farms, respectively, between Shepparton, Kerang, Hillston, Forbes and Wagga Wagga. Treatments included different nitrogen fertiliser rates at pre- and post-sowing and timing of topdressing. One such trial was presented by Graham Menzies and Rachael Whitworth in *IREC Farmers' Newsletter No.166*.

Good returns were achieved on some paddocks with topdressings between 50 and 150 kgN/ha in both years. In 2002 there were no differences in yield and protein responses between pre- and post-sowing nitrogen applications for all but four crops with yields variable around 5.7 t/ha and protein increasing from 10.5% with 1.9% per 100 kgN/ha applied. Four crops gave nitrogen topdressing returns by increasing yields above 7 t/ha. In 2003 pre-sowing applications showed a negative yield response of -0.6 t/ha per 100 kgN/ha, with that of post-sowing being 1.5 t/ha (excluding a stripe rust affected paddock). Topdressing returns to yields above 7 t/ha occurred for three crops. The protein increased that season from 10.6% by 2% per 100 kgN/ha pre-sowing applications, resulting from haying off, while protein across all topdressing entries was variable around 11.2%.

Negative yield responses to nitrogen were recorded at three farms in 2003 while there were none in 2002. These were occurrences of haying off when more nitrogen was not matched with sufficient, more, irrigation water. Uncertain water allocations also affected screenings, with higher screenings occurring when a 7-8 t/ha yield potential was irrigated at early boot stage with no follow-up second one. That early first spring irrigation increased the sink, kernel number set per spike, which could then not be filled through onset of water stress, reduced source, thereby resulting in 6.7 t/ha yield with 8% screenings.

Acknowledgements

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Growing eight tonnes a hectare of irrigated wheat in southern NSW

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Over the past 15 years, many irrigation farmers have aimed to achieve 7 to 8 t/ha wheat yields. The success rate has been around 1 in 10, with few, if any, farmers consistently obtaining yields in this range.

There are two major limiting factors:

- The first is excessive vegetative growth during winter and spring, which makes lodging more likely. Lodging also occurs when soils are saturated during irrigation, which greatly reduces the anchoring strength of plants, particularly at high plant densities (Stapper 2006). Lodging is a major risk when high yields are being targeted. It may lead to high screenings, low test weight, increased risk of weather damage and a slowed harvest.
- The second major factor limiting yields is foliar diseases such as Septoria tritici blotch (until the mid 1990s) and yellow leaf spot (*Pyrenophora tritici-repentis*).

Other factors impacting on achieving 8 t/ha yield potential and grain quality include black point, leaf death tipping, late watering, waterlogging, screenings, difficulty of predicting nitrogen needs and delays in topdressing nitrogen in wet winters.

Given that, due to these limitations, the chance of achieving a high yield is low, most farmers have adopted a low risk but profitable strategy of targeting a 4 to 5 t/ha yield and watering only once, in spring, particularly when water allocations have

been low. Although this has been a successful strategy, and returns per megalitre are attractive, the potential for lifting yield and profit per megalitre of water is limited.

Targeting 5 t/ha or 8 t/ha?

Up until the first node wheat growth stage, the risks in targeting a yield of 8 t/ha are not much higher than those of targeting a 5 t/ha crop. This is because the costs in establishing an 8 t/ha crop are similar to those for a 5 t/ha crop.

If crop prices, crop potential or water security are lower than planned, the decision can be made at the first node stage to target a 5 t/ha crop instead of an 8 t/ha crop.

The biggest difference between 5 t/ha and 8 t/ha is the extra management needed in achieving 8 tonnes, chiefly extra monitoring to ensure crops meet the key management checks or practices for higher yields. Neglecting one particular keycheck factor or a combination of factors may cause significant yield loss, reducing the chances of attaining a yield of 8 tonnes.

What this Primefact covers

This Primefact outlines a nitrogen management strategy which minimises the risk of overvegetative and lodged crops.

This nitrogen management strategy has been combined with the latest 'Irrigated Wheatcheck' best management practices. This combination greatly increases the ability to grow high yielding profitable wheat crops for each hectare and each megalitre of water.



Marketing your crop

Before planting:

- decide on the quality that you are going to produce
- ensure that you understand the specifications for this product
- determine how much it costs to grow the crop, both production (variable) and fixed (overhead) costs. This will help you determine the price at which a profit can be achieved. Use a gross margin from the NSW DPI website to determine variable costs and gross margin per hectare and per megalitre. (An example of a gross margin comparing 5 t/ha and 8 t/ha is shown in Table 6.)

The Wheatcheck Approach

In 1984 a crop monitoring wheat package called the 'Irrigated Wheat Five Tonne Club' was developed. It used objective factors for growing irrigated wheat from Siragcrop (Stapper 1984). As part of this package, farmers had to monitor crops and check to see if the crop had attained the benchmarks or checks in achieving higher yields at various growth stages. The checks were obtained by monitoring and recording the best practices from the higher yielding crops.

The crop checking approach is called 'Irrigated Wheatcheck'. The 'Eight Tonne Irrigated Wheat Club' monitoring package is a high yielding and profitable version of 'Irrigated Wheatcheck.'

Eight-tonne key checks

This Primefact contains the best management practices or 'checks' for growing 8 t/ha wheat yields. The key checks are:

- monitoring
- irrigation layout
- paddock history
- soil structure
- subsoil moisture
- nitrogen at pre-sowing and at sowing
- sowing date
- variety selection
- fertiliser at sowing
- plant establishment
- weed control
- crop nitrogen at late tillering
- crop nitrogen at head emergence
- soil moisture at stem elongation
- three green leaves at flowering
- Wheatcheck recording

Monitoring

You need a willingness to monitor and record the key checks.

Growing 8 tonnes of wheat per hectare requires a higher level of management, particularly in monitoring the crop to determine whether the checks are being adopted.

If you record paddock, crop practices and crop measurements then the crop can be benchmarked against other crops. This helps identify best practices for high yielding crops, and any barriers to attaining high yields.

You can obtain record cards from NSW DPI District Agronomists, who have supplies of Wheatcheck cards.

Irrigation layout

Use a layout which allows water application and drainage within 15 hours.

This check is to avoid waterlogging, which can be responsible for large yield losses from nitrogen deficiency, lack of tillering, poor grain filling and lower grain weight. Layouts such as beds, steeper border check layouts, terrace bankless channels and spray irrigation with effective water delivery and drainage are suitable.

Paddock history

Sow wheat after a break crop or long fallow to improve soil health, reduce root disease and reduce weed populations.

Paddock history is an important check, since wheat crops following break crops regularly show yield responses that are 20% above those of wheat crops following wheat.

Selection of a paddock which has had a break crop or legume pasture with minimal grass content minimises the risk of the root diseases take-all (*Gaeumannomyces graminis*) and crown rot (*Fusarium pseudograminearum*). Good break crops in irrigated rotations include the winter crops canola and fababeans and summer crops rice, soybeans and maize.

Avoiding high fertility legume pastures is important, as the high soil nitrogen following these pastures is likely to produce excessive vegetative growth in wheat crops, leading to the risk of lodging and foliar diseases. Refer to NSW DPI's *Winter crop variety guide*, updated each year, for the latest information on disease identification and control.

Soil structure

Choose paddocks with moderate to good soil structure, that is, the better paddocks.

Good to moderate soil structure is one of the most important checks for high yield potential. Paddocks with poor soil structure usually have poor water infiltration and generally give lower or inconsistent yields. Waterlogging and drainage can be a problem during wet periods.

Soils with moderate to good soil structure usually have an exchangeable sodium % (ESP) less than 6%: any greater than this indicates structural problems. Surface crusting may also be an indication of sodic soils. (Sodicity refers to the amount of sodium (Na) in a soil and indicates the structural condition of the soil.)

Another general indicator of good soil structure is an organic carbon level > 1.5%. Organic carbon % is the standard used by soil testing laboratories to measure the organic matter (OM) content of a soil. Organic matter consists of all living and dead plant and animal matter occurring in the topsoil. It acts as a 'glue' to bind soil particles into aggregates. The average organic carbon content of soil organic matter is approximately 58%.

Organic matter % = organic carbon % × 1.72

Subsoil moisture

Provide adequate subsoil moisture at sowing.

Although wheat crops need only low to moderate biomass in winter for high yield potential, significant moisture stress in dry winters will lower wheat growth and therefore potential yield. Moisture stress may be avoided by pre-watering before sowing or watering up just before or after sowing.

Alternatively, farmers may assess rainfall predictions and, in winters with above-average rainfall predicted, may decide to rely on rainfall for subsoil moisture. One study (Fisher 2001), based on 51 years rainfall, found a definite benefit from pre-irrigating in April in 44 of the years.

With paddocks to be pre-watered, water use and timing need to be considered. Pre-irrigation timing depends on the amount of rainfall in late autumn and winter. Experience has demonstrated that in wet winters the best timing of pre-watering is in February or early autumn. This early timing provides subsoil moisture and allows drying of the topsoil, so that, in wet winters, the dryness of the topsoil buffers against waterlogging. Paddocks with good drainage can be pre-watered until late March.

Late watering is risky, as follow-up rainfall and waterlogging can delay sowing, resulting in reduced potential yield, although in the drought seasons from 2002 to 2005, which had dry autumns and winters, late watering was very successful.

Bed layouts allow pre-watering before sowing or sowing dry and watering up for germination, plant emergence and subsoil moisture.

For spray irrigators, access to on-farm storage is ideal, allowing watering in winter if needed.

Nitrogen at pre-sowing and at sowing

Target paddocks to ensure the total amount of soil and sowing nitrogen supply is 100–120 kg N/ha.

The nitrogen demand by an 8 t/ha crop with 11.5% protein is:

$$\frac{8000 \times 11.5 \times 100}{100 \times 5.7 \times 80} = 201 \text{ kg N/ha}$$

In this example, the target yield is expressed in kg/ha (8000) and target grain protein (11.5%) is converted to kg/ha of N (nitrogen) using a constant (5.7), with the 100 for percentage. The N contained in the straw (20%) is included by the 100/80. Since soil and fertiliser N is normally inefficiently used by the crop, combined soil and fertiliser supply has to be about double the amount contained in the crop, that is, 402 kg N/ha.

If this amount is supplied via a fertile paddock and as fertiliser nitrogen by sowing, an excessively vegetative crop is likely, with consequent lodging

and leaf disease causing yield loss. In order to overcome this barrier to growing consistently high wheat yields, Angus and Lacy (2001, 2002a) devised a nitrogen strategy which limits the N at sowing and instead uses two nitrogen topdressings, with their timing depending on crop shoot numbers. Generally, as shoot numbers exceed 800 shoots/m², lodging increases and yield declines. This is also supported by recent research by Maarten Stapper (2006), as shown in Figure 1.

A deep soil nitrogen test can be used to determine whether the soil nitrogen supply meets the target of 100–120 kg N/ha. This test should be carried out as close to sowing as possible, allowing for the processing of the test results before sowing or as soon as possible after sowing.

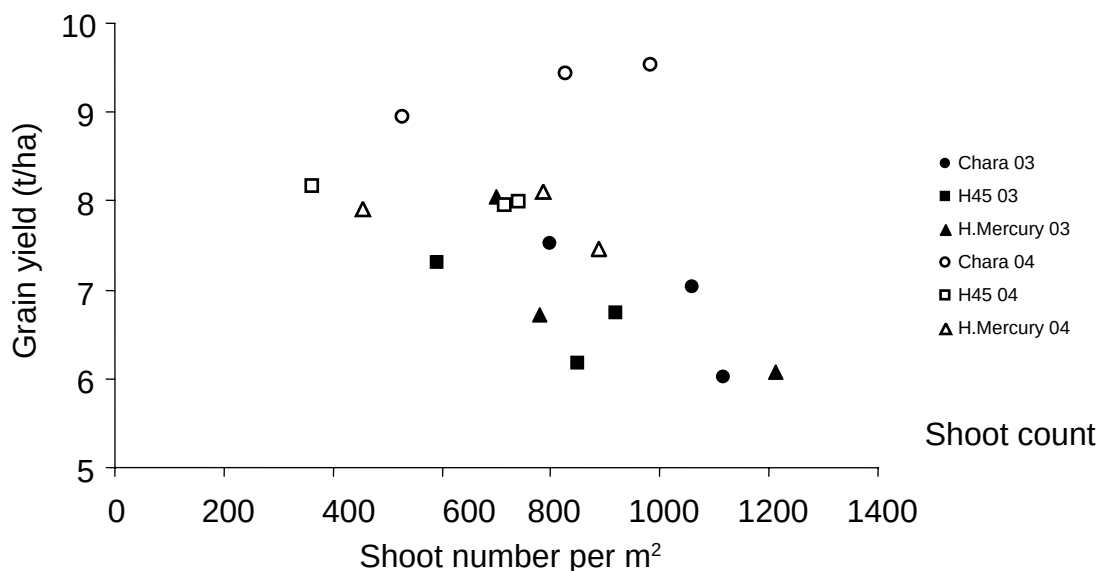
If the soil nitrogen is low (50 kg N/ha), a pre-sowing amount of nitrogen (for example 50 kg N/ha) will be required to top the paddock up to 100 kg N/ha. If the test shows the paddock has a nitrogen level well over 120 kg N/ha, we recommend you do not target this paddock for a high yield crop, as the risk of excessive vegetation and lodging is high.

Sowing date

Sow approved varieties within the preferred sowing window to achieve flowering in late September – early October.

The optimum sowing date for maximising yield potential has grain-filling occurring at the lowest possible temperatures in spring, which means flowering occurring as early as possible with

Figure 1. The relationship between shoot number and grain yield for three varieties by three sowing rates over two seasons at Griffith NSW.



minimal frost risk. Yields decrease by 5% for every 1°C increase in average daily post-flowering temperature above 14°C (Stapper 2006). Thus sowing is a compromise between wanting to sow earlier, and risking frost damage, and sowing later, resulting in flowering at higher temperatures and lowering yield potential.

The optimum flowering period which meets these criteria in southern NSW is late September to early October. Select sowing dates for any variety to achieve flowering at this time. Earlier flowering also helps to save one irrigation watering.

Table 1. Average Griffith CSIRO Temperatures (°C)

	August	September	October
Maximum	16.2	19.6	23.2
Minimum	4.0	6.0	9.1
Average	10.1	12.8	16.2

Variety selection

Use varieties which have yielded consistently well in trials over several years.

The new National Variety Trials (NVT) web-based database shows the variety results from all trials. Approved varieties offer the best combination of yield potential, grain quality and disease resistance.

Stapper (2006) found maturity and stem strength are also important variety traits for high yields under irrigation, with disease resistance facilitating ease of achievement. Varieties consistently achieving 8 t/ha under irrigation with efficient use of resources were identified as requiring a combination of these traits:

- good stem and anchorage strength (e.g. Chara)
- high sink strength (e.g. H45)
- restricted tillering capacity (e.g. H45)
- early maturity (e.g. H45)
- big grains (e.g. Arrivato) to lower screenings
- longer green leaf area duration (e.g. Chara)
- not susceptible to black point
- competitive growth

Fertiliser at sowing

Fertilise with 4 kg phosphorus per tonne of target yield.

Phosphorus is important for seed germination, early root development, leaf size, tillering, grain yield and the ripening process of grain.

Since each tonne of grain removes 4 kg phosphorus, this amount needs to be added to maintain soil phosphorus levels. Hence, for an eight-tonne yield target, apply 32 kg P/ha. This amount should be banded near the seed, commonly as starter fertiliser DAP or MAP (i.e. 160 kg DAP/ha or 145 kg MAP/ha).

Plant establishment

Aim for 150–200 plants/m².

A uniform plant population with adequate numbers is vital for maximising yield potential and to compete with weeds. The recommended population is 150–200 plants/m², which normally requires sowing rates of 90–110 kg/ha: difficult establishment conditions, such as heavier crusty soils, may need 150 kg/ha.

The target plant population, seed size, germination % and establishment affect sowing rate as follows:

$$\text{Sowing rate (kg/ha)} = \frac{\text{target plants/m}^2 \times 1000 \text{ gw (g)} \times 100}{\text{germination \%} \times \text{establishment \%}}$$

(gw: grain weight)

Example:

Target plant population	=	170 plants/m ²
1000 grain weight	=	42
Germination %	=	95
Establishment %	=	80

$$\begin{aligned} \text{Sowing rate} &= \frac{(170 \times 42 \times 100)}{(95 \times 80)} \\ &= 94 \text{ kg/ha} \end{aligned}$$

Lower sowing rates with good tillering conditions may also achieve good yields, as recent research shows (Table 2, Stapper 2006).

Table 2. Grain yield (t/ha) for three varieties sown 28 May 2003 and 20 May 2004 with three sowing rates at Griffith NSW

Treatment Isd for a variety is 0.4 t/ha.

	35 low	100 medium	200 high	mean
H45				
2003	7.3	6.2	6.7	6.7
2004	8.2	8.0	8.0	8.0
total	15.5	14.2	14.7	14.8
mean	7.7	7.1	7.3	7.4
Hybrid Mercury				
2003	8.0	6.7	6.1	6.9
2004	7.9	8.1	7.5	7.8
total	16.0	14.8	13.5	14.8
mean	8.0	7.4	6.8	7.4
Chara				
2003	7.5	7.0	6.0	6.9
2004	9.0	9.4	9.5	9.3
total	16.5	16.5	15.5	16.2
mean	8.2	8.2	7.8	8.1
mean				
2003	7.6	6.6	6.3	6.8
2004	8.3	8.5	8.3	8.4
total	16.0	15.2	14.6	15.2
2-year average	8.0	7.6	7.3	7.6

This sowing rate trial was conducted over two seasons with rates of 35, 100 and 200 kg/ha for each of H45, Hybrid Mercury and Chara (Table 2), all with a 1000 grain weight of 39 g. The lowest sowing rate resulted in only 60 plants/m².

Lodging was a problem in 2003, with low sowing rates having the lowest and latest onset of lodging, resulting in highest yields. There were no consistent yield differences between rates in 2004, a season without severe lodging.

Total production over two years was significantly higher for the lowest sowing rate.

The results in Table 2 relate to trials conducted in optimum conditions on a sandy loam soil, with high soil nitrogen and good soil moisture and plant emergence. Most wheat paddocks have varying soil types and soil moisture conditions at sowing which require moderate sowing rates, as represented by the 100 kg rate in Table 2.

According to Stapper (2006), row spacing influences the distance between plants and lodging effects.

Wider row spacing is increasingly being used to facilitate direct drilling into stubble. Plot trials as in Table 2 were all done with standard 17 cm row spacing. Plant anchorage was strongest with nodal roots evenly distributed around the crown, which occurred when the next plant was at least 2.5 cm away. The average intra-row distance with increasing rates in Table 2 were 10, 3 and 1.5 cm. To lower lodging risk, adjust sowing rates at wider rows to obtain a maximum intra-row distance of 2.5 cm.

Weed control

Undertake weed control before and after sowing to avoid yield loss.

Early removal of weeds with pre-emergent herbicides consistently produces greater yield increases than if weeds are left until the crop has tillered. It is important to check crops regularly during the first 6 weeks after sowing and monitor weed germinations and density.

Annual weeds compete with wheat during the tillering period. Therefore, remove weeds no later than 6 weeks after sowing to minimise losses.

Consult the latest edition of *Weed control in winter crops*, available from NSW DPI offices and website, for details on suitable herbicides and weed control. Other valuable sources of information on weed control include retail agronomists.

Crop nitrogen at late tillering

At the late tillering to initial stem elongation stage (DC30), check whether the crop has the target population of 500–800 shoots/m², and assess crop nitrogen.

The late tillering to first node stage is important for deciding whether the crop will be managed for 8 tonne or 5 tonne yield potential.

If there are constraints to achieving 8 tonnes (late sowing, poor tillering, low water allocations preventing the ability to apply a minimum of 3 spring irrigations, low wheat prices or other agronomic factors), you can decide to manage for 5 tonnes rather than 8 tonnes.

Conduct shoot counts to determine the nitrogen topdressing rates for either 5 or 8 tonnes potential (see Table 3).

For 8 tonnes yield, the target population is 500–800 shoots/m².

Table 3. Nitrogen topdressing rates based on shoot counts for 5 and 8 t/ha potential

Note: If there is obvious nitrogen deficiency before first node, topdress 30–45 kg N/ha at mid tillering.

8/ha			5 t/ha		
Shoots/m ²	First node (kg N/ha)	Booting to head emergence (kg N/ha)	Shoots/m ²	First node (kg N/ha)	Booting to head emergence (kg N/ha)
400	–	–	400	45–60	–
500	50	90	500	60–75	–
600	40	60–90	600	60	–
700	0–30	60–90	700	30–45	–
800	0	60–90	800	0	–

- If the shoot population is 750–800 shoots/m², there is no need to topdress at this stage, as the crop has more than enough shoots for 8 tonnes.
- If the shoot number is below 750 shoots/m², topdress with a 'top-up' rate of 30–50 kg N/ha.

If the shoot number is below 500, achieving 8 tonnes is less likely.

The chance of crops with shoot numbers above 800 for yielding 8 tonnes are also slim because the crops are too thick, with a greater chance of yield loss from lodging and extra disease risk.

Topdressing should be carried out before the first node (Z31) or second node (Z32) stage, preferably before a minimum of 5 mm rain. Trials and farmer experience show volatilisation losses without rain are low under southern NSW conditions during winter, but rain or an irrigation is needed to incorporate the nitrogen.

Crop nitrogen at head emergence

Reassess the crop for nitrogen at the head emergence to flowering stage and apply 60–90 kg N/ha.

If water is available in the spring for another 2 or 3 irrigations, and leaf diseases are under control, and the decision has been made to target 8 tonnes, a late application of nitrogen topdressing can be considered. This is after the flag leaf stage when stripe rust susceptible crops will require treatment.

This late application of 60–90 kg N/ha between head emergence (Z50) and flowering is designed to reduce the potential for lodging and extra disease. If 90 kg N/ha was applied at the first node stage to a crop with 600–800 shoots/m² there would be a significant vegetative response and risk of lodging. This strategy is for high yield potential 7–8 t/ha

crops which had 500 to 800 shoots/m² at the first node stage and with 3 to 4 green leaves per shoot. It is very important the crop is watered immediately after nitrogen application to avoid volatilisation losses with this late nitrogen application.

Late topdressing was evaluated by Stapper (2006) for Arrivato durum wheat (Table 4), a variety well suited to the high yielding irrigation environment, although grain quality for this variety is an issue. The base treatment yielded 7.3 t/ha and 8.5% protein with just 30 kg N/ha at sowing, indicating the high soil nitrogen status of this site. Topdressing with 60 kg N/ha at DC32 before the first irrigation increased yield to 9.1 t/ha with 8.8% protein. Another 40 kg N/ha at the next irrigation during early flowering raised yield to 9.7 t/ha with 10.4% protein.

Further evidence of the yield responses to late applied nitrogen (Angus and Lacy 2002b) is shown in Table 5. This table shows large yield and protein responses to N topdressed between tillering and flowering in irrigated and favourable dryland conditions.

The Arianah Park experiments were in collaboration with Tony Good, formerly of Incitec Fertilisers, and Kevin Harper, landholder. The Stockinbingal experiment was in collaboration with Bernard Hart. The Leeton experiment was at Leeton Research Farm in collaboration with John Thompson. At Arianah Park in 1995 and Stockinbingal in 2000 there was adequate rain after late topdressing, leading to large yield responses as well as additional grain protein. In the drier season of 1996, the yield response was smaller but the grain protein response greater. Under irrigation at Leeton, topdressing at tillering gave larger yield responses than topdressing at booting. The Leeton experiment included Suneca which lodged badly with topdressing at tillering.

Table 4. Grain yield, protein, screenings, grain weight and grain number of nitrogen treatments for Arrivato sown 20 May 2004 at Griffith NSW

Yield Isd is 0.6 t/ha. The trial site was the second wheat crop after canola following several years of lucerne on sandy loam soil. Soil nitrogen was high.

Treatment	0	ON0	ONN	N00	N0N	N0N
Grain yield (t/ha)	7.3	8.3	8.8	9.1	9.7	9.6
Protein (%)	8.5	12.0	12.5	8.8	110.4	10.6
Screenings	1.9	3.5	3.4	2.6	2.8	3.4
Kernel weight (mg)	54.4	58.6	58.9	55.6	57.7	58.7
Kernel number (1000/m ²)	13.4	14.1	15.0	16.4	16.8	16.3
Nitrogen applications						
1 – sowing	20 May	DC00	30	30	30	30
2 – 2nd node	26 Aug	DC32	0	0	60	60
3 – late boot	16 Sep	DC46	0	60	0	0
4 – early flowering	30 Sep	DC63	0	0	40	40
Total N fertiliser (kg/ha)			30	90	130	130
Sowing rate (kg/ha)			100	100	100	60

Table 5. Evidence for wheat responses to late topdressing with nitrogen fertiliser

	Yield (t/ha)	Protein (%)	Fertiliser recovery %
Ariah Park 1995 variety Janz, dryland			
Control	4.1	10.2	
50N sowing	6.1	11.1	91
50N sowing+ 50 N flowering	7.1	12.9	87
Ariah Park 1996, variety Janz, dryland			
Control	5.1	10.0	
50 N sowing	5.5	11.2	37
50 N sowing + 50 N flowering	5.8	13.3	46
Stockinbingal 2000, variety H45, dryland			
Control	5.2	9.2	
50 N tillering	7.0	10.0	78
50 N flowering	6.9	11.5	100
Leeton 1990, variety Wyuna, irrigated			
Control	3.9	7.8	
60 N at tillering (DC30)	6.6	8.3	71
120 N at tillering	8.2	9.0	63
60 N at booting (DC45)	4.9	9.6	49
120 N at booting	6.4	11.0	59

Soil moisture at stem elongation

Available soil moisture from stem elongation to the mid dough stage needs to be 50% or more to avoid yield losses from moisture stress.

Crops with an 8 tonne yield potential will have a higher moisture demand than crops with a lower yield potential, so any moisture stress will be more critical and could cause a significant dip in yield.

The stem elongation growth phase coincides with rapid growth and higher water use, so it is more important to maintain good soil moisture between elongation and the mid dough stage than at the tillering growth stage.

As a rule, soil moisture should be kept above 50% of the plant available water (PAW) in the root zone to minimise plant moisture stress. This amount is often referred to as readily available water (RAW) or allowable depletion. (Depending on the soil type, wheat RAW may vary from 45% to 65% of PAW.) Once below 50% of PAW, plants use a lot of energy extracting the remaining moisture from the soil. Less energy is available for growth, and so production falls.

Soil moisture at head emergence

Check soil moisture regularly for the full rooting zone.

The most critical moisture stress stage is head emergence. The first 10 days after flowering, when grains are enlarging and forming, decide grain size, so this is also important. In most seasons it is likely there will be a need to water crops during the elongation stage, just prior to head emergence and at the early milk stage to allow good grain fill up to the mid dough stage. In very dry seasons up to 5 spring irrigations may be required to maximise yield potential.

Check soil moisture regularly for the full rooting zone, which is commonly 60 cm deep. Checking soil moisture to 15 cm with a shovel usually leads to inaccurate or a misleading diagnosis. Irrigations can be scheduled using a variety of different methods: for example, there are tensiometers, gypsum blocks, neutron probes, gophers and evapotranspiration, which require observation or measurement of plant growth, soil moisture, the weather or a combination of these. All methods aim to determine when to irrigate to avoid water stress and how much water to apply to refill the soil.

Three green leaves at flowering

For high wheat yield potential, maintain as large a photosynthetic area as possible by maintaining 3 green leaves per shoot at flowering to maximise filling of grain.

Adequate nutrition, soil moisture and disease control through a combination of disease-resistant varieties and fungicide seed treatments and leaf control should result in crops with 3 green leaves per shoot at flowering.

Foliar stripe rust: fungicide timing for stripe rust is very important to prevent loss of photosynthetic area. Because management strategies for stripe rust control are constantly being updated, make sure you keep in regular contact with your local District Agronomist or retail agronomist for the latest control measures.

Wheatcheck record

After harvest, complete a Wheatcheck record showing the crop yield and quality and the practices used to grow the crop.

Return the record to your District Agronomist for benchmarking in the Cropcheck database. Feedback results comparing crop practices with the highest yielding and most profitable crops are sent to each participating farmer.

Table 6. Irrigated wheat gross margin budgets for 5 t/ha and 8 t/ha yields

			5 t/ha	8 t/ha
Income	\$150/t		\$750.00	\$1200.00
Variable costs (per hectare)				
Cultivation	Burn			
	Scarify		\$7.71	\$7.71
	Landplane		\$7.71	\$7.71
Pre-irrigate	1.5 ML/ha	\$26/ML	\$39.00	\$39.00
Knockdown herbicide	Roundup CT®	1 L/ha @ \$6	\$6.00	\$6.00
	Application		\$2.50	\$2.50
Presow	Urea	125 kg/ha at \$520/t	\$65.00	\$65.00
	Application		\$10.48	\$10.48
Presow herbicide	e.g. Logran®	35 g/ha	\$5.60	\$5.60
	Application		\$2.50	\$2.50
Sowing	Seed	100 kg/ha	\$61.00	\$61.00
	Application		\$10.48	\$10.48
Seed treatment	e.g. Baytan®	150 mL/ha	\$7.65	\$7.65
Sowing fertiliser	DAP	150 kg/ha, \$520/t	\$78.00	\$78.00
Broadleaf herbicide	e.g. Kamba M®	1.7 L/ha	\$15.75	\$15.75
	Application	contract	\$10.00	10.00
Subtotal variable costs up to first node stage			\$329.38	\$329.38
First topdress	Urea	125 kg/ha, 520/t	\$65.00	
	Application		\$10.48	
	Urea	100 kg/ha, \$520/t		\$52.00
	Application			\$10.00
Stripe rust	e.g. Bayleton®	1 L/ha @ \$9.50	\$9.50	\$9.50
	Application by air		\$10.00	\$10.00
Second topdress	Urea	185 kg/ha, \$520/t		\$96.20
	Application by air			\$25.00
Spring irrigation	Tail drains		\$12.08	\$12.08
	First	1 ML/ha	\$26.00	\$26.00
	Second	1 ML/ha		\$26.00
	Third	0.75 ML/ha		\$19.50
Harvest	Contract	\$12.90/t	\$70.95	\$103.20
	Chaser bin		\$9.91	\$11.00
Levies	1.02%		\$7.65	\$12.24
Insurance	2.28%		\$17.10	\$27.36
Variable costs, 1st node to harvest			\$238.67	\$440.08
Total variable cost			\$568.05	\$769.46
VC/tonne			\$113.61	\$96.18
GM/ha			\$181.95	\$430.54
GM/ML	2.5 ML/ha		\$72.78	
	4.25 ML/ha			\$101.30

Summary of the steps in growing 8 t/ha

- Determine the marketing strategy and the returns and costs.
- Be prepared to monitor the crop and record the key checks.
- Select a paddock which had a break crop or non-grass pasture last season.
- Choose paddocks with moderate to good soil structure.
- Use a layout which allows water application and drainage within 15 hours.
- Avoid paddocks with high nitrogen, that is, over 120 kg N/ha.
- Ensure there is a minimum of 50% available soil moisture at sowing.
- Sow on time.
- At sowing or before sowing top up soil nitrogen if needed so that the total soil and fertiliser nitrogen is 100–120 kg N/ha.
- Fertilise with 4 kg phosphorus for each tonne of target yield.
- Aim for 150–200 plants/m² at the plant emergence stage.
- Undertake pre-sowing and post-sowing weed control to avoid yield loss due to weed competition.
- At the late tillering to first node stage, count shoots to determine whether the crop has the target population of 500–800 shoots/m² for 8 tonnes. Assess seasonal factors such as wheat price, irrigation allocation and crop health and decide whether to manage for 8 tonnes or 5 tonnes.
- If the decision is to manage for 8 tonnes, refer to the first node nitrogen topdressing rate table.
- Manage irrigations to maintain 50% soil moisture from stem elongation to the mid dough stage, budgeting 2 to 3 spring irrigations. Plan the last irrigation at the early milk stage to allow good grain fill up to the mid dough stage.
- Maintain three green leaves per shoot at flowering using foliar fungicide sprays for stripe rust and other diseases.
- Apply a second nitrogen topdressing of 60–90 kg N/ha (125–188 kg urea/ha) between the booting to head emergence stages and water in the fertiliser.
- Complete a Wheatcheck record of the crop yield and quality and the practices used to grow the crop. Return the record to your District Agronomist who can arrange for the crop practices to be benchmarked with other crops.

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ALWAYS READ THE LABEL

Users of agricultural or veterinary chemical products must always read the label and any Permit, before using the product, and strictly comply with the directions on the label and the conditions of any Permit. Users are not absolved from compliance with the directions on the label or the conditions of the Permit by reason of any statement made or not made in this publication.

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Disclaimer: The information contained in this publication is based on knowledge and understanding at the time of writing (July 2006). However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of New South Wales Department of Primary Industries or the user's independent adviser.



NSW DEPARTMENT OF
PRIMARY INDUSTRIES



Root and Crown Diseases of Wheat and Barley

in Northern NSW

Kevin Moore, Bill Manning,
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NSW DPI Tamworth NSW



GRDC

Grains
Research &
Development
Corporation

EFS

Eastern Farming
Systems Project

Getting the most from this brochure

This brochure will help you identify the major root and crown diseases of wheat and barley in northern NSW. For each disease, the symptoms in **bold type** are the distinguishing symptoms; if you have the disease, you will always see these symptoms. Current best management practices are given for each disease.

Remember, accurate diagnosis is the first step in disease management. A number of other problems (e.g. frost and herbicide injury) can produce symptoms that may resemble those described in this brochure.

Further, the symptoms you see in your paddock can sometimes vary from those described in this brochure. We encourage you to use this brochure in the paddock as part of a group with your local agronomist and seek further diagnosis from the authors if unsure.

Crown Rot

(Cause - The fungus *Fusarium pseudograminearum*)

ONSET AND DISTRIBUTION

- ▮ Usually not obvious until after heading, when whiteheads appear.
- ▮ Individual plants or patches; sometimes first seen in wheel tracks.
- ▮ Whiteheads develop with the onset of water stress, usually after flowering.
- ▮ Durum wheat is highly susceptible.
- ▮ The extent and development of Crown Rot is influenced by the interaction between soil and plant water potential, soil N and inoculum loading.
- ▮ Yield loss can occur even without the formation of whiteheads.

SYMPTOMS

- ▮ **Tiller bases always brown**, often extending up 2–4 nodes.
- ▮ Some tillers on diseased plants may not be affected.
- ▮ Whitehead formation is most severe in seasons with a wet start and dry finish.
- ▮ Plants difficult to pull up, often breaking off near ground level.
- ▮ Cottony fungal growth may be found inside tillers.
- ▮ Pinkish fungal growth may form on lower nodes especially during moist weather.
- ▮ Pinched grain at harvest.

MANAGEMENT

- ▮ Reduce levels of the fungus in your paddocks by rotating with crops such as field pea, faba bean, canola, mustard, chickpea, mungbean, sunflower or sorghum. This will work only if you control grass weeds in these break crops – particularly barley grass and phalaris. Note that break crops with denser canopies increase the breakdown of infected cereal residue.

Sowing break crops on wide or skip rows will reduce the breakdown of cereal residue in the inter-row area.

- ▮ Reduce moisture stress in your wheat or barley crop through fallow management, avoiding excessively high sowing rates, matching nitrogen fertiliser inputs to available soil water, and controlling in-crop weeds.
- ▮ The Crown Rot fungus is stubble-borne so in a no-till system inoculum becomes concentrated in the previous winter's



Brown discolouration of stem bases; normal plant on right. (Lester Burgess)



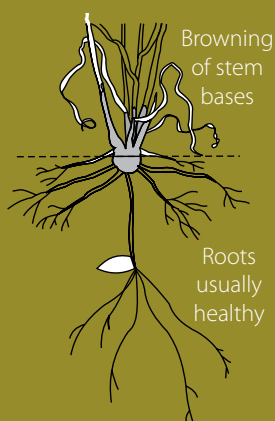
Pink/red discolouration of stem bases. (Kevin Moore)



Cross-section of affected tillers showing white fungal growth. (Lester Burgess)

cereal rows. Use of precision guidance to establish new wheat or barley crops in between previous cereal rows reduces infection. Note that this relies on the previous cereal rows remaining as intact as possible, because any fragmentation (e.g. cultivation, mulching, grazing) redistributes inoculum to the inter-row area.

- ▮ Ensure adequate nutrition, especially with zinc.
- ▮ Sow bread wheat varieties with partial resistance to Crown Rot. Note that all current barley varieties are very susceptible and will encourage considerable build-up of inoculum. However, barley rarely suffers significant yield loss from Crown Rot largely because its earlier maturity limits the impact of moisture stress interactions with infection, which result in the production of whiteheads.
- ▮ Burning stubble does not guarantee freedom from Crown Rot. Burning removes only above-ground inoculum; the Crown Rot fungus still survives in crown tissue below ground. Hence burning is not a 'quick fix' for high inoculum levels. There is also no heat kill of inoculum in the soil.



Common Root Rot

(Cause - The fungus *Bipolaris sorokiniana*)

ONSET AND DISTRIBUTION

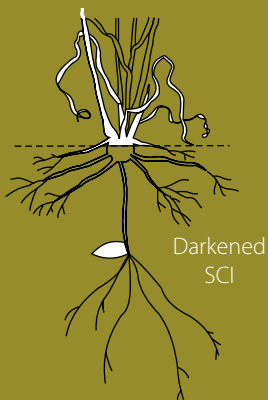
- ▶ Can occur from tillering onwards but most obvious after flowering.
- ▶ No distinct paddock symptoms, although the crop may lack vigour.
- ▶ Severe infections can lead to stunting of plants.
- ▶ Appears more prevalent in paddocks that are N deficient.
- ▶ When N is not limiting, yield loss occurs through a reduction in tillering due to poor N use efficiency.
- ▶ Affected plants are usually scattered through the crop.
- ▶ Widespread through the grain belt; often found in association with Crown Rot.

SYMPTOMS

- ▶ **Dark brown to black discolouration of whole or part of the SCI.**
- ▶ Tiller bases and surrounding leaf sheafs may be brown.
- ▶ Severely affected plants are stunted and have fewer tillers.
- ▶ Pinched grain at harvest.

MANAGEMENT

- ▶ Reduce levels of the fungus in your paddocks by rotating with crops such as field pea, faba bean, canola, mustard, mungbean, sorghum or sunflower.
- ▶ Break crops or pasture must be grass-free.
- ▶ Grow partly resistant wheat or barley varieties.



- ▶ If moisture permits, reduce sowing depth to limit the length of the SCI.
- ▶ Ensure adequate nutrition especially of phosphorus which reduces severity.
- ▶ Burning does not decrease spore levels in the soil.



Plants from an affected crop (right) are stunted and have fewer tillers. Plants from a normal crop (left). (Kevin Moore)



The darkened SCI is a distinctive symptom of Common Root Rot. (Kevin Moore)



Common Root Rot causes darkening of the SCI and browning of the roots; healthy plant on right. (Kevin Moore)

Root Lesion Nematode (RLN)

(Cause - The nematodes *Pratylenchus thornei* and *Pratylenchus neglectus*)

ONSET AND DISTRIBUTION

- ▮ Can occur from tillering onwards.
- ▮ Uneven patches or waviness across the paddock.
- ▮ Affects wheat, chickpea, soyabeans, mungbeans and black gram.
- ▮ Barley, sunflower, sorghum, canola and mustard are less affected.
- ▮ Crops such as field pea, faba bean, lupin, lentil, rye, triticale, durum wheat and oats make good break crops.

SYMPTOMS

- ▮ Diagnosis is difficult and can be confirmed only by a laboratory test.
- ▮ Severely affected plants are yellow and stunted, with decreased tillering.
- ▮ Plants may wilt later in the season.
- ▮ Root systems are stunted, with reduced branching.
- ▮ Indistinct dark brown areas on roots, especially side branches.

MANAGEMENT

- ▮ First reduce RLN numbers by growing resistant crops.
- ▮ Resistant crops reduce nematode reproduction but do not eliminate the problem, as nematodes can survive in the soil for many years.
- ▮ Grow tolerant wheat cultivars, because these yield well in spite of being hosts to RLN.
- ▮ Avoid sowing wheat late, as these crops tend to be more severely affected than earlier-sown crops.
- ▮ Nematodes are spread by surface water, vehicles and farm machinery; adopt hygiene measures to prevent introducing RLN to your farm.
- ▮ Some crops may be resistant to one species but susceptible to others (e.g. canola is susceptible to *P. neglectus* but moderately resistant to *P. thornei*).
- ▮ Where mixed populations of species occur, use of crops resistant to only one species may allow the other species to increase.

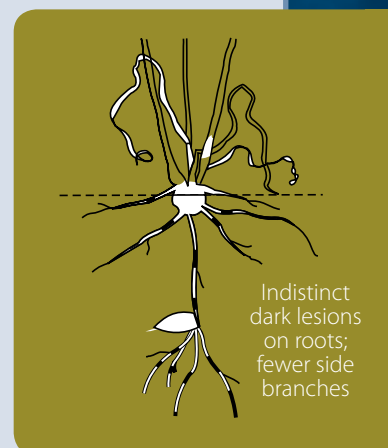
At right: Roots affected by RLN, showing reduced branching and darkened sections of the main roots.
(John Thompson)



Trial wheat plots showing stunting caused by RLN (centre), compared with tolerant varieties each side.
(John Thompson)



RLN (stained red) in a wheat root, as seen under the microscope. RLN is a small (0.5 – 1.0 mm long) worm-like animal that feeds and reproduces inside the young roots of many crops. It survives in soil between crops.
(John Thompson)



Indistinct dark lesions on roots; fewer side branches

Take-all

(Cause - The fungus *Gaeumannomyces graminis* var. *tritici*)

ONSET AND DISTRIBUTION

- Can occur from emergence onwards, but most obvious after flowering.
- More common in no-till crops.
- Usually in poorly defined patches.
- Generally more severe on wheat than on barley.

SYMPTOMS

- Roots always black.**
- All tillers on diseased plants are affected.**
- All heads on diseased plants become whiteheads.**
- The SCI, crown and tiller bases can also be black, especially in a wet spring.
- Stunted yellow plants with reduced tillers.
- Plants easily pulled up, roots usually rotted.
- Whitehead development worse after hot dry conditions.
- Weeds often invade Take-all patches.
- Pinched grain at harvest.

MANAGEMENT

- Reduce levels of the Take-all fungus in your paddocks by rotating with crops such as field pea, faba bean, canola, mustard, chickpea, oats, mungbean, sunflower or sorghum to provide one year free of grass hosts.
- Break crops or pasture must be free of grass weeds.



Black roots are a distinguishing feature of Take-all; normal plant on the left. (Kevin Moore)

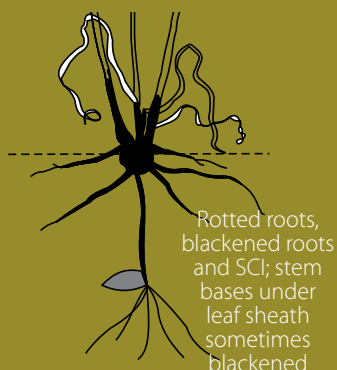


Blackening of the crown and lower stems, also a symptom of Take-all. (Gordon Murray)

- 'Winter clean' pasture in late winter before cropping to remove grasses by spraying with grass-selective herbicide.
- Use adequate fertiliser, especially phosphorus and nitrogen.
- Seed treatment with the fungicide fluquinconazole or in-furrow treatment with flutriafol can provide suppression.



Whiteheads in a crop affected by Take-all. (Percy Wong)



Rotted roots, blackened roots and SCI; stem bases under leaf sheath sometimes blackened

Fusarium Head Blight (FHB)

(Cause – the fungus *Fusarium graminearum*)

ONSET AND DISTRIBUTION

- ▮ Causes a head infection rather than root or crown disease.
- ▮ Seen after flowering when prolonged wet weather occurs during heading and grain fill.
- ▮ Overhead irrigation can favour infection.
- ▮ Durum wheats are all highly susceptible.
- ▮ Inclusion of maize in the rotation favours the build-up of inoculum.
- ▮ Spores produced on maize, wheat, barley, sorghum, oats, triticale or grass weeds are windblown into heads.
- ▮ *Fusarium pseudograminearum* (Crown Rot fungus) can also cause FHB in some years through the rainsplash of conidia produced on lower stem nodes into heads.

SYMPTOMS

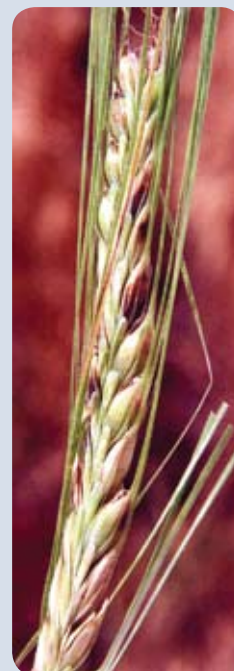
- ▮ In wheat, seen as premature bleaching of individual or several spikelets within a head.
- ▮ Frequently only part of the head (usually the upper half) is affected.
- ▮ During prolonged warm, humid weather infection also produces **salmon pink to orange spore masses (sporodochia)** of the fungus at the bases of infected spikelets.
- ▮ Infected wheat grains have a **chalky white appearance** and are usually shrivelled and lightweight. Infected wheat grain may also sometimes have a pink staining.
- ▮ Symptoms are different in barley; infected spikelets have browning or a water-soaked appearance, rather than bleaching.
- ▮ Infected barley grains have an orange or black encrustation on their surfaces rather than being chalky white.

MANAGEMENT

- ▮ Avoid sowing durum in close rotation with maize or adjacent to maize paddocks.
- ▮ Rotate to non-host pulse or oilseed crops.
- ▮ Control grass weeds in break crops and fallow.
- ▮ Sow partly resistant wheat and barley varieties in high-risk situations.
- ▮ Stagger planting within the recommended sowing window, or select varieties differing in days to maturity to minimise risk of all crops flowering during a period when weather is favourable for infection.



Durum wheat head infected with FHB. Note premature bleaching of infected spikelets. (Steven Simpfendorfer)



Barley head infected with FHB. Note brown water-soaked appearance of infected spikelets. (Steven Simpfendorfer)



Wheat grains infected with FHB are lightweight and have a chalky-white appearance. Pink staining may also be present. (North Dakota State University)

- ▮ Application of fungicides (e.g. tebuconazole) at early flowering can reduce infection. Note application timing and nozzle configuration are critical.
- ▮ Avoid high-risk rotational situations when using overhead irrigation.
- ▮ Use clean seed, or treat infected seed with thiram + carboxin to prevent seedling blight. Note that this does not control FHB later in the season.

Is my crop diseased?

- ▶ Inspect your crop regularly - is it healthy or diseased?
- ▶ When does the problem occur – early season, after heading, all season?
- ▶ Where does it occur – low spots, everywhere, ridges, individual rows?
- ▶ Are there patches, or does the crop generally lack vigour?
- ▶ Are there stunted, discoloured or dead plants?
- ▶ Has the crop gone off quickly?
- ▶ Are there whiteheads; if so, are they in patches or as scattered plants?
- ▶ Any evidence of insects or vermin?
- ▶ What's the weather been like – cold and wet, frosty, suddenly hot & dry?
- ▶ What chemicals have you used: last year, this year?
- ▶ What is the nutritional status of the crop?
- ▶ How does it compare with other crops?

Reducing losses from disease

These management practices work for all the diseases covered in this brochure:

- ▶ Don't grow wheat or barley after wheat, barley, or grassy pastures.
- ▶ Control weeds in crop and in fallow – some harbour disease and all compete with your crop for water and nutrients.
- ▶ Conserve soil moisture – many of the diseases in this brochure are worse in water-stressed crops.
- ▶ Fertilise to provide adequate nutrition – well nourished crops can cope better with disease.
- ▶ Grow resistant or tolerant crops and varieties where available (note: all varieties are equally susceptible to Take-all and Rhizoctonia bare patch).

Acknowledgments

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Further Information

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NSW DPI website, www.dpi.nsw.gov.au

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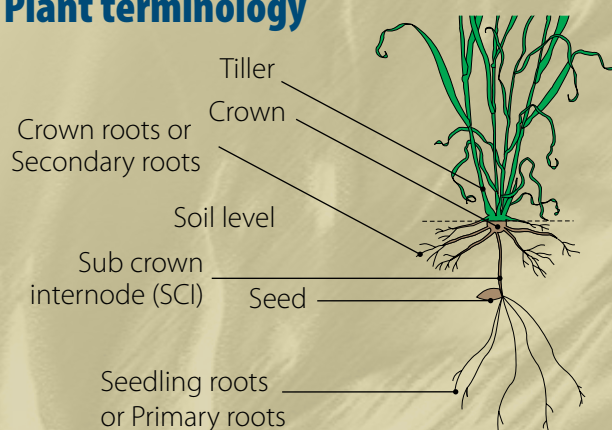
Identification



Whiteheads can have many causes: hail, mice, frost, insects, disease (in this photo, Crown Rot). Accurate identification is essential for effective disease management. (Kevin Moore)

- ▶ Do plants pull out easily or do they break off near ground level?
- ▶ Dig up plants, soak roots in water and shake gently to remove soil.
- ▶ Examine roots – a white tray with clean water makes this easier.
- ▶ Compare with roots of healthy plants.

Plant terminology



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Cereal Cyst Nematode (CCN)

(Cause - The nematode *Heterodera avenae*)

ONSET AND DISTRIBUTION

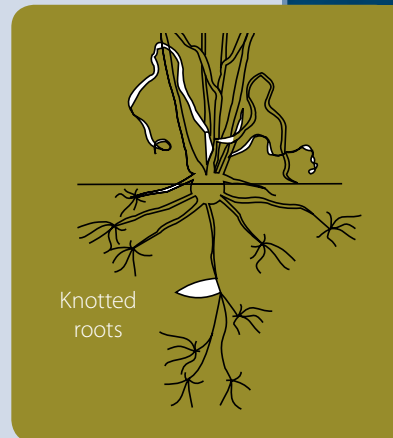
- ▮ Rare in northern NSW.
- ▮ Usually seen early in the season.
- ▮ Irregular patches in crop that persist throughout the season.
- ▮ Can occur on heavy and light soils.
- ▮ Barley is tolerant.

SYMPTOMS

- ▮ **Roots are always knotted.**
- ▮ Soil adheres to root knots and is difficult to wash off.
- ▮ Yellow or pale green patches appear in the crop in early winter.
- ▮ Affected plants are stunted, less vigorous, have fewer tillers and appear nutrient deficient.
- ▮ Plants are easy to pull up, often with a 'ball' of soil clinging to them.
- ▮ Roots are severely stunted and may be swollen, but are not discoloured.
- ▮ In late winter/early spring white cysts 1–3 mm in diameter develop in the knots; these cysts eventually turn brown.



Knotting of roots and shortened lateral roots are symptoms of CCN. (Kevin Moore)



MANAGEMENT

- ▮ Use rotations with non-cereal crops or resistant cereal varieties.
- ▮ A two-year break is needed to reduce nematode numbers.
- ▮ Control wild oats and susceptible cereal volunteers in break crops and pastures.
- ▮ Use adequate fertiliser.

Rhizoctonia Bare Patch

(Cause - The fungus *Rhizoctonia solani*)

ONSET AND DISTRIBUTION

- ▮ Usually seen early in the season.
- ▮ More likely where sulphonylurea herbicides have been used.
- ▮ More likely in light soils.

SYMPTOMS

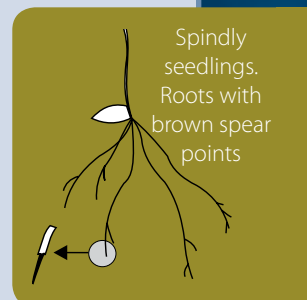
- ▮ **Well defined patches** in crop up to several metres across that persist throughout the season.
- ▮ **Some roots are always shorter, and these always have spear-pointed tips.**
- ▮ Affected plants are very stunted and have reduced tillers and erect leaves that are often reddish/purplish.
- ▮ Affected plants either die or remain stunted throughout the season.

MANAGEMENT

- ▮ Soil disturbance to 5–10 cm below sowing depth at, or within 2 weeks of, sowing.
- ▮ In a no-till system, use modified sowing points that provide soil disturbance below the seed.
- ▮ Take care with using Group B herbicides especially on alkaline soils.
- ▮ Optimise crop nutrition through application of fertiliser.



Rhizoctonia often produces well defined patches in the crop. (Kevin Moore)



Affected plants on the left show shortened, spear-pointed root; healthy plant on the extreme right. (Kevin Moore)

- ▮ Consult with the authors of this brochure or your local agronomist for further options.

Section 4

Irrigation systems

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Furrow irrigation systems

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Drip irrigation systems

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4.1 Alternative irrigation systems: a case study

Robert Collins
'Merrowie', Hillston

Key point

- 'Whatever system you have – you must think appropriately – your management and your operations will change and should change as you review what return you are making on every millimetre of water you have - whether it be rain or pumped.'

Many of the systems that have been installed as alternatives to furrow irrigation for large scale irrigation can be characterised by a history of errors, wrong expectations, inappropriate installations and incorrect advice. There are successful installations out there, but we always hear of the failures.

What has been our experience with all three types of irrigation on different soil types, in different valleys and on different crops? Following are the characteristics of each system, and the things that matter.

Furrow irrigation: The devil you know

Experience

- Heaps of years in all areas
- Tried everything under the sun
- Machinery designed and built around the system, with the help of SOILpak
- Very successful delivery systems
- Problems can be seen and fixed relatively easily

Efficiency

- Highly variable – poor to good
- High yields have led to some great returns per megalitre
- System built around tailwater – drainage inherent in system
- Differences in uniformity of application negated by over-application
- Systems optimised with adequate capacities in design
- Run length and slope appropriate for soil type and region and crop critical

Agromony

- Train plant to use water from profile
- Good understanding of profile and plant stress

Losses

- Large channels with high head
- Furrows
- Water moving below root zone
- Tailwater
- Reservoirs

Problems

- Water use ML/ha \$/ML
- Levelling – touch-up

Drainage capacity – generally on-farm storages viewed as benefit and run-off collected as unmetered water, 'got one anyway'

Soil movement

- channel maintenance
- pesticide movement
- trash and disease
- row shape – slaking and slumping
- filling of pores

Hardsetting soils

Access for operations – ground rigs

Waterlogging during irrigation

Fixed application rate – one size fits all, the ‘flush’ is a full irrigation

Positives

- Reliable – we can see it all
- Good knowledge of water use, where from and plants’ response
- Uniformity in profile filling – inundated!
- Variable infiltration rates managed (time of inundation limited)

There is a lot that can be done to improve the system. Very tactile, positive and fixable systems but expensive on water.

Lateral move – The other woman!

They take all your energy, demanding at inappropriate hours and you don’t want your friends to find out how much attention you are paying them; they can cost more than they are worth!

Experience

- Heaps of years of reports of failed projects – but the good stories are out there.
- Machinery can be problematic and require specialist help.
- Rarely meets design expectations.

Efficiency

- Good design guarantees uniform application laterally at the nozzle.
- Good nozzle package can deliver water to soil with minimal losses.
- Extremely high if all goes well.

Agronomy

- Managing crop with vegetative areas – hot spots.
- Growth control critical but this is hard if uneven moisture develops a variable crop.
- Surface feeding and training for deeper foraging.
- Irrigation timing.
- Infiltration rate.

Losses

- Evaporation of droplets and from surface water.
- Evaporation and drying of surface following application – this adds up!

Problems

- Water movement therefore uneven moisture – undoes all the value of uniform application. If water moves, you’ve got problems.
- Managing soils with variable moistures.
- Filling profile from the top – instantaneous application rates.
- Catch-up very difficult.
- Wheel tracks – How do you keep them dry?
- Drainage capacity – What do you do if it does rain a lot?
- Dispersion of soils – Droplets will separate all soil particles and cause the surface to seal. The risk of sandblasting is high if you plant on the flat, without stubble.
- Incorrect design and expectations
- Trash in channels
- Experts with winter crop experience only – these are dream machines when evaporation is low.
- Can be stopped by technology – cannot fix with a shovel, plastic and star posts

Positives

- No soil movement – good for disease, no trash movement
- No tail drains, no rotobucks, no head ditch – easy access for machinery
- Establishment is easy – as long as you don’t seal the surface
- Variable application amounts
- Water use is low: ML/ha is low
- When operating they are fantastic



The key to management is water staying where it falls – getting water to ‘go in’, not seal.

- Irrigator capacity correct for replenishment of profile and designed for daily water use.
- Low energy application through hose drags (socks) can be extremely effective, as long as there is no uneven ‘run-off’ causing one area to be wetter than another.
- The technician is your best friend – how much electronics or electrical knowledge do you have?
- Pivots are way easier to control than laterals – they are tethered and always stay in the same place, but capital cost per hectare is higher.
- Be wary of high pressure and high flow – this is expensive to pump, and wear of the pipe internal surface can be high. Most lateral suctions are costly in terms of friction loss.
- Keep it simple as possible, because, although most designers love technology, at 5 am on Christmas morning you will not be proud of the new ‘best thing’.
- Inspect existing set-ups and thoroughly question the operators, not the designer.
- When it all comes together, they are magic. Plenty of people now have solved the problems.

Drip irrigation – The name says it all

Experience

- Mostly horticultural: infrastructure has been a minor component
- Surface feeders with intensity of management high
- Machinery problematic and requiring specialist help
- Often fails to meet design expectations because of ‘other’ problems
- Fantastic yields with low water use – it can deliver all it promises

Efficiency

- Uniformity of application directly related to cost of installation
- Extremely high if all goes well

Agronomy

- Assuming good uniformity, it’s a dream
- Training roots to wetted zone
- Moisture-holding capacities included in design
- Growth management must be tight
- Infiltration rate matched to application rate

Losses

- Virtually none if all OK – usually use most in wetting up
- Water below plant line and some surface evaporation

Problems

- Cost per hectare
- Lower designed uniformity (lower cost) – possibly uneven application
- Rotation – what crop of value?
- Holes – they will happen, they do happen, no quick solution
- Specialist help required
- Abundance of extras supplied by resellers – keep it simple!
- Experts and over-design
- Establishment – all that money and we rely on rain for germination
- Rain – if water moves – uniformity destroyed
- Drainage – where can it go?

Positives

- No soil movement – good for disease, no trash movement
- Access for operations – no head ditch, no rotobucks
- Water use is close to ideal if you address watering up
- Remote and automatic
- Infinitely adjustable
- Fits all the ideals – but at what cost?

If you address the establishment issue, if you keep the system simple – this system can be amazingly efficient by any measure and will only be limited by the value of the crop produced.

Talk to various designers and make sure there is good product support – the difference between manufacturers is the level of technical support they offer.

- The designer’s proof is existing installations – check them out! See how much mud they have between their toes.

Test yourself

Each system requires appropriate management, operations and thinking – and this applies for new development, redevelopment and continuing systems. The one underlying truth is that our irrigation systems all supply water and you must consider the whole system, from the source, that is river pump, bore or rain. You bought access to the rain when you bought the land, you have bought the access to river, surface flow or groundwater – how well are you using all of it?

Why are you wanting to change?

What are you going to do with drainage? 25 mm rain? 250 mm rain?

Cost of levelling for drainage?

Have you taken your existing system as far as possible?

Expert help or specialist part: is it available?

Where to from here?

The tools we are using to improve are:

- Analysis of successes. There are fields achieving 1 bale/ML+. We need to identify their characteristics.
- Electromagnetic Ground Conductivity Survey, soil cores and testing, soil pits.
- Infra-red (IR) mapping of the crop
- Identify relationship between flow rates, irrigation time, advance, wetting pattern
- Yield mapping, then incorporating all of the layers of information. Some treatments can be made across whole paddocks, but others will be specific. Cost of treatment must be judged against benefit.
- Cut out areas where yield per ML is worse. Cost of addressing the problem: deep ripping, gypsum, rotations?
- Closer monitoring of movements of water, particularly in trying to identify system losses, such as reservoir losses. Reliable metering.
- Deep drainage is poorly quantified. We will probably need help in quantifying this.
- Evapotranspiration and evaporation need to be better understood, particularly as we know that some soils simply require more water to achieve the same plant growth.



Table 4.1.1 Comparing three irrigation systems

System	Furrow	Drip	Lateral
Area – green hectares	439 ha	139 ha	206 ha
Area – hectares	574 ha	146 ha	228 ha
Area if all furrow	439 ha	95 ha	155 ha
Year of development	1999	1999	1999
(All numbers below are per hectare.)			
Delivery capacity	0.5 ML/day, 50 mm	0.12 ML/day, 12 mm	0.13 ML/day, 13 mm
Drainage capacity	0.25 ML/day, 25 mm		
Rainfall capacity	0.25 ML/day, 25 mm	0.25 ML/day, 25 mm	0.25 ML/day, 25 mm
Installation (\$/ha)			
System price	\$1,422 (@ 663 m ³ /ha)	\$3800	\$1850
Supply	\$106	\$121	\$121
Drainage	\$69		
Total	\$1597 /ha	\$3800 /ha	\$1850 /ha
Average operating costs (\$/ha)			
Water applied	9 ML/ha	6.5 ML/ha	6.1 ML/ha
Water costs	\$159	\$115	\$108
System pumping		\$75	\$63
Tailwater pumping	\$28		
Irrigation labour	\$84	\$30	\$20
Irrigation R & M	\$8	\$20	\$5
Channel maintenance	\$20		\$2
Channel herbicides	\$25		\$3
Rotobucks	\$12		
Total	\$336 /ha	\$240 /ha	\$201 /ha
Yield average over 2 years	7.5 bales/ha	8 bales/ha	7.8 bales/ha
Expectations – cold start	7 bales/ha	8 bales/ha	7.5 bales/ha
Observations			
Water use efficiency	70–83%	96%	92%
Wetted zone	100% profile	50%	70%
Cycle	10 days	Daily	3 days
Management	Twice weekly	Daily	Daily
Timing	Generalised	Precise	Precise
Incrop rainfall	Drainage time	50% capacity	30% capacity
Drainage	Designed	Field capacity	Field capacity/stubble
Ground rig	Limited, rotobucks	Full season	Full season (hoses)

Comparing three irrigation systems

(Note: This information is applicable to our farm and must not be taken as correct for anywhere else.)

The performance of each system depends on soil type, system configuration, supply and drainage capacities, design uniformity, management, groundcover, and, most importantly of all, the **uniformity of moisture held in the soil.**



4.2 Applying furrow irrigation water

Mitchell Carter

NSW DPI, Tamworth

Michael Grabham

NSW DPI, Griffith

Key points

- Adequate management and maintenance of all components between the head ditch and the tail drain is important for furrow irrigation systems.
- Improving furrow irrigation performance involves careful management of flow rates and irrigation duration and appropriate timing (scheduling) of irrigation events.
- The relationship between head and flow rate determines the amount of water applied to a field. Flow through siphons and culverts increases as head increases and decreases as head decreases, hence variations in head cause variations in volume of water applied.
- Optimal furrow irrigation performance requires understanding of application efficiency and distribution uniformity and the methods for improving both.

This topic examines various aspects of the application of surface irrigation water and provides points to consider when designing and operating your system. The first section discusses the hydraulics and management of irrigation water as it flows down the furrows, whilst the second section discusses the theory and practice of each component of a surface irrigation system.

Furrow irrigation practice

Furrow irrigation involves the application of irrigation water at the top end of a field into furrows. The water then flows along these furrows to the bottom of the field, infiltrating into the soil along the length of the furrow. The length of time the soil is exposed to this water is known as the **infiltration opportunity time** (t_{op} or IOT). To achieve the ultimate in furrow irrigation performance, the infiltration opportunity time should equal the amount of time necessary to apply the required depth of water (**target deficit**, see Topic 2.9).

The infiltration opportunity time is different at different points along the length of the furrow. This is because the length of time that the water is present on the surface

of the soil at any location is the difference between the time the water arrives (advance) and the time the water leaves (recession). As illustrated in Figure 4.2.1, the rate at which water advances down the field is different to the rate at which it recedes.

Even infiltration is achieved when the advance and recession rates are similar, resulting in a more uniform infiltration opportunity time along the furrow length. This is illustrated in Figure 4.2.2.

Distribution uniformity (DU)

The measure of how evenly this infiltration occurs is called **distribution uniformity (DU)**. Distribution uniformity is explained in Topic 2.9. During a furrow irrigation event, distribution uniformity is primarily influenced by the soil infiltration characteristic (soil type, variability and moisture content), rate of water flow into the furrow (inflow) and the length of time this water is flowing (time to cut-off). Other factors that influence uniformity include field slope and variability and field length.

Figure 4.2.1. Infiltration opportunity time varies with distance down the field

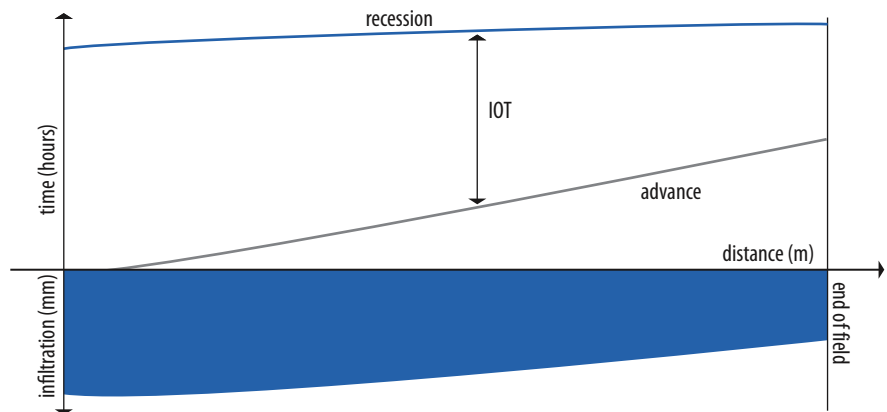
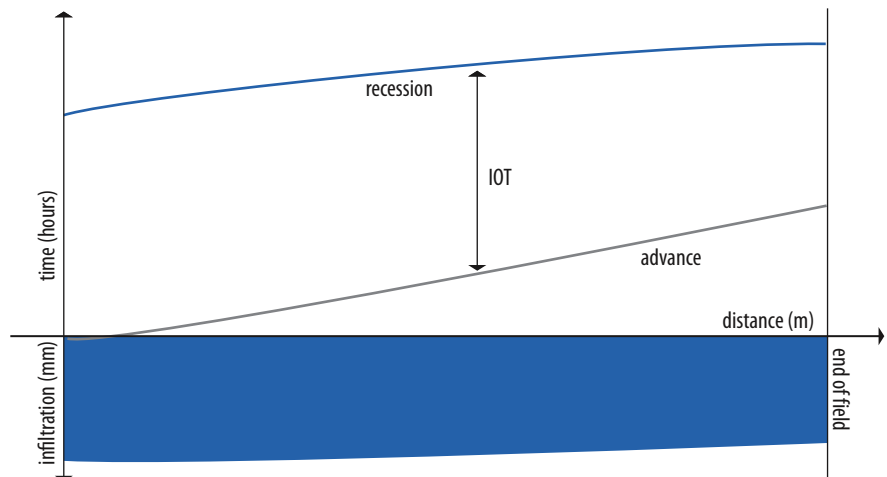


Figure 4.2.2. More even infiltration from advance and recession curves that are similar



Historically, to compensate for poor uniformity, irrigation events have been run for longer than necessary to ensure the whole field receives at least the required water application. This, however, typically results in much of the field being over-irrigated, leading to waterlogging and associated production impacts. Furthermore, water infiltrated in excess of that which can be held by the soil within the root zone is lost through the soil profile as deep drainage.

In addition to the variation in uniformity along the length of a furrow due to differences in IOT, infiltration may vary between furrows across the width of a field. Greater compaction in wheel tracks decreases infiltration compared with non-wheel track furrows. Similarly, head may vary along the length of a head ditch, resulting in different inflow rates to furrows in different parts of a field. Irrigation duration may also vary, particularly between different siphon sets, and this variation is often correlated to the time of day that sets are started. When evaluating distribution uniformity of a furrow or group of furrows, it is important to understand how representative these furrows are of the remainder of the field.

Irrigation efficiency

Improving the performance of a furrow irrigation system requires more than achieving high distribution uniformity. The other primary measure of irrigation performance, **application efficiency** (E_a), is just as important (see Topic2.9 'Assessing field-scale water use efficiency'). Application efficiency relates the amount of water applied in an irrigation to the amount of water available to the crop for use. A high efficiency means that most of the water applied has remained in the root zone available for plant use.

A uniform irrigation does not guarantee efficiency, and an efficient irrigation need not be uniform.

For example, an irrigation may be perfectly uniform, in that the same amount of water is applied to every part of a field, but if the total amount of water applied were twice that required, the application efficiency would only be 50%. In contrast, an irrigation may be perfectly efficient, such that all of the water applied to the field remains in the root zone available for use, but if this water only made it across half of the field, the uniformity will be extremely low.

Hence optimum system performance is achieved when both application efficiency and distribution uniformity are high. One other term that may be used to describe the performance of an irrigation system is **requirement efficiency**. The requirement efficiency simply refers to how well the irrigation event satisfied the target deficit. If any part of a field is under-irrigated, the requirement efficiency will drop below 100%. The closer the requirement efficiency is to 100%, however, the greater the chance that the application efficiency will be reduced.

Improving furrow irrigation performance

A number of modifications can be made to improve furrow irrigation performance. Design changes include modifying furrow slope and geometry, although these parameters have very little effect on irrigation performance. Changing field length has a larger impact on performance, but typically the most significant improvements are possible through management changes. The three management characteristics which can be modified are:

1. infiltration characteristic
2. inflow rate
3. time to cut-off.

Infiltration characteristic is the most difficult to modify, although it is influenced by the moisture content at which irrigation occurs. Stretching irrigations causes a larger soil moisture deficit which typically slows the rate at which irrigation water advances. The effect on performance relies significantly upon soil characteristics, particularly the cracking properties of clay soils. For many soils, stretching irrigations may have a detrimental effect on performance unless inflow rates and cut-off times are adjusted accordingly.

Increasing or decreasing compaction in furrows will also modify the infiltration characteristic (for example, wheel tracks). In some soils with adequate infiltration, including many black cracking clays, wheel tracks actually perform better than non-wheel track furrows. Depending on the method of construction, compaction can also occur during furrow formation, particularly in deeper furrows. In some instances, performance benefits in such situations have been attributed to the change in furrow shape, where the actual cause has been a change in level of compaction.

Fortunately some of the biggest improvements in performance can be accomplished through changes to some of the most easily manipulated characteristics. Varying time to cut-off is easy to accomplish given adequate labour flexibility. Whilst many irrigation events can be improved through simply modifying the total irrigation time, it is more usual to require a change in both cut-off time and inflow rate. Inflow is typically not infinitely variable, as it is usually a function of the siphon sizes and heads available and the economic viability of starting additional or different-sized siphons. Through-the-bank pipes may offer additional restriction in the range of flow rate options available.

The most common changes to improve furrow irrigation system performance are an increase in flow rate and corresponding decrease in irrigation duration. However it is vital that measurements are taken before implementing changes so that current performance can be identified and appropriate changes can be implemented. An appropriate strategy may be:

- Compare total inflow and target deficit. An application in excess of the target deficit indicates potential run-off or deep drainage, or both.
- Analyse soil moisture data to investigate wetting and extraction patterns and waterlogging. Sometimes it is possible to identify the occurrence of deep drainage using such data, but soils that remain saturated at depth may not show drainage, even when it occurs.
- Investigate commercial analysis and modelling services.

Case study: Measuring and modelling to improve irrigation performance

Data from fields in two different cotton-growing regions was collected and analysed to determine the application efficiency and distribution uniformity as well as the maximum inundation time. Maximum inundation time (the largest infiltration opportunity time) is important to many growers, as longer periods of inundation are likely to be detrimental to crop productivity (and indicate potential waterlogging). The strategies investigated for improved performance included (where appropriate):

- cut-off when water reached the end of the field
- cut-off one hour before water reached the end of the field
- increased application rate (inflow)
- increased application rate, and cut-off when water reached the end of the field

It should be noted that these strategies were selected as representative of the types of changes possible and whilst leading to increased performance in these situations may not be the choices that lead to optimum performance. Optimum performance needs to be assessed on an individual basis. Field 1 data is sourced from Raine and Walker (1998).



	Typical management	Cut-off when reached end	Cut-off one hour before end	Increased application rate	Increased application rate and cut-off when reached end
Field 1					
Application rate (L/s/furrow)	2	2	2	4	4
Cut-off time (min)	918	745	685	552	377
Inundation time (min)	990	810	732	600	396
Application efficiency (%)	70	86	93	58	84
Requirement efficiency (%)	100	99	99	100	99
Distribution uniformity (%)	93	92	90	97	95
Field 2					
Application rate (L/s/furrow)	3	3	3	4	4
Cut-off time (min)	680	380	320	300	232
Inundation time (min)	692	392	335	315	245
Application efficiency (%)	46	82	89	68	87
Requirement efficiency (%)	100	99	91	100	98
Distribution uniformity (%)	94	86	63	92	88

For both fields, the data indicates the variations in application efficiency and distribution uniformity. It should be noted that some strategies may have improved either efficiency or uniformity but not all strategies improved both. For both of these fields, the best strategy of those tested in terms of application efficiency, distribution uniformity, requirement efficiency and inundation time was an increased application rate and decreased cut-off time. In both cases the period of inundation was reduced by over half and the application efficiencies were increased substantially with little effect on the already high requirement efficiency and distribution uniformity.

The strategy of having a cut-off time one hour before the water reached the end of the field was unsuccessful for Field 2 because insufficient water was applied to the bottom of the field: hence the values for distribution uniformity and requirement efficiency are reduced.

Furrow irrigation system components

Head ditch

The purpose of a head ditch is to consistently deliver sufficient water at an appropriate head. The aim is to achieve a steady flow rate onto the field. Maintaining a constant flow rate requires specific management and maintenance. Management involves regulating flows in the system and selecting and operating outlets appropriately, while also maintaining adequate freeboard. Regular maintenance such as desilting, weed control and removal of obstructions must also be done.

Head ditch flow is regulated at the source, while head ditch levels are determined by downstream control structures. Water level should be kept as constant as possible while irrigating, as fluctuations cause the outlet discharge to change. Consequently, to maintain a constant head, discharge from all outlets should equal the head ditch inflow. A minimum 0.15 m freeboard should be maintained in the head ditch.

Because soils other than heavy clays are more susceptible to erosion, head ditches in these soils should be designed to keep water velocity below 0.6 metres per second (m/s). Heavy clays should be limited to flows below 1 m/s. A velocity above this may cause scouring. Velocity should also be kept above 0.15 m/s, or silting may occur.

Measurement of flow in head ditches is quite complex and is typically achieved using ultrasonic flowmeters (for example, Doppler meters: see Topic 2.8) or by measuring depth through calibrated control structures such as flumes or weirs. It may be possible in some circumstances to measure flow over irrigation checks.

Obstructions in the head ditch can cause scouring and increase the system head loss. While head ditches less than 1 metre wide or less than 0.2 m deep are most susceptible, obstructions in all head ditches should be avoided. Obstructions can be caused by silting, weeds and embankment slumps.

Siphon and culvert hydraulics

Water movement requires energy. Overcoming the resistance or friction as water moves through channels or pipes accounts for most of this energy use. The energy driving a system is called 'head' and the loss in energy is called 'head loss'. Careful design and management of a system can reduce the head loss of a system. Irrigation systems are usually designed and operated to limit the total system head loss, which usually minimises energy costs, channel and pipe sizes, and prevents the overtopping of channels.

Head loss occurs whenever water flows. It increases when water goes from a broad slow flowing channel into a fast-flowing pipe. Bends, restrictions and sudden changes in channel size or pipe diameter all increase head loss.

In surface irrigation systems, head loss is evident as a drop in water level from upstream to downstream. This means it can be measured reasonably across any structure, such as through-the-bank pipes, culverts or checks.

Understanding the interaction of head and flow rates is important for correct application of water onto a field. Flow through siphons and culverts increases as head increases, and decreases as head decreases. It is important to install culverts so they run at their full capacity, as culverts running partially full have greater head loss and restrict flow.

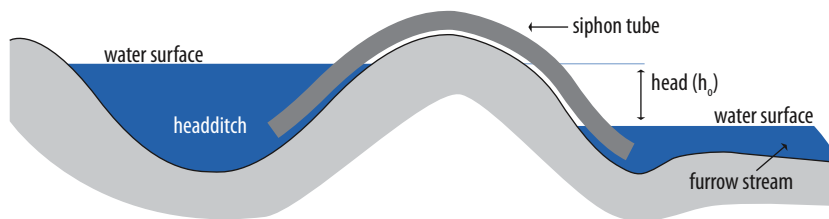
Siphons

Siphons can operate under two situations: submerged flow and free flow conditions (Figures 4.2.3 and 4.2.4).

- When operating under submerged flow conditions, the available head is the difference between the upstream water level and the downstream water level.
- Under free flow conditions the head is the difference between the upstream water level and the level of the siphon outlet.

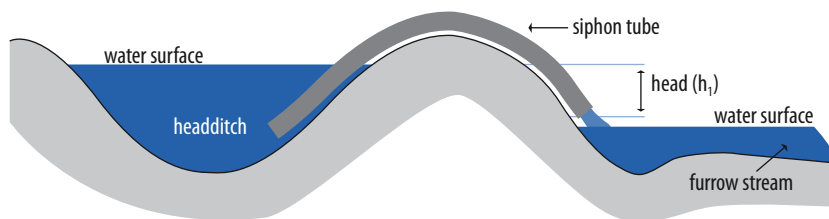


Figure 4.2.3. Siphon operating with submerged flow



Source: J Purcell

Figure 4.2.4. Siphon operating with free flow



Source: J Purcell

In most cases, with typical irrigation head ditch layouts, siphons will be operating with submerged flow (Figure 4.2.3). Under these conditions, siphon flow rates can be affected by water level in the furrow stream and the head ditch, siphon length and diameter, and the internal roughness of the siphon. In one trial, variations ranging from 27% to 152% of the mean siphon flow rate occurred as a result of these variables. This has obvious implications for the distribution uniformity of a given field.

Pipe diameter has a significant influence on siphon capacity. Siphon flow rates can be measured using methods outlined in Topic 2.9 'Assessing field-scale water use efficiency'.

Siphon placement can affect flow rate. Placement of siphons at different angles to the flow of the head ditch causes a preferential flow into some of the siphons that results in flow variation. Placing all siphons perpendicular to the head ditch can help overcome this problem.

Any variation in cross-sectional area will affect flow rate. Walking on siphons or accidentally pushing them into the ground when starting them may cause kinks, reducing their cross-sectional area. Extreme heat may cause them to become oval, also reducing the cross-sectional area. The cross-sectional area may vary between siphon brands so care is needed if siphons are replaced or substituted.

Theoretical flow rates for a range of siphon sizes are presented in WATERpak Appendix 9.11.

Pipes through the bank

Pipes through the bank (PTBs) operate like conventional culverts and may be either inlet- or outlet-controlled depending on the water level in the head ditch and the irrigation field and the pipe geometry. The relationship between head and pipe size on the theoretical flow of PTBs again demonstrates the importance of pipe diameter and amount of head (Table 4.2.1).

PTBs are different to most other culverts on an irrigation farm. Flow rates in PTBs are often controlled from the inlet. As a result, changes in supply level can have significant effects on PTB flow rates. Preferential flow down some furrows, caused by wheel tracks and trash build-up, and maintaining adequate head are two problems often encountered with PTBs.

Table 4.2.1. Theoretical flow (L/sec) for pipes through-the-bank (PTBs)

	Pipe diameter (mm)					
Head (mm)	150	200	225	300	380	450
100	16	29	38	70	114	162
150	19	36	46	85	140	199
200	22	42	54	99	162	229
250	25	46	60	110	181	256
300	27	51	66	121	198	281

Note: Inlet controlled flow

Furrows

Furrow and bed dimensions can assist in improving water use efficiency and crop health on farm. Cotton has traditionally been grown on 1 metre beds, however there are a number of alternative bed configurations being used to achieve a variety of outcomes to suit local conditions and soil types. Two metre beds and 1.8 metre beds with ultra narrow row (UNR) planting help to reduce waterlogging, improve the earliness and yield of the crop. Provided rainfall can be drained adequately, wider beds are less likely to be waterlogged than 1 metre beds. (See SOILpak D1.)

A significant loss of water may result from deep drainage in the field. Studies estimating deep drainage have reported values of 1-2 ML/ha (10-30 %) of water applied lost in this form. Improved management techniques to reduce soil compaction have, in some cases, caused increased infiltration and more deep drainage. If an irrigation is undertaken using appropriate flow rates for an appropriate duration, deep drainage will be minimised. Soil water monitoring below the root zone may assist in determining when deep drainage occurs (see Topic 2.3). To manage the advance in wheeltrack rows on red soil, where often the irrigation water does not infiltrate very deeply,

irrigation with a high flow rate can improve water movement into the mounds. However, due to a reduction in infiltration, these soils will need more frequent irrigations to keep up with crop demand.

While weed control in furrows is important, the presence of stubble or a root mat on bed edges can reduce the incidence of erosion while creating biopores (holes created by roots and soil organisms) that improve infiltration.

Deep furrows may promote adequate drainage of the field. However, deeper furrows mean steeper bed edges, which are difficult to maintain and be prone to slumping. Slumping encourages erosion and may dam furrows, resulting in waterlogging of the bed. More information on furrow design can be found in SOILpak D1.

Reduced in-crop cultivations in Roundup® Ready cotton sometimes results in hill slumping. Cultivation reforms hills, helping to prevent slumping and subsequent damming of furrows. Blocking off a furrow leads to poorer DU. Where two or more rows are irrigated using one siphon, preferential flow into one furrow may result, leading to poor DU. Slumping or silt build-up in one furrow can also cause preferential flow.

Waterlogging can result in dramatic production losses (see Topic 3.3). This should be considered on very flat fields (flatter than 1:1500) both from an irrigation perspective and a rainfall drainage perspective. Furrow lengths that are too long may result in excessive deep drainage and waterlogging at the top end of the field. This is because the infiltration opportunity time is too long.



Fields are laser graded to a certain slope for good drainage and high DU. Fill areas and gilgai country suffer slumping over time. Fields should be re-laser-graded or polished as required to ensure a high DU is maintained. Steep slopes or application rates that are too great can result in furrow water velocities that may cause erosion of the furrow and siltation problems elsewhere.

Fields with point rows (non-square fields) need to be carefully managed. The varying furrow lengths will require different irrigation times to avoid waterlogging. This has a greater labour requirement as siphons will need to be cut at different times but a high DU can be maintained. A different approach is to reduce the siphon sizes on the shorter rows to slow the flow rate. This may be appropriate, however remember that the aim in these sections of the field is to have an infiltration opportunity time equal to that of any point in the remainder of the field. These furrows do not necessarily need to come out at the same time as longer furrows provided the IOT is managed correctly.

Tail drain

Tail drains remove run-off from the field created by both irrigation and rainfall events. Tail drains are typically designed to drain run-off generated by a one-in-five-year, 24 hour storm event. Rapid removal is necessary to prevent in-field waterlogging and reduce the yield penalty created by waterlogging (see Topic 3.3).

In order to correctly design tail drains, stormwater run-off needs to be estimated. Climatic factors, current soil moisture content and the size of the field will influence the total run-off. It must be appreciated that designing tail drains is site specific with many factors to consider. Tail drains should be constructed with a minimum gradient of 1:3000. Drain capacity should increase from the beginning of the drain with maximum capacity at the end of the tail drain. Batters should be shallow, 10:1 on field side to minimise erosion and 5:1 on road side to allow machinery access. Drains should be sufficiently deep to prevent water backing up into the field, yet sufficiently shallow to prevent erosion occurring between the furrow and the drain. Generally the depth between the furrow and the tail drain should not exceed 250 mm. There is a compromise between the cost of constructing large tail drains to cope with rare storm events against the penalty of suffering yield losses associated with water backing up onto field due to smaller tail drains.

Tail drains should drain into the tailwater return system with a minimum depth of 700 mm between the furrow level and the drainage return system. This will ensure complete drainage of the field is achieved, minimising waterlogging. It is important that the tailwater return system and pump are designed to cope with the large volumes of water storms can generate. Construction of surge areas is an option to minimise drain and pump sizes and allow settling of sediment. The water in the surge area can then be pumped once the immediate storm water is removed.

As in head ditches, water velocity in the tail drain should be kept below 0.6 m/s in soils other than heavy clays, which should be limited to flows below 1 m/s. Flows above these velocities can cause scouring. In contrast, flows should be kept above 0.15 m/s or excessive silting may occur.

Culverts should be adequately sized to cope with drainage requirements and high trash loads. High volumes of trash in undersized culverts may lead to blockages and result in field waterlogging problems caused by backed up water. Blockages can also lead to scouring and significant head loss. Some design considerations for trash management include:

- Install drainage culvert upstream of the channel end to allow trash accumulation at the end of the channel while preventing culvert blockage.
- Enlarged culverts allow trash to be carried through rather than causing blockages.
- Ensure regular maintenance is carried out to limit blockages.

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4.3 Drip irrigation: design, installation and management

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Key points

- A system designed by a row crop engineer who is experienced, preferably in cotton, is critical to achieve the potential water savings and flexibility in crop management that drip irrigation can offer.
- A well-planned maintenance program is essential to maintain proper system operation.
- It is important to monitor and control the quality of water used with the drip system, which determines the frequency of flushing required.
- Drip allows accurate application of water and fertiliser to suit crops' requirements and flexibility in field operations, but the management requirement is higher than conventional surface systems.

Drip irrigation has the ability to optimise water and fertiliser use in row crops. When crops are irrigated daily with small volumes, the potential yields can be increased and maintained, or crops can be finished faster in short season areas.

Drip irrigation is a relatively new technology. It has been used in row crops for just 20 to 30 years. In Australia, drip has become the standard irrigation method in high value permanent crops. Worldwide it is becoming more widely used in row crops.

The widespread adoption of this technology has been largely restricted by high costs involved in setting up a system. With the increasing pressures on growers to increase water use efficiency and maximise production, drip will definitely play a role in many developments.

Drip irrigation is a system of pressurised water run through tubes placed in the field. Emitting devices are placed at intervals along the tube, so water is distributed uniformly. In most row crop situations today this tube is buried, and known as **subsurface drip irrigation** (SDI).

With SDI, water is placed into the plants' root zone, and therefore losses due to evaporation and run-off are minimal. The uptake of the applied water can be very efficient with accurate management, as water is applied daily with fertiliser added as required.

The system capacity is measured in millimetres per day. Systems are most often designed to replace the maximum daily use of the crop, around 12 millimetres per day. Systems should not be designed for a lower supply rate because the risk of under-supply is increased if rain doesn't arrive as expected. Each day the grower can alter the applied water to keep soil moisture levels in optimum range. Soil moisture levels can also be manipulated to influence crop growth habit.

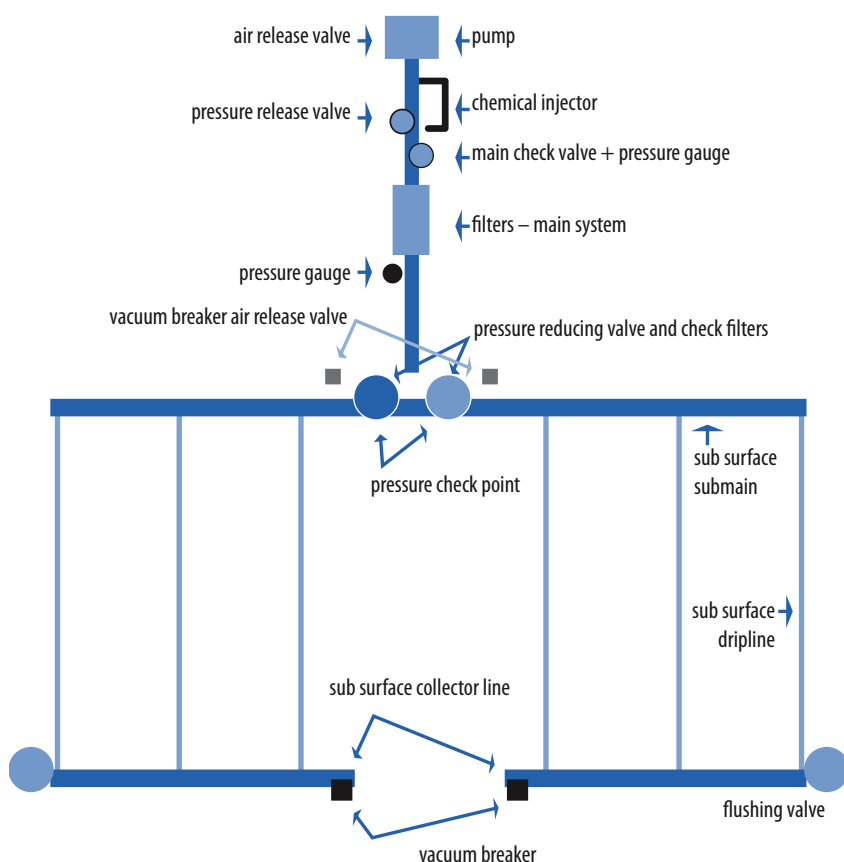
The practice of fertigation, or irrigation with fertiliser added, is as important as water is with drip irrigation. Soluble fertilisers are taken up faster and more effectively, and fertiliser can be added daily, reducing leaching and soil losses. Drip has the ability to apply very small quantities of elements, uniformly and precisely as required with irrigation water.

Design of drip systems

A drip system contains some standard components (Figure 4.3.1), but each system is tailormade to the fields' requirements. Soil, water and farming systems all play a part in the system's specifications. As a result it is difficult to compare outcomes.

It is important that a prospective user of drip irrigation assess their aims and goals prior to a system being designed.

Figure 4.3.1. A typical drip irrigation system design



SDI systems require the following components:

Pump – carefully selected for performance and safety, an SDI pump's performance curves will often be 'flat' with maximum pressures below that of the pipelines.

Filtration – variety of filtration methods, sand media or disc filtration being the most common. Nearly all are automatic flushing. Micron or 'fineness' of the filters is determined by the drip tube manufacturer – they do not all have the same requirements! (Figure 4.3.2).

Pressure gauge – to check pump output pressure and pressure after filters; difference between the two is how blocked filters are.

Fertiliser injector – pumps or venturis for fertiliser injection and maintenance.

Water meter – for performance checks and safety.

Controller – an electronic computer runs field valves and system safety; also turns pump off and sometimes on.

Mainlines – Mostly PVC, designed for cost-effective movement of water to fields.

Air valves – very important that these are installed and working. Trapped air can compress, releasing at pressures much higher than pipes are designed for. Air valves are located at all valves and high points in mainline, and must release air whilst under pressure; they are often dual purpose air/vacuum release.

Valves – mostly hydraulic regulating valves, these reduce pressure from mainline to suitable operating pressure for drip lines. Require pressure check points either side for setting valves and checking performance.

Vacuum release valves – these are important to let air back in after system shut down, are located downstream of valves and at all ends of submains and flush collection manifolds, and prevent air including mud being sucked back into emitters.

Submains – critical to system uniformity, drip tube is connected to these; they are positioned after valves, so pressure differences relate to dripper flow rates.

Drip tube – the real key to system operation. Various flow rates, spacing of emitters and diameter of tube. These attributes all play a part in run lengths and costs and uniformity, and can be confusing. Should be determined by soil types and uniformity and flushing ability. Wall thickness is also an issue; a thicker wall is more resilient to damage.

Emitters – not all emitters are the same: they vary in clogging resistance, CV (coefficient of variation, that is, emitter uniformity), size of flow path, ability to clean inlet filter, length of labyrinth (shorter path means more efficient, more turbulent and easier to clean). Beware of low flow rate emitters in long-term systems.

Flushing manifold – the collection pipe where drip tubes are connected, these are opened for flushing out dirt. They are not necessary but greatly reduce maintenance times. Also, they have more vacuum release points.

Figure 4.3.2. Filtration equipment



An experienced, qualified irrigation designer should design all drip systems. For cotton systems they should be experienced in row crop designs and have a record of successful projects. The designer should consult with growers and consultants to ensure the project has the highest chance of success, fitting with farm infrastructure and long-term farm plans. To do this the designers must have adequate information to work with. This will include: accurate GPS maps and contour maps showing 0.5 m variations in slope, field layout and size, access and roads, soil properties and possible changes in soil types. If field conditions are variable, this detail will enable the designer to develop a system that will allow separate within-field management. A detailed soil survey may also be useful.

Almost all SDI row crop systems use non-compensated emitters, meaning the output changes with pressure. Uniformity is a major issue in design and can be complex. Systems can be designed much more cheaply if uniformity is compromised. This makes management very difficult always having to manage for the 'middle or dry' areas. Uniformity is measured in a few ways, the most accurate being field flow variation (FV). This is represented as a percentage, for example, $FV \pm 7\%$ means all emitters in the block or valve will perform better than 7% either side of the specified flow rate of the design. Few row crop designs are adequate beyond $\pm 7\%$ FV. It is important to compare similar uniformity measurements, as it is easy to confuse them.

Installation of drip systems

Good installation can improve performance and longevity. Extreme care and high levels of supervision are required to ensure systems are installed correctly and best suit the farm and the grower. Often problems can be avoided if small changes are made to placement of flush points and other equipment. There should be almost no aboveground components within fields, locating flushers and valves beyond fields, or they can at least be grouped and protected.

Accurate injection of tube is also critical and specialised equipment is available for placement (Figure 4.3.3). Emitters should always be positioned facing upward and into loose soil. Bed preparation and pre-ripping can make accurate depth and location much easier (Figures 4.3.4 and 4.3.5). The use of global positioning satellites (GPS) is now considered essential, making relocation of beds possible over time.

Figure 4.3.3. Tube installation equipment



Figure 4.3.4. Depth of tube placement is critical



Figure 4.3.6. Trench construction



Figure 4.3.5. Placement within bed system prior to sowing



Photograph all major valve assemblies and pipe junctions before backfilling. This is a big help if they ever need repair.

Drip tube connections should be perfect. Risers from pipelines should be accurately drilled. Extreme care is needed filling trenches. The system should be pressurised and loose fill delicately pushed into trenches to prevent movement and kinking of risers or tube.

Accurate depth and straight trenches with smooth, soft floors will allow good support of pipes (Figure 4.3.6). PVC pipe elbows reducers and ends should be adequately thrust to prevent movement, following the pipe manufacturer's instructions. Valves and command tubing should be supported if required, and protected from machinery and animal damage. Control systems need to be electrically protected from both supply and lightning.

Maintenance of drip systems

Like any complex system or machine, drip systems need maintenance to prevent breakdowns and loss of performance.

Maintenance requirements need to be included in the design. Drip tube sizes and run lengths are often determined by flushing capability. Keeping systems clean, particularly on silty river water, is the key to emitters' longevity. The tube and emitters don't degrade or break down. If kept clean, very long life can be expected – often, with the high cost of establishment, 10 years or more. There are systems that have been well maintained that are beyond this age and performing as new.

Maintenance is largely preventative, with silt and organic matter needing to be removed with water. Inlet water pressure to tubes may need to be raised to achieve scouring velocity in the tube once ends are opened. This will be indicated on the design. Frequency of flushing is determined by water quality. Monitoring system flow rates on the water meter can reveal emitter clogging.

Flushing needs to be commenced from the pump onwards. Ensure filters are cleaned well and pressures set. Progress systematically, cleaning mainline, submains, then drip lines.

In most situations additives such as chlorine and acid may need to be used. Chlorine kills algae and can loosen up bonded organic matter, enabling it to be flushed out afterwards. It is important to understand there is no particular volume of chlorine that will achieve this task. Silt and organic matter consume chlorine as it proceeds through the system. An injection rate of chlorine can be calculated and must be injected until free or spare chlorine is sampled at the farthest point. Rates of between 5 to 20 ppm chlorine may be required, depending on the severity of the problem. Irrigation suppliers and some manufacturers can supply the necessary technical help to keep this job as cost-effective as possible.

Acid injection is often over-recommended. In other parts of the world, acid is very cheap and can be used in place of chlorine, although high rates are needed. It should really only be used for chemical-based deposits, and works on the basis that solubilities of chemicals change with pH. By dropping the pH of water, these chemicals may become soluble again and can be flushed out.

To accurately calculate the volume of acid required to drop the pH of the irrigation water, simply perform a bucket titration. Get 10 litres of irrigation water; add acid one millilitre at a time and test pH until water drops to desired pH. Using these measurement and system flow rates, an injection rate in litres per hour of acid can be calculated.

ADD ACID TO WATER: NEVER ADD WATER TO ACID!



The exception in the use of acid is for root intrusion, where the corrosiveness of the acid is used to break down intruding root material. Very high rates are required and it is very expensive. Prevention is by far the best method.

Strategic use of herbicides is effective in preventing the roots' entry to emitters. When injected late in the irrigation, herbicide stays close to the emitter outlet, making this an unattractive area for the roots to enter. Careful cutting back of water can also reduce the tendency for roots to search for more water.

Before and after addition of acid or chlorine the drip systems should be flushed strongly with water. This reduces consumption of chlorine and buffering of pH by silt and organic matter that are easily removed. Flushing after treatment is important to prevent loosened material attempting to exit through emitters and clogging them.

Pumps, filters, valves and control systems also need maintenance. This can most often be carried out in the off-season. Suppliers and some manufacturers can provide advice or a service to do this work.

In summary

Drip irrigation is one of the most powerful agronomic tools available to the grower. It allows accurate application of water and fertiliser to suit crops' requirements and push plants to achieve their potential. Field access is increased with no flooded period. Labour costs can be reduced, with large areas being centrally controlled. Grower lifestyle can be improved with planned tasks and little odd hours or heavy work. Complex fertiliser regimes or watering strategies can be implemented easily. Drip systems can be designed to suit irregular fields and difficult soil types. Many current systems are purchased for this reason alone.

As demand increases for higher crop production with efficient use of resources, drip irrigation will provide the ability to accurately manage crops to achieve the forward-thinking grower's goals.



4.4 Case study, evaluating drip irrigation: Lower Namoi Valley

(Drip as an alternative to furrow irrigation on grey cracking clays in the Lower Namoi Valley)

Stefan Henggeler

Auscott Ltd - Namoi Valley Operations

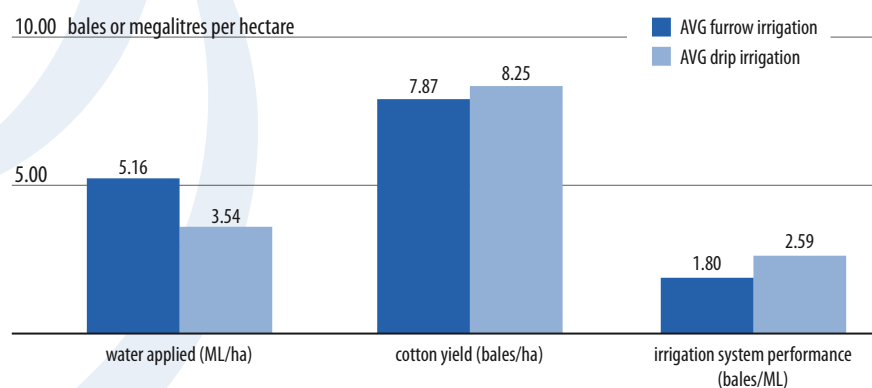
Irrigation system performance

The drip system installed at Auscott Narrabri worked very well with only minor technical problems. One of the issues we faced was that the lines and at the head ditch end of the field were not buried deep enough and therefore dug up a couple of times while scarifying the rotobuck area. Diligence when installing drip systems is crucial.

The system performed well and even issues such as watering up after planting were not a problem in our soils.

The yield results over the four trial years were quite consistent, with small variability only. The fourth trial year (1999-2000) is not included in Figure 4.4.1 but has performed very similar to the average of the first three years: because it was a cool season, water savings were not quite as high, but still around 20%. Yield difference was 0.395 bales/ha before ginning in favour of drip, and therefore pretty much the same as the 3-year average.

Figure 4.4.1. Increased irrigation performance of drip irrigation compared to furrow irrigation



(Note: No measurement of deep drainage or evapotranspiration)

Estimated capital investment costs

Table 4.4.1 Drip irrigation quotes, Field 34, Auscott Namoi Valley

Major product supplier						
Centre-fed system	Supplier A 25 mm tape		Supplier B 25 mm tape		Supplier C 28 mm tape	
Installation company	total \$	\$/ha	total \$	\$/ha	total \$	\$/ha
Installer 1	341,324	3,111	341,324	3,111		
Installation	70,040	638	70,040	638		
Total system costs	411,364	3,750	411,364	3,750		
Installer 2	377,700	3,443	-	-	353,200	3,220
Installation	65,000				65,000	
Total system costs	442,700	4,036	-	-	418,200	3,812

Major product supplier						
Side-fed system (800 m run)	Supplier A 35 mm tape		Supplier B 35 mm tape		Supplier C 35 mm tape	
Installation company	total \$	\$/ha	total \$	\$/ha	total \$	\$/ha
Installer 1	426,240	3,886	398,258	3,630		
Installation	57,667	526	57,667	526		
Total system costs	483,907	4,411	455,925	4,156		
Installer 3					323,457	2,949
no installation quoted						

Notes:

Field size: 109.7 hectares (271.1 acres)

Run length: 801 metres

Slope: 1-in-1430

All quotes were given in 2000, so prices are likely to have changed since.

All companies quoted for systems with one lateral every 2 metres in the middle of the wide bed and filtration to allow for muddy channel water.

All companies except Installer 3 agreed that 800 m is too long for 35 mm tapes. This is mainly because of creating water flows high enough to be able to flush the system and the time it takes to fill the 35 mm tapes. The agreed practical limit for 35 mm tapes is thought to be at 700 metres.

For the purpose of the calculation of breakeven points we used the quotes of \$3750/ha for centre-fed systems and \$4156/ha for side-fed systems. This is not because of a preference but because they compare best to each other.



Break-even yield improvements making drip irrigation valuable

Table 4.4.2 Break-even yields needed for four different drip irrigation scenarios

		Break-even yield difference			
		Furrow	Drip	b/ha	b/ac
Centre-fed system	H ₂ O capitalisation at A\$1200/ML	7.40	8.17	0.77	0.31
Side-fed system	H ₂ O capitalisation at A\$1200/ML	7.40	8.35	0.95	0.38
Centre-fed system	no capitalisation for H ₂ O savings	7.40	8.91	1.51	0.61
Side-fed system	no capitalisation for H ₂ O savings	7.40	9.09	1.69	0.68
Actually achieved:	4-year trial-average Auscott Namoi	7.64	8.02	0.38	0.15

Notes:

depreciation: drip tapes, 10 years; filtration etc., 15 years

bale price: A\$ 450/bale

cotton rotation: 100%

assumed water savings: 1.5 ML/ha

center fed system: A\$3750/ha

side fed system: A\$4155/ha

furrow yields: 7.4 b/ha = 3.0 b/ac

While the system itself performed technically very well, the necessary yield differences to pay for the additional capital investment for drip irrigation were not achieved under the soil and climatic conditions of our trial.

For this reason, the drip system was moved from Auscott Narrabri to Auscott Warren, where it is very successful on a red soil. The yield difference achieved in the first year on red soil of 1.73 bales per hectare clearly makes drip irrigation under the above assumptions a valuable investment.

Additional benefits

Substantial water savings (20% to 30% of applied water) were achieved using drip versus furrow irrigation, even on heavy clay soils. Those savings are likely to be even higher on lighter soils.

Drip irrigation allows the usage of ground rigs all season (except after rain) and therefore reduces the risk of off-target chemical drift as well as decreasing insecticide cost early in the season (banded sprays).

Drip reduces the need for physical labour and therefore potentially reduces the chances of workers compensation costs. It also suits an older workforce (experienced irrigation operators with reduced physical abilities).

Drip reduces soil erosion and therefore decreases de-silting costs. It is also better suited to zero-till farming systems than furrow irrigation because it avoids waterlogging.

Financial considerations

Drip systems should probably be installed on land not previously developed for irrigation, because when considering the capital put into development, you do not work with the full development cost, but only the difference between the cheapest option (for example, furrow irrigation) and drip irrigation.

The capitalisation of water savings (in our case, around 1.5 ML/ha @ \$1200/ML) needs to be taken into account to be able to justify drip irrigation versus other irrigation systems.

To capitalise on the great expense, soils should be chosen for new systems that favour drip irrigation and are less suitable or even unsuitable for furrow or lateral move. This will increase the yield benefit and therefore the return on capital, hence the recommendation to move our drip project to Warren.

Chose a field protected from flood and other external influences to protect invested capital.

Centre-fed systems are less expensive than side-fed systems (\$3750/ha versus \$4200/ha mainly due to decrease in cost of laterals).

Issues when considering drip irrigation in cotton

Some design specifics for the Auscott trial site:

- 1 lateral tape around 25 cm deep every 2 metres, in the middle of the wide bed
- 1 dripper/50 cm @ 1.1 L/h

Design of filtration to take muddy water out of a channel

The maximum row length for 35 mm tape seemed at the time to be 700 metres. No valves, fittings or joiners are in the field. The problem is not system uniformity while the system is applying water, but to achieve water flows fast enough when flushing the system when longer than 700 m. Using long run length therefore demands less frequent irrigations to minimise the filling and emptying times of the lines as the main source of bad uniformity in 35 mm tapes.

To my knowledge, it is still doubtful to date (2002) if 700 metre drip tapes are successful.

Centre-fed systems require a tail drain in the middle of the field to allow access to submains and fittings during the season and still drain off stormwater. Practically, it means that fields are split in half to a maximum length of 400 to 450 metres.

Do not under-design a system in regards to its capacity to save on initial capital costs! The system needs to be designed to be able to grow the highest yields possible to make it worthwhile. The Auscott trial system was designed to supply 13 mm per day.

EnviroSCAN® tubes proved themselves very well suited for scheduling water applications. Soil moisture can be monitored

on a regular basis to avoid deep drainage. In our heavy clay soils, 6 hours application per irrigation and section was ideal to keep the water in the root zone. On lighter soils the optimal application time is likely to be shorter.

The installation of a good fertigation injection system is very important. Evidence from other drip systems suggests that spoon-feeding of nutrients through drip could give additional yield benefits we have not yet explored in our trial. We installed a very simple and cheap but effective system using a mixing drum, separate water supply through a float valve and a fire fighter to inject fertilisers.

Absolutely crucial are a well-designed maintenance system and a maintenance procedure to avoid silt and algae build-up as well as root intrusion.

The quality of the installation will make or break a system. Purchasing a fully installed system should be considered instead of doing some of the critical jobs yourself. This approach clarifies the responsibilities when potential system faults occur.

All parts and fittings have to be checked by the owner of the system for leaks, kinks and so on before trenches are filled in. Avoid being caught by rain while the trenches are still open. The order of installation of the different system components is also very important: **laterals last**. Laterals have to be filled with water as soon as possible after installation to reduce the risk of insect damage.

Suppliers and installers offer after-sale service to get the system working to its full potential (irrigation scheduling, fertigation and maintenance).



4.5 Case study, evaluating drip irrigation systems: Yambocully

Peter Cross

Corish Farms, Goondiwindi

We decided to give subsurface drip a try after hearing about the water savings to be made and looking at some of the systems in the Macquarie Valley.

The area we were looking at to develop was a ridge in the middle of the farm. This area was impractical to develop for flood irrigation because of the amount of soil to be moved and the number of point rows we would create.

Our reasons to go ahead with subsurface drip were:

- water savings to be had
- use of land inside developed area
- keen to give it a go
- potential for higher yields.

Summary of our experience

Negatives of drip:

- high capital costs of installation
- potential problems of wet harvest
- some soil types are hard to wet up
- life expectancy of tape is unknown
- thin walled tape is prone to insect damage

Positives of drip:

- lower water use – 35% to 40% less than flood irrigation
- higher yields
- less crop stress due to waterlogging
- able to use rainfall more effectively
- fewer OH&S issues – for example, less manual handling, less chemical contact when watering while spraying
- lower labour costs
- better soil tilth (in our case)
- fewer workings
- fertigation – feed as you need
- greater ability to use stored water at the end of the crop
- use ground unsuitable for flood irrigation

Must haves:

- natural drainage
- system that can deliver peak daily water use of crop
- good distribution uniformity
- good filtration
- soil moisture monitoring tools
- maintenance program
- correct installation (use a guidance system)
- position valves to suit soil types and slopes

The system has worked well for us, especially the second installation with heavier tape. We have achieved a water saving over the last 4 years of 35% to 40%.

This has enabled us to grow 2 bales of cotton for every megalitre of water applied consistently.

Drip versus flood irrigation: 1999–2000 and 2000–01 seasons

Introduction

The two seasons were very different, with 1999–2000 having almost perfect growing conditions, which produced some very high yields, while 2000–2001 was almost the opposite with some very low to moderate yields. This was caused by some adverse climatic conditions – an extremely wet November, followed by a very hot January and another very wet period in January/February. However, there were still some significant differences between drip and flood irrigation fields.

Outcomes

The main difference between flood and drip irrigation was still the water saving (Table 4.5.1) plus a small increase in yield under drip irrigation (Table 4.5.2). Table 4.5.3 notes the increase in bales produced per megalitre with drip.

Table 4.5.1. Water savings made under drip irrigation

Megalitres of water applied ML/ha		
Season	Flood	Drip
1999-2000	7.0	4.2
2000-2001	7.2	5.0
Average	7.1	4.6

The increase in water usage under drip in 2000-01 was caused by the very dry winter, with drip using 1.6 ML/ha to wet up at planting time.

Table 4.5.2. Yields for both seasons under flood versus drip irrigation

Average yields Bales/ha		
Season	Flood	Drip
1999-2000	9.02	10.34
2000-2001	7.7	8.1
Average	8.36	9.22

Table 4.5.3. Bales per megalitre produced for both seasons: flood versus drip irrigation

Bales/ML		
Season	Flood	Drip
1999-2000	1.28	2.46
2000-2001	1.08	1.6
Average	1.18	2.03



4.6 Centre pivot and lateral move machines

Joseph Foley

CRCIF, National Centre for Engineering in Agriculture, Toowoomba

Key points

- Ensure the system capacity of centre pivots and lateral moves (CP&LMs) is large enough, when managed correctly, to keep up with peak crop water requirements.
- Using larger diameter pipe spans costs more, but lifetime running costs are dramatically reduced.
- All CP&LMs will operate with sprinklers to germinate cotton crops, including those machines that operate LEPA irrigation throughout the main growing season. Sprinkler packages represent a small part of the overall capital investment (usually less than 5%), but probably influence the overall performance of the machine more than any other aspect.
- New systems have problems with wheel tracks and wheel ruts, but these become less as levelled land compacts. Simple equipment alterations can help: reducing nozzle flow rates around towers; relocating LEPA outlets and sprinklers to keep wheeltracks dry; and reducing tower water interception from sprinklers. Consider larger tyres, or using third or fourth inline wheels and gearboxes on electrically powered towers.

- Support and assist local manufacturers who are prepared to resize jigs and build 48 metre spans for guidance systems, popular in the Australian cotton industry. Guidance systems can now operate in circles for centre pivots, and swath widths can be adjusted under spans that are not 48 metres.
- Ensure that all water drains from span pipes, so that pipe insides remain dusty dry between irrigations. Test irrigation water quality before you buy a system, to ensure compatibility of irrigation waters and pipe coatings.
- Continue irrigation long enough after fertigation has finished to ensure machine is fully flushed.

History of centre pivot and lateral move machines

Centre pivot and lateral move irrigation machines (CP&LMs) represent the largest (in both physical size and flow rate) of the mobile machines used by growers to apply water to crops and fields. The first CP&LMs were developed in the late 1940s with the patenting of a 'self-propelled sprinkling irrigation apparatus' by Frank Zybach in Nebraska. A.E. Trowbridge manufactured these early machines. Prior to this time, sprinkler irrigation was commonly performed using steel pipe and impact sprinklers, as aluminium pipe was only just becoming available. These early centre pivot machines consisted of towers that supported the pipes via suspension cable and were powered by the irrigation water pressure using hydrostatic drives at each wheel set. The right to manufacture these machines was acquired in the 1950s by Robert Daugherty who began manufacturing under the 'Valley' brand name. The first Australian innovation in this arena saw the Layne and Bowler Company of the USA introduce the Australian Raincat ideas of electric motor drives, today's

standard bowstring truss suspension and track drives which were later replaced with rubber tyres. During the 1960s, machines also started to be manufactured with water piston or water spinner drives rather than oil hydraulic drives. The standard machine manufactured prior to 1970 was a high-pressure unit (~80 psi at the centre) fitted with large impact sprinklers located along the top of pipe. However, the energy crisis in the early 1970s resulted in the introduction of low-pressure static plate sprinklers located on droppers below the pipe. These modifications meant that the machines could be operated at much lower pressures (<40 psi) with lower operating costs.

By the mid-1970s, centre pivot and lateral move machines were rapidly starting to dominate the new and expanding irrigation developments in the USA and the Middle East. Of the 25.6 million hectares currently irrigated in the USA, approximately 32% (or 8.1 million hectares) is irrigated with this equipment. Centre pivots were first introduced into Australia in the 1960s, primarily in South Australia and Victoria. Centre pivot and lateral move machines currently irrigate 8% to 10% of the total irrigated area in Australia. Centre pivot irrigation of cotton has been undertaken in the USA since the late 1960s and in Australia since the early 1970s.

The last thirty years have seen the four main CP&LM manufacturing companies based in Nebraska (Valley, Lindsay Zimatic, T&L, and Reinke) dominate the world market for these machines. There

are approximately 350 machines sold in Australia each year and around thirteen manufacturers or distributors. However, the majority of the machines available in Australia are manufactured in either the USA or Europe, with only a handful being manufactured by Australian companies. In most cases, common components such as electric motors, gearboxes and control panels are imported, with pipes, framework and other major structures manufactured locally. Not all of the manufacturers build lateral move machines. In particular, USA-based companies are often not interested in the manufacture of lateral move machines due to the comparatively small market size and the additional level of complexity associated with controlling and guiding these machines, yet they remain the only suppliers.

The expansion of the area irrigated by CP&LMs in the USA resulted in a substantial research and development effort focused on the appropriate design and management practices for these machines. The USDA - Agricultural Research Service and the extension centres located in the state universities conducted much of this work. The most relevant work for Australian cotton growers has been undertaken by Texas A&M University in areas where cotton is grown with limited water supplies using these machines. However, very little research and development work has been conducted on CP&LMs under Australian conditions.

Equipment overview

Centre pivot systems are usually no longer than 500 metres, with the most common size being around 400 metres long. Lateral move machines are not commonly used overseas, and, when used in other crops, are rarely greater than 500 m long. The popularity of large machines in the cotton industry has resulted in lateral move machines of up to 1000 m in length being installed locally.

The main components of these CP&LMs are the self-supporting frame spans. These structures use the water delivery pipes (located along the backbone of the span) as compression members that are held together by tie-rods acting as tension members. The pipe spans are supported at each end by a tower that incorporates gearboxes, drive wheels and either an electric or a hydraulic drive motor. Emitters (either sprinkler heads or low energy precision application fittings) are attached either directly to sockets on the main pipe or suspended closer to the crop on either rigid or flexible droppers.

Flexible mechanical and hydraulic couplings that allow the separate spans to act as individual elements connect individual spans. This ensures flexing, rotating and twisting of the joint and spans so that the machine can traverse land contours and obstacles. Machine speed governs the volume (depth) of water applied in each pass, while system alignment is maintained via micro switches, alignment levers and control equipment.



Centre pivots consist of a number of spans attached to a fixed centre tower containing a water supply point and power source around which the other spans and towers rotate (Figure 4.6.1). Lateral move machines are constructed in a manner similar to centre pivot machines except that they do not have a central rigid supply point: instead, they have the water supply point located either in the middle or at one end of the machine on a cart-tower assembly containing a mobile power plant. Lateral move machines that are supplied from open channels are provided with a large lift pump, while hose-supplied systems are fitted with an attachment point for connection to the watermain hydrant via a flexible water delivery hose.

Figure 4.6.1. Centre pivot irrigation machine showing centre tower, spans, and wheel towers



Spans and pipe sizes

Spans commonly range in length from 34.2 m (113 ft) to 62.4 m (206 ft) with variations in exact size between different manufacturers. Span lengths are commonly limited due to the weight associated with the pipe itself and the volume of water transported. Internal diameters of the span pipes range from 135 to 247.8 mm, with the most common pipe sizes being 162, 197 and 213 mm. Typical pipe wall thickness is about 2.77 mm for these systems.

Types of emitters

There are a wide range of emitter nozzles and application heads currently available for CP&LMs. The application heads can be broadly grouped into either low energy precision application (LEPA) attachments or sprinklers. LEPA systems apply water at low pressure either directly onto the soil surface or below the crop canopy to eliminate sprinkler evaporation from the plant canopy and drastically reduce the wetted soil surface and soil surface evaporation. These systems commonly operate at very low pressures (10-20 psi) and, hence, have reduced pumping energy costs. Although LEPA systems have been in existence since the mid 1980s, the adoption of these application heads in Australia has been slow.

LEPA application heads are available as either a drag sock or a combination head known as the 'Quadspray' or bubbler (Figure 4.6.2). Both types of head are commonly suspended from the main pipe by flexible hose at either one or two crop row intervals. Drag socks come in both double- and single-ended sock options. Double-ended socks are used in conjunction with furrow dykes or tied ridge structures to reduce the risk of washing these structures away (Figure 4.6.3). The 'Quadspray' unit has four operating modes that allow water to be either bubbled out in a low-pressure circular sheet, sprayed horizontally (germination mode), sprayed vertically upward (chemigation mode) or dribbled out directly from the bottom (Figure 4.6.4). Changeover from one operational mode to another only involves a click and twist rotation.

Drag socks are replaced with static plate sprinklers for crop germination and are positioned well above the soil surface to ensure good sprinkler overlap. When using the static plate sprinklers for germination, LEPA head hose lengths need to be either reduced or slung over the pipe to gain the height typically needed for the sprinkler throw. Hence, where any LEPA system is employed, there are requirements for both time and labour after crop establishment to allow a changeover from the static plate sprinklers to the LEPA heads.

Figure 4.6.2. Emitter options for low energy precision application

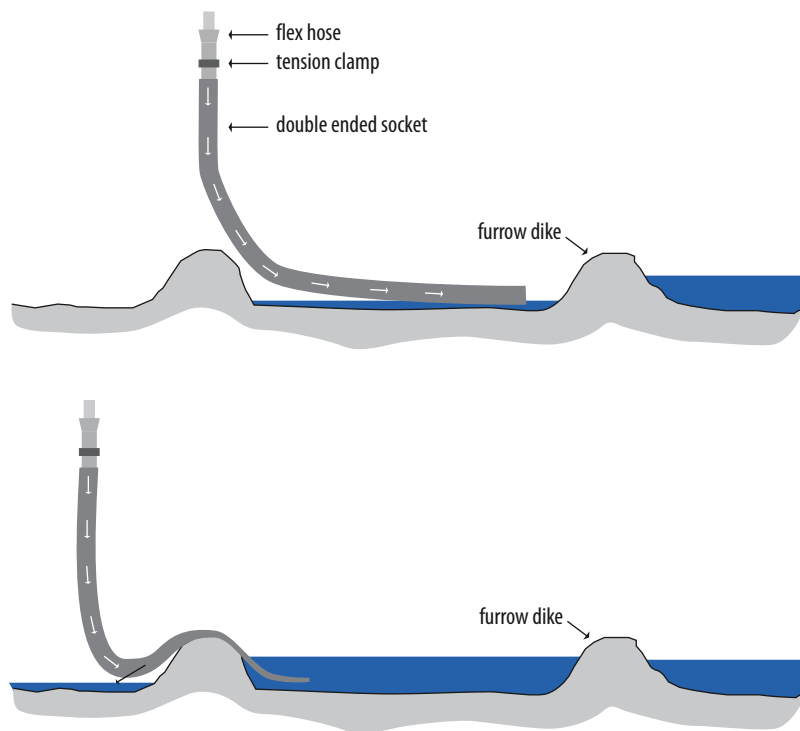
(a) Drag sock



(b) Quadspray in bubbler mode

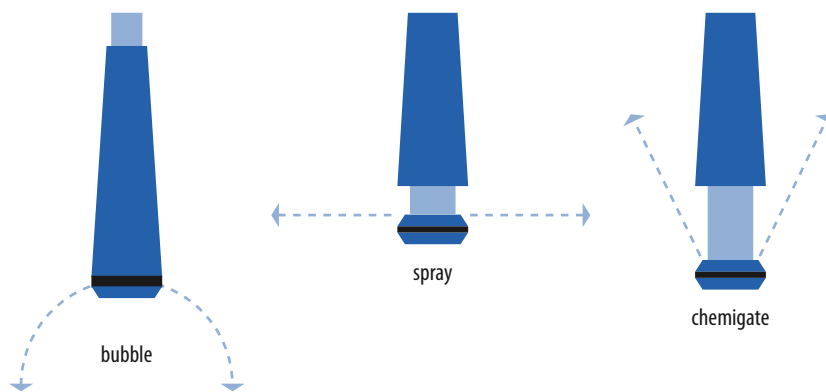


Figure 4.6.3. Operation of a double-ended LEPA drag sock in conjunction with furrow dykes



Source: New and Fipps 1990

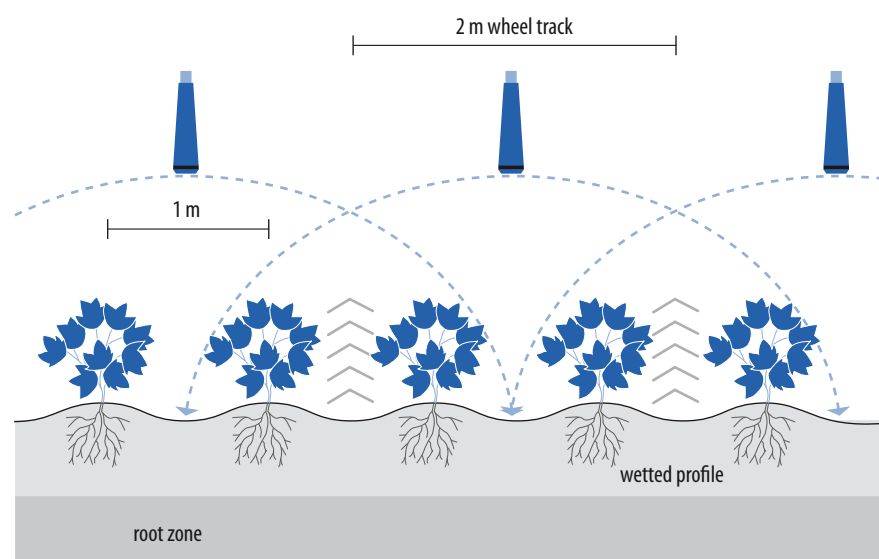
Figure 4.6.4. Operational modes for Quadspray LEPA heads



Source: New and Fipps 1990

Sprinklers are widely used on CP&LM machines and are typically offered as standard fittings. While overhead and top-of-pipe sprinklers were common on older machines, newer machines are typically configured with over-crop sprinklers that hang down from the pipe (Figure 4.6.5). These over-crop sprinkler heads are available as either static or moving plate sprinkler heads. Static plate heads do not have any moving parts but use a range of groove configurations upon a plate to produce the streamlets. Various static plates configurations are available to alter the number of streamlets and the angle of streamlet throw. Moving plate sprinkler heads represent the newer generation of heads that have been steadily increasing the number of streamlets while maximizing throw distances.

Figure 4.6.5. Over-crop sprinkler irrigation



The different types of moving plate devices available include spinners (low operating pressure but fast rotation), rotators (higher operating pressure but slower rotation) and wobblers (medium to low pressure with multi-path streamlets). All of these heads are typically suspended on rigid dropper pipes that hold the sprinkler head at spacings of 2.4 to 3.0 m (8 to 10 ft), and at a height just above the full crop height. While this form of sprinkler head and configuration is the most simple to design and use, it does suffer from evaporative losses (particularly during peak evaporation periods) associated with soil and plant surface evaporation, and these losses must be taken into account when designing the system capacity.

It is generally accepted that the replacement of older sprinkler technologies (both top-of-pipe and static head over-crop sprinklers) on existing CP&LMs is a relatively simple and cost-effective way of improving system performance. In general, the larger the number of streamlets produced by the emitter, the smaller the droplet size and the lower the drop impact energy applied to the soil surface.

However, the lower the sprinkler head pressure, the larger the droplet size. Modern low-pressure sprinklers impart roughly 60% of the energy of old top-of-pipe high-pressure impact sprinklers (Kincaid 1996). Low pressures and large numbers of streamlets typically provide the best result in terms of reducing the instantaneous application rate, reducing the impact energy imparted to the soil and increasing the throw distance. These benefits typically minimise surface crusting and reduce run-off.

Each emitter (either sprinkler or LEPA attachment) on a centre pivot is positioned at a greater radial distance from the centre and must provide water for an increasingly sized concentric ring of field area. This is achieved by either increasing the nozzle size and maintaining the nozzle spacing or, alternatively, maintaining the same nozzle size and decreasing the emitter spacing as the radius increases. Sprinkler spacing is not altered along the length of lateral move machines, with little if any increase in nozzle size.

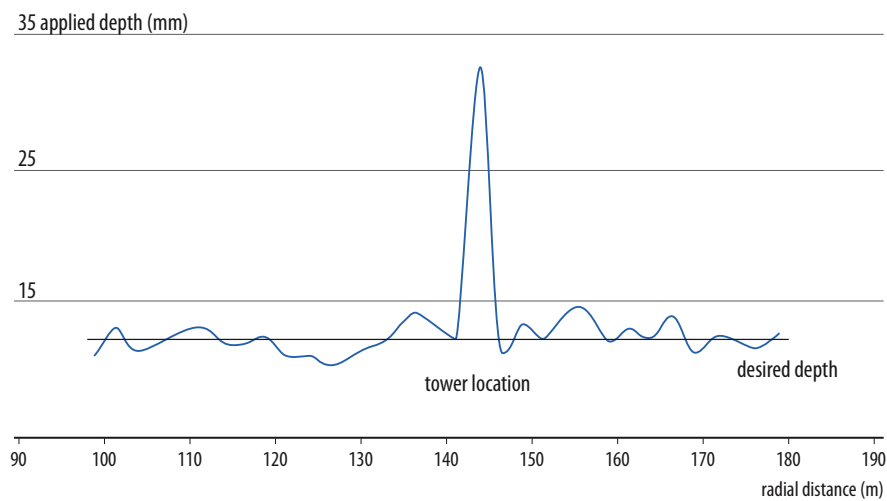
Boombacks

Boombacks are used to suspend the emitters at a distance of 3 to 6 m behind the machine towers (Figure 4.6.6). These optional fittings are used to improve the uniformity of sprinkler application to the crop near the towers and to reduce the potential for irrigation water intercepted by the tower (Figure 4.6.7) causing either rutting or bogging. Where the machine is required to move in both directions, boombacks can be fitted to both sides of the tower with the appropriate set of emitters selected using either manual or automated valves. Alternatively, a single boomback mounted on a hinged fitting can be used and swung either side of the towers, depending on the direction of travel.

Figure 4.6.6. Fixed and swivel mounted boombacks for CP&LMs 1 m



Figure 4.6.7. Field test results showing three times the normal amount of water being applied around the tower through interception of sprinkler water by tower structure



Source: Foley 2000

Tyres and wheel sizes

CP&LMs represent a considerable investment in tyres and wheels, so growers should also ensure that they have the necessary equipment to re-inflate, replace or otherwise repair tyres on the machine. This typically involves having spare tyres, along with lightweight jacks and blocks.

Larger tyre sizes are sold as options to reduce wheel rut formation. Common tyre sizes for centre pivot and lateral move machines include 14.9' × 24', 16.9' × 24', 16.9' × 28' and 11.2' × 38'. However, these sizes result in ground pressures for a wet 48 m span (weight ~ 3750 kg) with a 100 mm deep wheel rut of 12.9, 11.4, 10.8 and 14.6 psi respectively. Hence, while there are some differences in ground pressure associated with changes in tyre size, larger tyres do not generally reduce rutting as much as boombucks, which reduce the wetting of the wheeltrack area. Larger wheel and tyre sizes also increase loading upon gearboxes and drive trains. Tyre wheel combinations can also be purchased in sizes up to 18.4' × 28', 16.9' × 34' and 16.9' × 38'. However, manufacturers do not normally like to supply these larger sizes because of the higher drive train loads involved.

High speed ratios are also sometimes sold as solutions to wheel rutting problems. However, high speed drive-train combinations may produce start-up torques that are greater than the design specification for the machine, leading to increased occurrences of motor burnout. Gearbox failures are also often the result of overloading the machine drive-train. Larger width tyres may result in tyre centrelines that overhang from the gearbox attachment points, thus increasing

the risk of failure. Where larger and wider tyres are used, the power cable size and hydraulic lines should be increased in capacity to cope with the greater power requirements.

Automation

Control panels vary in complexity depending on requirements. Where necessary, all functions can be manually controlled. Features that are commonly available include machine remote control using either computers or mobile phones with voice feedback and programs to apply varying amounts of water over different periods. It is possible to program the machines to stop where required or vary the application across the field. For lateral move machines, it is possible to progressively apply lighter amounts of water and then to reverse direction at the end of the field, applying increasingly larger amounts of water.

Pressure switches are commonly incorporated to stop pumps when pipes burst (that is, on low pressure) or to start the machine moving when water pressure builds up. Hydraulically driven machines often employ electric over hydraulic controls to perform the more complex tasks of automation. Automation is essential to take full advantage of the CP&LMs' capacities. While automation may increase the machine complexity, it can substantially reduce the time involved in management and provides the level of control required to maximise the return on investment.

Chemigation

Chemigation using CP&LMs can be conducted in two distinct ways. Chemical can be injected into the irrigation water in the main pipe for distribution through the emitters with the water. Products that can be distributed in the irrigation include fertilisers, herbicides, insecticides, and fungicides. Alternatively, chemigation can be conducted using a separate system of distribution pipes with spray heads suspended underneath the CP&LM truss rods to enable the application of chemical with or without irrigation water.



Measuring the performance of CP & LM machines

The three most important measures of CP&LM performance are application rate, uniformity of application and application efficiency. This section explains the importance of each measure and outlines the design and management factors that influence the relevant machine performance variable.

Application rate

Three measures of the application rate are important: the system capacity, the average application rate (AAR) and the instantaneous application rate (IAR). These measures differ primarily in the time scale being considered: system capacity measures are commonly reported as volumes applied per day or week, the average application rate reported as volumes per hour, and instantaneous rates reported as volumes per second.

System capacity: The system capacity of a CP&LM machine is the average daily flow rate of water pumped by the machine divided by the area of that irrigated crop field. It is expressed in the units of millimetres per day, so that it can be directly compared with the peak crop evapotranspiration rate. Alternative units for system capacity would be in $\text{ML/ha} \times 10^2/\text{day}$ (that is, ML per hundreds of hectares per day). System capacity is the maximum possible rate at which the CP&LM can

apply water to the chosen area of irrigated field. It is **not** the amount of water that the machine applies per irrigation pass.

Dealers and manufacturers commonly use system capacity for their calculations and their assumption is that the pump is running for 24 hours a day, seven days a week, providing 168 hours a week pump running time.

The system capacity (in millimetres per day) is calculated by converting the CP&LM's pump flow rate into litres per day, and dividing by the irrigated field area in square metres. Remember, 1 litre over 1 square metre equals 1 millimetre depth of water applied. Alternately, growers can calculate the system capacity (mm/day) by taking the megalitres per day pumped onto the irrigated field and dividing by the irrigated area in hundreds of hectares.

The design and management issues associated with the system capacity are often not well understood by Australian growers using these machines and account for many of their perceived failures.

Average application rate: The average application rate (AAR) is the average depth of water applied to the irrigated field during the irrigation. The AAR is calculated by dividing the emitter flow rate (in litres per hour) by the wetted soil surface area (in square metres). The AAR is normally reported in millimetres applied per hour, to allow for a direct comparison with soil infiltration rates.

AAR is altered when emitter wetted area or flow rate is changed. The wetted area is affected by sprinkler height, wind, and sprinkler impact plate changes. Nozzle pressure, nozzle size and sprinkler spacing affect individual sprinkler flow rates.

The introduction of low-pressure fixed sprinkler plate technology in the 1960s and 1970s resulted in increases in AARs because the area wetted by the sprinklers was smaller than that with the previous higher-pressure sprinklers. However, the more recent development of rotators, wobblers, spinners and other moving plate sprinklers have resulted in a substantial decrease in AARs due to the larger throw and greater average droplet diameter of these emitters.

For centre pivot machines, the highest AAR is found at the outer end of the machine. AAR will always be greatest at the outer ends of centre pivots equipped with only one type of emitter and nozzle, as individual emitter flow rates increase in response to the larger annular area irrigated. The AAR of lateral move machines will be lower than the AAR at the outer ends of centre pivots. Individual emitter flow rates on a lateral move will be much smaller than an emitter located on the outer end of a centre pivot that has a similar irrigated area and managed system capacity.

Considerable research in the USA has been conducted upon the common mismatch of AAR and soil infiltration rates at the outer ends of centre pivot machines. For example, Scherer (1998) showed that sprinklers that throw to a radius of 10 metres, sited on the end of a 400 metre long centre pivot, produce average and peak application rates in the order of 40 and 50 mm/h, respectively. When these AARs are compared to the 5 mm/h average infiltration rates common for many clay soils, it is inevitable for the resulting excess water to be temporarily stored in surface roughness or run-off. This is supported by a range of work which suggests that the AAR associated with low pressure sprinklers on the outer ends of centre pivots will commonly exceed the infiltration rate of all soils except sands (for example, Kincaid et al. 2000; King and Kincaid 2001). Other options to reduce surface run-off under these conditions include retaining crop stubble, using spreader bars to increase separation between emitters and using long throw spray emitters.

Instantaneous application rate: The instantaneous application rate (IAR) describes the rate at which water is applied by an individual streamlet from an emitter head to a very small area of irrigated field (for example, hundredths of a square metre). The time scale under consideration for determination of IAR is in the range of seconds and the IAR is typically 1.3 to 1.5 times greater than the AAR (Kincaid et al. 2000). High IARs are commonly recorded where streamlets from static plate sprinklers impact upon a small

portion of irrigated field during the stop cycle of electrically driven centre pivots. However, there will be zones of high IAR within the wetted area of every sprinkler pattern.

IARs under CP&LMs are rarely measured in the field. However, the genesis of larger run-off issues is contained in this small area and time scale. Puddling of the soil surface begins from the impact of the streamlets, and is rapidly followed by soil surface sealing through the rearrangement of the destroyed soil crumbs. Most CP&LMs in this country are equipped with rotating, spinning and oscillating plate sprinklers that overcome the high IAR by not having individual streamlets that apply water to any one point. Irrigator concern regarding droplet impact energy (Stillmunkes and James 1982) creating soil crusting issues during germination has led manufacturers to develop specific sprinklers to help germination.

Uniformity of application

Uniformity of application refers to how evenly the irrigation water is applied across the field. In fields not watered uniformly, some parts will be irrigated to the desired depth, while other parts will be either under- or over-irrigated. These non-uniformities lead to yield variation across the irrigated area, resulting in differences in economic return for different portions of the field (Solomon 1988). The factors that contribute to non-uniformity include:

- emitter spacing, nozzle operating pressure, and emitter configuration
- nozzle size and selection with location along machine
- nozzle height, angle and wear
- machine movement including step size and its consistency
- flow rate variations due to discontinuous end-gun operation, and variations in pump duty, and
- run-off from high application rates.

Large nozzle gun sprinklers, which are commonly positioned on the ends of CP&LMs, are also often responsible for the poor uniformity performance of application (Molle 1999). Poor uniformity around wheel towers on CP&LMs is also a common problem, as growers and distributors often employ inappropriate techniques to reduce wheel bogging, resulting in lower uniformity and application rates in the vicinity of the wheel towers.

As CP&LMs do not irrigate all parts of the field at any one instant, they must apply the same depth of water along their travel path and machine length to irrigate uniformly. This requires a different evaluation methodology from that employed on static sprinkler systems. Measurements are commonly taken along one or two transects across their travel path. However, this always results in an underestimate of the uniformity, because no measure of the variation along the direction of travel is obtained. To adequately determine uniformity across the whole field, monitoring is necessary along the full travel path of the machine.



While standards for testing the spatial uniformity are available (for example, ISO11595; ASAE S436) there is still some debate over the appropriateness of the methodology employed in these standards. The dependence of uniformity measures upon sampling spacings (for catch-can layouts) has been discussed by Smith and Black (1991). On the basis of sampling theory, they recommended that catch can spacings should be of the order of $\frac{1}{4}$ of the sprinkler spacing (Smith 1995). Bremond and Molle (1995) likewise analysed catch-can spacing and determined that assessment errors could be minimised and catch-can spacings maximised when 5 m spacings were used for CP&LMs with sprinkler wetted diameters of 20 metres.

Two coefficients are commonly used to express the uniformity of irrigation systems – distribution uniformity (DU) and uniformity coefficient (Cu). The DU is an empirical index that is calculated as the ratio, expressed as a percentage, of the mean of the lowest one-quarter of applied depths and the mean of all applied depths:

$$DU (\%) = \frac{\bar{x}_{\text{lowerquarter}}}{\bar{x}} \times 100$$

where $\bar{x}_{\text{lowerquarter}}$ equals the mean of the lowest 25% of individual catch-can depths and $\bar{x}$ equals the mean of all individual catch-can depths. The uniformity of application for solid set impact sprinklers has traditionally been considered acceptable if the calculated DU is greater than 75%. However, Bremond and Molle (1995), Heermann (1991) and Yonts et al. (2000b) have suggested that DU should be greater than 90% for CP&LMs to be considered to be performing well.

The Uniformity Coefficient (Cu) was first proposed by Christiansen (1942) and is defined as:

$$C_u = 100 \left(1 - \frac{M}{\bar{x}} \right)$$

where M is the mean absolute deviation of the applied water depths $\bar{x}_i$ (or catch-can depths from sampling grid) and is given by :

$$M = \frac{\sum |\bar{x}_i - \bar{x}|}{n}$$

where $\bar{x}$ is the mean applied depth and n is the number of measurements. For systems that have a considerable variation in uniformity, there will be large variations from the mean and the coefficient will decrease. Solid set sprinkler systems that have a Cu less than 86% would typically be viewed as under-performing while CP&LMs would be expected to have a Cu greater than 90% to be considered acceptable.

Heermann and Hein (1968) proposed a measure of application uniformity that should be used specifically for centre pivot machines. In this measure, the applied depths are weighted according to their radial position along the length of the machine, to allow for the different annular area represented by each depth. The modified Heermann and Hein (1968) coefficient of uniformity can be written as:

$$C_u = 100 \left[1.0 - \frac{\sum S_i |D_i - \bar{D}|}{\sum D_i S_i} \right]$$

where D_i is the applied water depth for one collector position, $\bar{D}$ is the average applied water depth for all collectors, and S_i is the distance to equally spaced collectors.

Marek et al. (1986) and Bremond and Molle (1995) introduced other areal weighted uniformity coefficients specifically for centre pivot machines. Both of these methods use the square of the differences from the mean, rather than mean deviation as used by Heermann and Hein (1968). These methods emphasise any significant deviations from the mean and are useful in highlighting the poor performance of broken or blocked emitter nozzles. A number of researchers (for example, Heermann 1994; Smith 2000) have also suggested that representing the irrigation variation using a cumulative irrigation depth distribution curve may better describe the performance of an irrigation system than the use of a simple coefficient.

Application efficiency

The **application efficiency** (AE) is a measure of the losses associated with applying water to a field. It is calculated as the ratio, expressed as a percentage, of the volume of irrigation water stored in the root zone divided by the volume of water supplied to the field inlet (IAA 1998). The loss mechanisms that decrease application efficiency for CP&LMs include:

- sprinkler loss of fine water droplets
- evaporative losses from either the soil surface or plant surfaces
- run-off from the irrigated field; and
- deep drainage.

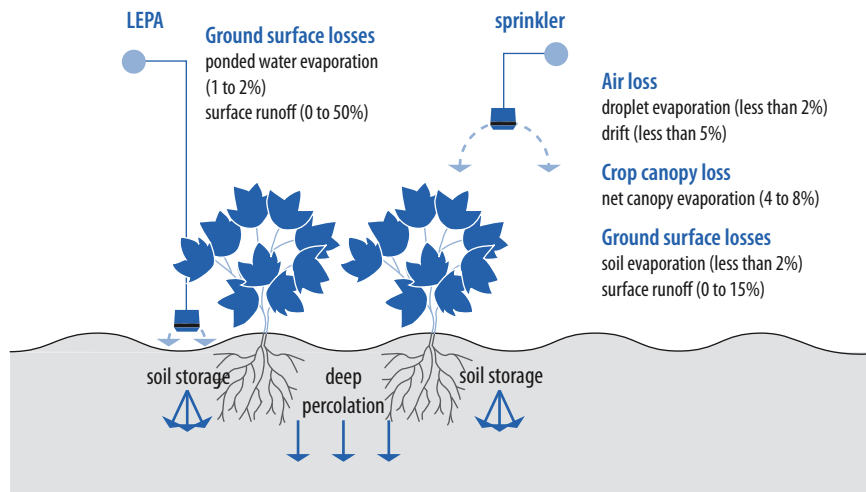
As with other forms of irrigation, run-off and deep drainage are most commonly associated with poor management and system operation. However, wind drift and evaporative losses are strongly influenced by emitter selection, nozzle size, operation pressures, and emitter location in relation to the crop canopy and weather conditions. A large number of studies have been conducted in the USA (for example, Silva and James 1988; McLean et al. 2000; Yonts et al. 2000a&b) to quantify evaporative losses under a range of conditions, and compare the efficiency of the various emitter options. Older style low angle, high pressure impact sprinklers located above the pipe have been found to commonly operate with efficiencies of 70% to 85% (for example, Schneider and Howell 1999; Harrison 1995). However, low

pressure, static plate sprinklers commonly operate at between 80% to 90% application efficiency while the moving plate sprinklers have application efficiencies up to 95%. LEPA socks and bubbler emitters have been found to have application efficiencies up to 98% where surface run-off is controlled. However, up to 50% run-off has been found (Schneider 2000) where LEPA systems are operated under adverse conditions without furrow dyking.

Evaporative losses are not well understood by Australian growers using irrigation. Drift and evaporation losses of sprinkler droplets (Figure 4.6.8) using a typical CP&LM sprinkler configuration (nozzle pressure=138 kPa, nozzle diameter=4.7625 mm) are commonly reported as less than 5% and rarely greater than approximately 8%, even under extreme weather conditions (relative humidity = 10%, dry bulb temperature = 43°C, wind speed = 19 km/h, for example, Frost and Schwalen 1960). Similarly, evaporation losses from the crop canopy surfaces may be as small as 1% to 2% (New and Fipps 1995; Yonts et al. 2000a) and are commonly reported as less than 8% (Schneider and Howell 1999). Hence, moving the emitter into or below the crop canopy may not necessarily increase application efficiency dramatically and may result in greater run-off water losses due to the increased IAR associated with the smaller wetted area.



Figure 4.6.8. Illustration of the water loss pathways for LEPA and sprinkler application methods under CP&LMs



Source: from Schneider 1999

Designing the system capacity of CP&LMs

Furrow irrigating cotton growers continue to install more centre pivots and lateral moves (CP&LMs) every year. The main reasons given for the adoption of CP&LMs are the reduction of irrigation labour requirements of 80% over that used for traditional furrow irrigation, the greater control of soil moisture, the 1 bale/ha average potential yield increase due to reduced crop waterlogging, the greater beneficial capture of in-crop rainfall, the overall simplicity of use and the 30% to 50% reduction in applied water possible over traditional furrow irrigation.

System capacity is the most important design parameter for CP&LM machines in the Australian cotton industry. Many machines installed in Australia in the past do not have a system capacity large enough to ensure cotton crop success. The problem of low system capacity has been the single greatest reason for the continuing low uptake of CP&LMs in Australia, and only if they can supply water onto irrigated cotton fields at a rate great enough to cater for peak crop evapotranspiration rates can they succeed in the Australian cotton industry.

The highly variable climate in which the Australian cotton industry operates means that timely and beneficial rainfall cannot be relied upon to help irrigation systems during peak crop water requirement. No benefit can then be allocated to rainfall supplementing irrigation during that period when the crop most requires water and is not included in any of the following analyses.

This discussion assumes that growers have an adequate volume of water allocated for the irrigated area underneath their CP&LM. Understanding your water resources is important, and other authors in WATERpak have addressed this issue.

Calculating the system capacity of your CP&LM

To calculate your system capacity, take the flow rate of water pumped by your CP&LM installation and divide by the area of crop that the CP&LM will cover in any one cotton season.

Example 1: LM system capacity

A lateral move is capable of pumping 300 litres per second onto 180 ha in a day – what is the system capacity?

$$\begin{aligned}\text{Volume applied (L/day)} &= 300 \text{ L/s} \times 60 \text{ s/min} \times 60 \text{ min/hour} \times 24 \text{ hours} \\ &= 25\,920\,000 \text{ L/day}\end{aligned}$$

$$\begin{aligned}\text{Area irrigated (m}^2\text{)} &= 180 \text{ ha} \times 10\,000 \text{ m}^2/\text{ha} \\ &= 1\,800\,000 \text{ m}^2\end{aligned}$$

$$\begin{aligned}\text{System capacity (mm/day)} &= \text{volume applied (L/day)} \div \text{area irrigated (m}^2\text{/day)} \\ &= 25\,920\,000 \text{ L/day} \div 1\,800\,000 \text{ m}^2\text{/day} \\ &= 14.4 \text{ L/m}^2 \\ &\approx 14.4 \text{ mm/day (as } 1 \text{ L/m}^2 = 1 \text{ mm)}\end{aligned}$$

Alternatively, divide the CP&LM flow rate in ML/day by the area in hundreds of hectares, that is, 25.92 ML/day divided by 1.8 hundred hectares equals a system capacity 14.4 mm/day.

Example 2: Large lateral move capacity

A large lateral move runs along a supply channel that is 6600 metres long. The overall length of the lateral move machine is 1008 metres and the width of irrigated field underneath the lateral move is 984 metres. The pump flow rate for this lateral move is 300 L/s or 25.92 ML/day. If two 800 metre long fields, back to back, are used to grow cotton in one season, then what is the system capacity?

$$\begin{aligned}\text{Volume applied (L/day)} &= 300 \text{ L/s} \times 60 \text{ s/min} \times 60 \text{ min/hour} \times 24 \text{ hours} \\ &= 25\,920\,000 \text{ L/day}\end{aligned}$$

$$\begin{aligned}\text{Area irrigated (m}^2\text{) in a single cropping season} &= 984 \text{ m} \times 800 \text{ m} \times 2 \text{ fields} \\ &= 1\,574\,400 \text{ m}^2\end{aligned}$$

$$\begin{aligned}\text{System capacity (mm/day)} &= \text{volume applied (L/day)} \div \text{area irrigated (m}^2\text{/day)} \\ &= 25\,920\,000 \text{ L/day} \div 1\,574\,400 \text{ m}^2\text{/day} \\ &= 16.46 \text{ L/m}^2 \\ &\approx 16.5 \text{ mm/day (as } 1 \text{ L/m}^2 = 1 \text{ mm)}\end{aligned}$$



Example 3: CP system capacity

Calculate the system capacity of a 496 metre long centre pivot, that is, 10 × 48 m spans + 16 m overhang with a pump flow rate of 141 litres per second

$$\begin{aligned}\text{Volume applied (L/day)} &= 141 \text{ L/s} \times 60 \text{ s/min} \times 60 \text{ min/hour} \times 24 \text{ hours} \\ &= 12\,182\,400 \text{ L/day}\end{aligned}$$

$$\text{Area irrigated (m}^2\text{)} = \pi \times \text{radius}^2$$

Where, $\pi = 3.14$

$$\text{radius} = 496 \text{ m}$$

$$\begin{aligned}\text{Therefore, Area} &= 3.14 \times 496 \text{ m} \times 496 \text{ m} \\ &= 772\,490 \text{ m}^2 \text{ or } 77.249 \text{ ha}\end{aligned}$$

$$\begin{aligned}\text{System capacity (mm/day)} &= \text{volume applied (L/day)} \div \text{area irrigated (m}^2\text{/day)} \\ &= 12\,182\,400 \text{ L/day} \div 772\,490 \text{ m}^2\text{/day} \\ &= 15.77 \text{ L/m}^2 \\ &\approx 15.8 \text{ mm/day (as } 1 \text{ L/m}^2 = 1 \text{ mm)}\end{aligned}$$

Alternatively, the flow rate, 12.1824 ML/day divided by 0.77249 hundred hectares = 15.77 ML per hundred hectares per day = 15.77 mm/day.

This is how to calculate the system capacity of CP&LMs. It is a very important design parameter and is the maximum possible flow rate the machine can apply onto the irrigated area. Remember this is not the amount of water applied per irrigation pass.

Managing CP&LM system capacity

The system capacity is the maximum possible flow rate that the CP&LM can apply to the area of an irrigated field. The system capacity of a CP&LM is reduced considerably in the real world by the number of hours that the pump is turned off during any given irrigation cycle. The amount of time the pump is running during any irrigation cycle is called the **pumping utilisation ratio**.

The pumping utilisation ratio can be calculated from the average number of pumping hours per day divided by 24 (or divide the total hours of pumping over a 10-day period by 240 hours, let's say $204 \div 240 = 0.85$). Remember to take into account the non-irrigating time necessary for any pesticide spraying with over-crop sprinklers and the dry travel time of the CP&LM that you think that you may need.

System capacity is further reduced by losses that occur when the water travels from the nozzle on the machine into the crop root zone. This ratio of the water that actually makes it into the crop root zone divided by the total amount of pumped water is called the **application efficiency** (see earlier discussion). For LEPA systems, choose an application efficiency of 0.98, and for modern over-crop sprinkler systems choose a value between 0.9 and 0.95. As an example, a grower running a CP&LM pump for 204 hours throughout

a 10 day period during peak crop water use period, using a well-tuned over-crop sprinkler system, would be able to irrigate at a rate of $0.85 \times 0.95 = 0.81$ of the system capacity.

In a worst case scenario you might have a system capacity of 14 mm/day, but if the pump only ran for 0.75 of the time, even with a LEPA system, then on average 10.5 mm/day would be applied into the crop root zone.

Remember that these system capacity values have nothing whatsoever to do with the amount of water applied by the CP&LMs during each irrigation pass. The amount of water that is applied per pass is governed by the pump flow rate and the amount of time that the machine takes to complete one irrigation pass of the complete irrigated area. Just as a constant flow rate boomspray operator would reduce speed to apply a greater amount of water to the field, so too is the average speed of a CP&LM reduced to apply more water per pass.

For example, a centre pivot grower using good over-crop sprinklers with a system capacity of 14 mm/day, decided to set the machine speed so that the centre pivot took 2.5 days to irrigate the full circle, and then stop the machine for 0.5 day before restarting the machine. Under this management, the centre pivot would apply $14 \text{ mm/day} \times 2.5 \text{ days/pass} \times 0.95 = 33.25 \text{ mm}$ for that irrigation.

Calculating the water applied into the crop root zone

A large lateral move is designed with LEPA socks and a pump flow rate of 300 L/s with an irrigating width of 984 metres. The pump will run for 8.5 days out of 10 during peak crop evapotranspiration period. This downtime of 1.5 days includes time where the machine is being shifted across ends of fields or returning to the dry end of the field, or while aerially sprayed pesticides are being applied to the crop. The LEPA lateral move runs across two fields that are 900 metres long for a total cropped field length of 1800 metres. The average amount that the machine will apply into the crop root-zone per day will be:

Average amount applied

$$\begin{aligned}
 &= \frac{\text{volume applied(L/day)} \times \text{pumping utilisation ratio} \times \text{application efficiency}}{\text{area irrigated (m}^2\text{)}} \\
 &= \frac{300 \text{ L/s} \times 3600 \text{ s/h} \times 24 \text{ hrs/day} \times 0.85 \times 0.98}{984 \text{ m} \times 1800 \text{ m}} \\
 &= \frac{21\,591\,360 \text{ L}}{1\,771\,200 \text{ m}^2} \\
 &= 12.19 \text{ L/m}^2 \\
 &\approx 12.2 \text{ mm/day}
 \end{aligned}$$

Alternatively, the 300 L/s equals 25.92 ML/day, and calculating how much water this will apply into the root zone per day over the 177.12 ha is given by $25.92 \text{ ML/day} \times 0.85 \times 0.98$ divided by 1.77 hundred hectares = 12.19 mm/day.



Choosing a system capacity for your CP&LM

A common question raised by many cotton growers who are contemplating the installation of CP&LMs is 'what system capacity should my CP&LM have on my field?' A process for choosing a suggested CP&LM system capacity has been developed using the evapotranspiration maps of Australia recently developed by the CRC for Catchment Hydrology and the Bureau of Meteorology under their technology transfer program (Wang et al. 2001) (see Topic 2.12).

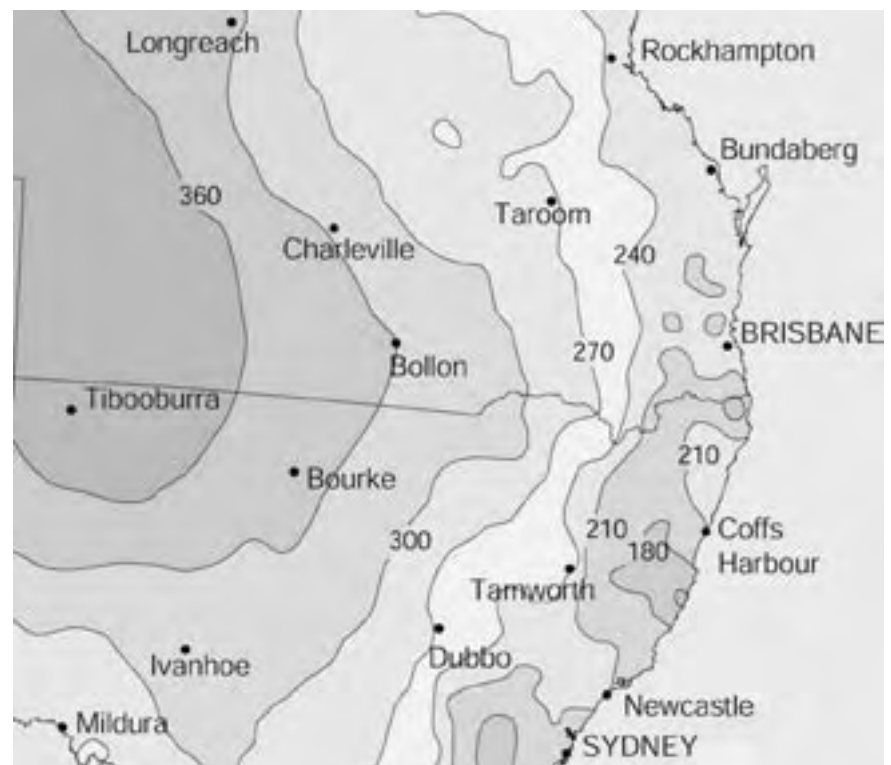
A calibration factor has been derived, from the system capacities of CP&LMs across the cotton industry and the January map of average point potential evapotranspiration (ET_0), to allow growers to choose their location and calculate their own system capacity. This calibration factor was developed by using previously recorded system capacities for CP&LM installations across a number of regions in the cotton industry.

The ET_0 map for January was chosen as it represents the period of greatest crop water use for cotton. The calibration factor takes into account the conversion of the monthly average value to the more useful 3 day peak ET_c value and assumes a pumping utilisation rate of 0.85 and the use of a LEPA system with an application efficiency ratio of 0.98.

The proposed process involves initially locating the proposed site of your CP&LM on the point potential evapotranspiration map for the month of January, provided in Figure 4.6.9. The second step is to then interpolate for the value from the closest lines of evapotranspiration for your particular location and divide the value by the cotton industry system capacity calibration factor for cotton-growing CP&LMs of 21.5. The resulting number will be in millimetres per day, and is a starting point for grower's decisions regarding the appropriate system capacity for their CP&LM design.

If growers are concerned about the particular value they calculate, consult appropriately skilled irrigation professionals. Note that the mapped lines of equal potential evapotranspiration are in incremental steps of 30 mm.

Figure 4.6.9. January monthly average point potential evapotranspiration map for Australia's existing cotton-growing regions



Source: Wang et al. 2001. Originally developed by the CRC for Catchment Hydrology and Bureau of Meteorology, based on data from 1961 to 1991.

A similar process was recently used by the original authors of the evapotranspiration maps to develop an understanding of the complete range of evapotranspiration rates across the state of Victoria.

For example, a cotton grower wishes to install a centre pivot at Bollon, which lies on Figure 4.6.9 at the 330 mark. Divide 330 by 21.5, and the suggested system capacity is 15.3 mm/day. This would be the system capacity a grower would install when the pumping utilisation ratio is 0.85 and the application efficiency is 0.98.

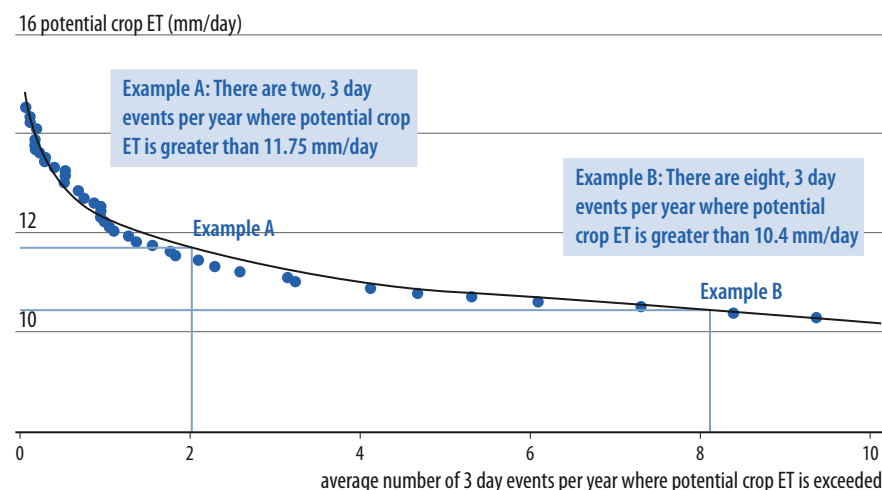
How does your CP&LM system capacity compare to a 3-day peak crop evapotranspiration rate?

In trying to understand whether or not a particular system capacity for a CP&LM will adequately cater for the peak crop water requirements of a fully grown cotton crop, consider the evapotranspiration rates that would be likely to occur in any given crop growing season at a particular location.

If we were to undertake an analysis of the evapotranspiration for the St George region, the chances of having a 3-day average potential crop ET value greater than a certain size would look like the information detailed in Figure 4.6.10. When growers choose a certain system capacity for a CP&LM installation in the St George region, for example, they are essentially choosing the number of days per year where the potential crop ET will be greater than the chosen system capacity of the CP&LM installation. The nature of potential crop evapotranspiration is such that there is always the possibility in any year of a number of the days where high evaporation occurs.

The number of days per year where potential crop evapotranspiration is greater than the rate at which water can be supplied by the irrigation system needs to be reduced by choosing CP&LM system capacities capable of handling these extremes. It does not matter how large a CP&LM system capacity you choose, there will always be a day where peak crop evapotranspiration is greater.

Figure 4.6.10. Recurrence of 3-day peak crop evapotranspiration rates for the St George region



From the X-axis, consider the number of times per year where corresponding potential crop ET will be exceeded and then choose your own appropriate CP&LM system capacity.

Understanding how many extreme 3-day peak crop evapotranspiration events per year will occur allows growers to determine their own level of risk in relation to their chosen CP&LM system capacity. In effect, when growers choose their irrigation system capacity, they are choosing the level of risk that the machine will not be able to keep up with particularly high evaporative days. Growers who are not prepared to risk the possibility that

their CP&LM will 'not keep up' choose larger CP&LM system capacities. The real consequences of choosing lower system capacities will be the reduction in the average amount of water held in the crop root zone as each passing day extracts on average more than the CP&LM system capacity can supply. This does not necessarily mean crop failure, but rather the gradual decline in the readily available water supply for the crop and the potential for crop yield reduction.

For example, if the average 3-day peak crop evapotranspiration rate was 14.5 mm/day and the CP&LM LEPA system capacity was 12 mm/day with continual operation, the average moisture content would decrease by 2.5 mm every day, and over 3 days this would create a total soil moisture deficit of 7.5 mm average across the entire field. This will not necessarily mean crop failure, but may lead to crop yield reduction.

A complete analysis of possible CP&LMs system capacities and resulting irrigated crop performance in relation to regional peak crop potential evapotranspiration rates is only possible through the use of a crop model used for long-term climatic data in various growing regions with a wide range of system capacities.

Increased capital costs associated with larger CP&LM system capacities do not necessarily increase in proportion to system capacity. For large lateral moves, whose upper size limit is currently controlled by the maximum flow rate of the largest pumps that manufacturers are prepared to place upon drive carts (typically a Cornell 10 RB @ 300 L/s), increasing the system capacity can be changed by decreasing the overall irrigated run length irrigated in any one season. This is a cost-effective and simple matter as no substantial change to the lateral move design is necessary. However, costs could be incurred if changes are necessary to the field drainage network.

Increasing centre pivot system capacities involves changes in the nozzle set, imposing a very minor cost. More importantly, however, alterations in the pump and pipe diameters, both in the span and supply line, can have significant associated costs. If pumps and pipes are incorrectly designed, the lifetime running costs of the system can be greatly increased.

Remember that choosing larger system capacities for CP&LMs does not mean that larger water volumes are applied to the crop. Choosing greater system capacities for CP&LMs simply means that there is adequate capacity to cater for the peak crop water requirements of well-grown cotton when the crop requires it most. As one cotton grower saying goes 'Change the things you can, and don't worry about the rest'.

Recent purchases of large lateral moves in the cotton industry have all been with the largest pump flow rate possible for these machines. There currently exists an upper pump size limitation to the flow rates possible through the larger lateral moves. This is based upon the largest flow capacity from the Cornell 10 RB, a highly efficient double volute pump preferred by the small number of companies building larger lateral moves. Based upon this fact, a range of different field lengths have been calculated and are presented in Table 4.6.1.

Table 4.6.1. Lateral move field lengths for various irrigating widths and system capacities

Pump flow rates of 300 L/s, pump utilisation ratios 0.85 and 0.95 and an application efficiency ratio for LEPA of 0.98.

Irrigating width under lateral move in metres	Pump utilisation ratio – expressed as no. of days per 10 days	Wetted total field length for system capacity of 12 mm/day	Wetted total field length for system capacity of 14 mm/day
700	8.5	2570	2200
	9.5	2870	2460
750	8.5	2400	2050
	9.5	2680	2300
800	8.5	2250	1920
	9.5	2510	2150
850	8.5	2110	1810
	9.5	2360	2020
900	8.5	2000	1710
	9.5	2230	1910
950	8.5	1890	1620
	9.5	2110	1810

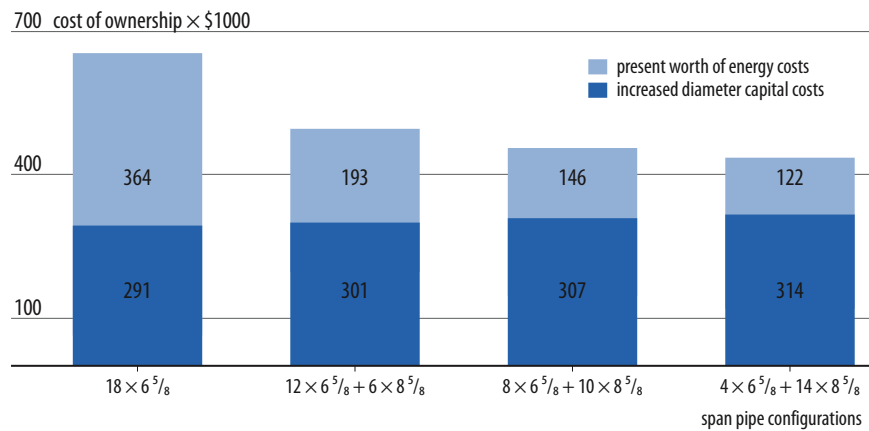
Running costs of CP&LMs – implications of poor hydraulic design

One of the largest costs of ownership of CP&LMs is the on-going pumping energy cost associated with supplying irrigation water through the machine. Many growers who have purchased CP&LMs in the past have not completely understood the implications of purchasing equipment with small pipe span diameters. Consequently, their overall cost of ownership was drastically increased when they purchased a slightly cheaper pipe span configuration. It is important to understand how increasing the overall upfront capital costs slightly can drastically reduce long-term ownership costs.

A present worth analysis of the long-term pumping energy costs of a large lateral move with four different configurations was conducted, as shown in Figure 4.6.11. This analysis translates the future costs of pumping energy involved with the lateral move into today's dollars. The analysis was carried out over a 15-year lifetime, with 835 ML being applied per annum through the lateral move. Pumping energy costs were \$0.75/ML/m head; an interest rate of 7% was used for this example. All spans available for this analysis were 48 metres long and two different diameter pipe spans were used as 6⁵/₈" and 8⁵/₈" nominal diameters. (Pipe diameter terminology is in keeping with current industry practice.)



Figure 4.6.11. Cost of ownership for long-term energy costs and up-front capital for four different 18 span lateral move designs with numbers of larger diameter span pipes from 0, 6, 10 and 14



The lowest cost option of the four different lateral move designs consists of 18 small diameter spans. The most expensive design consists of 14 spans of the larger diameter pipe spans. The economic and hydraulic modelling used to generate Figure 4.6.11 shows that increasing the number of spans with large pipes costs an additional 7.9%, but reduces the 15 year pumping energy costs to one-third of that from the lateral move with all small diameter pipe spans.

Similarly, when the analysis is conducted for a 10 span centre pivot, under the same economic modelling conditions, the analysis shows that a 6.4% increase in capital costs can reduce the overall pumping energy costs to one-half of that of a centre pivot with all small diameter pipe spans (see Figure 4.6.12).

These long-term ownership costs contrast with typical US designed centre pivot installations with lower overall machine flow rate, where there is a very small difference in the long-term ownership costs, as shown in Figure 4.6.13.

Figure 4.6.12. Ownership costs for long term energy costs and up-front capital for four different 10 span centre pivot designs with system capacity of 14 mm/day with the number of larger diameter span pipes increasing from 0, 3, 5 to 7

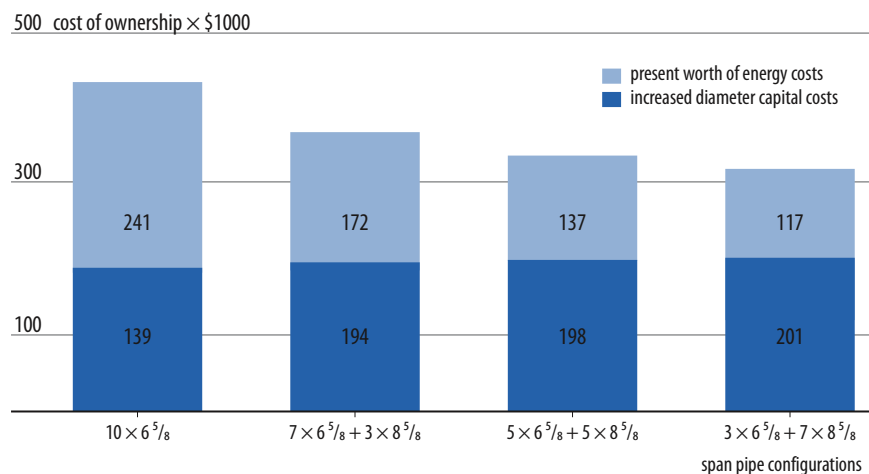
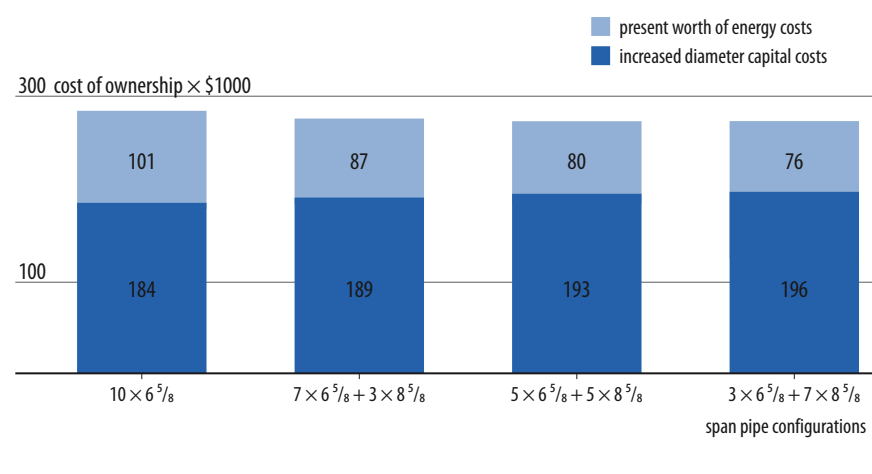


Figure 4.6.13. Ownership costs for long term energy costs and up-front capital for four different 10 span centre pivot designs with system capacity of 6 mm/day with the number of larger diameter span pipes increasing from 0, 3, 5 to 7



Practical management tips for CP & LMs

Cotton crop growth management

Management of cotton crop growth under CP&LMs can prove to be difficult for many who normally operate with furrow irrigated crops. Cotton crops under these machines do not suffer from the significant waterlogging and crop growth reduction that occurs with furrow irrigation. This means that crop growth is not slowed and adjustments to the application of plant growth regulators, such as Pix, need to be made. Growers and agronomists should operate under the principle of 'Go early, go heavy and go often.'

Wheel track and wheel rut management

One of the most important issues any new grower faces in the first few years of owning and managing CP&LMs relates to wheelruts and wheeltrack management. Few issues are more bothersome for a grower, but few are less discussed by dealers and manufacturers than the issue of wheel track and wheel rut management.

There are a number of things that growers can insist upon in the design of CP&LMs that will lessen the anxiety many growers feel in relation to this troublesome issue:

- Boombacks upon wheel towers direct irrigated water to that part of the field behind the travelling machine, allowing the tower to run upon dry ground. Ensure that the boomback reaches a great enough distance behind the wheel tower to minimise the water thrown up on it.



- Use half-throw sprinklers on solid drops immediately around the towers to ensure water is not thrown directly into the ground, as is the case with soft hose droppers.
- Consider reducing nozzle sprinkler flow rates immediately adjacent to towers to 80% of their existing flow rates.
- Larger tyre and wheel sizes are more commonly installed on CP&LMs today and many growers are successfully conducting trials where three and four wheels are driven inline upon the tower base, instead of the traditional two. Track and dreadnought options abound in the US.

A number of factors are important to remember when initially managing a new CP&LM. As the first seasons pass, significant wheel track compaction levels rise and wheel rutting issues tend to decrease. This compaction is a significant help to the operation of your machine under saturated soil conditions and it is important to consider leaving it alone during deep ripping operations.

Managing germination under sprinkler irrigation

All growers using CP&LMs will use sprinklers to germinate their crop, and it is essential that growers understand some of the ways that this can be successfully carried out. During this germination phase, consider using a second nozzle set that reduces the total machine flow rate through the pump. This is sometimes called a dual nozzle pack and is one of the cheaper options that growers

can employ to successfully apply water softly to freshly cultivated soils without inducing crusting and causing seedling emergence issues. A number of growers also plant dry and irrigate the crop up with a number of light slow sprinkler irrigations. A number of light slow irrigations throughout the germination period can also assist crops to move through soils prone to crusting.

LEPA irrigation systems

After germination and crop establishment, some growers employ LEPA systems to apply water throughout the rest of the crop life. When growers move to LEPA systems they need to remember that water is now being applied at much higher application rates than any soil is capable of retaining at the time of application. A critical part of the original LEPA system was to build a retention system into the soil before using the LEPA heads. This involves building small dams or dikes in the furrow between crop rows to capture the water applied at a very high rate. The original system developed in Texas was built for irrigation systems that are supplementary in nature and was only designed for machines with system capacities in the order of 5 to 7 mm/day. This means that while trying to use LEPA systems in Australia upon machines with system capacities of 14 mm/day, we are essentially using these systems at over twice their originally designed capacities. Growers need to ensure that while they are operating LEPA systems on CP&LMs at these high system capacities that the soil being

irrigated has the retention capacity in the form of significant cracking or soil surface roughness to hold water where it is placed. Alternatively, growers need to consider the correct implementation of dikes and small dams in alternate rows as part of the normal field preparation process for the use of LEPA irrigation systems.

Ensuring longevity from your CP&LM investment

One of the simplest ways to ensure that CP&LMs remain cost-effective is to ensure their longevity. Some of the greatest risks associated with the longevity of the valuable investment that you have made in the CP&LM irrigation system come from the natural world. Provided below are a number of practical tips to ensure the longevity of your CP&LM investment.

Corrosion – ensure that, if the water quality tests that your dealer has analysed prior to purchase suggest that the standard galvanised machine will be prone to corrosion, you invest in machines that are constructed of material that is resistant to corrosion. An additional 5% upfront investment in the capital cost of the machine can mean up to a five-fold increase in the life of the machine.

Ensure that, regardless of the water quality used in the machine, all water is drained from the lowest points of the spans: some span drain designs do not allow this, and other designs include automatic valves that have variable operational success. One alternative is to plumb this low span drain point out to a tee placed into the second or third sprinkler

dropper. This overcomes both the tower and wheeltrack flooding at irrigation shutdown and ensures that there is no valve to become blocked by irrigation sediment.

The risk from overland flooding with CP&LMs is minimal, except through flooded areas where fast moving water exists. Some growers install earthen berms (mounds of soil) raised above the flood-prone field level that allow growers to park the machine above the level of the floods. Gearboxes should be drained and refilled with new oil after inundation and electric control panels professionally cleaned and checked by professionals if they become immersed.

A number of CP&LMs have been damaged by violent windstorms over the history of their use in Australia. A number of practical techniques can be employed by growers to prevent and or lessen the damage. Anecdotal evidence from machine constructors on-site during a violent wind storm report that the machine developed a bouncing action which threatened to loosen truss rods and collapse the recently built spans. The action of the wind past the round main pipe span was inducing vortices which alternately forced the main pipe up and down, causing the whole span to develop a wild bouncing action. Purchasing low-profile towers for low growing crops means that the span intercepts lower general wind speeds closer to the ground, in any wind event. Some growers park their centre pivots so that the centre point is directed into the prevailing storm path. Other growers operate their pumps and fill their machines with water to increase the weight and reduce the risk of these machines

being moved by wind. Another option is to employ tie-down points at the end of field or on access roads. These can consist of submerged earth anchors such as large buried concrete blocks, vertically placed railway iron or wooden piles placed at intervals equal to span spacings, which have cable or chain attached to tie down span towers.

Modern tower gearboxes contain gas expansion chambers (flexible rubber diaphragm enclosed within steel enclosures) that allow for the expansion and contraction of the gases and liquids in the gearbox during heating and cooling, without creating differential pressure upon the axle seals. This design does not allow suction pressure to build up on the axle seals of the gearbox when it is cooled during sprinkler irrigation, thus preventing water being drawn into the gearbox to corrode drive trains. In any instance, ensure that sump plugs are regularly removed and water is drained from gearboxes. CP&LM manufacturers specify gearbox oils that have properties allowing water to separate from oil and settle to the bottom of the gearbox.

Towable gearboxes are available in a number of different designs, with the older style having caused enormous difficulty for growers over the years. The original design contains a second set of bearings that are positioned outside the original axle of the gearbox. They are configured so on removing a single pin, the wheel hub disengages from the gearbox axle. This allows free rotation of the wheel during

towing of the centre pivot from one site to another upon this secondary bearing system. Over time the pin and secondary bearings wear and allow movement of the wheel hub upon the gearbox axle, resulting in a failure of the gearbox drive train. More modern designs allow the worm gear to be physically disengaged from the bull gear in the gearbox, so that the wheel hub remains attached to the original gearbox drive axle. They do not use a secondary set of bearings within the drive-line.

Ensure that you flush the main span pipes on a regular basis, especially if you are using any surface water or groundwater bores that are pumping sand. This will ensure that excessive sediment weight is removed from the spans, particularly overhangs, where this material tends to accumulate and induce additional loading stresses. Corrosion that can occur underneath these saturated sediments upon the wall of galvanised pipes can lead to early pipe failure. Many growers install large valves upon the end of the overhang and last spans to allow higher water velocities to scour sediment from the pipe spans when the valve is opened.



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4.7 Case study, Linear move irrigators: Auscott Midkin, Moree

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Cotton CRC, NSW DPI, Moree

Prior to the 2002/03 season Auscott Midkin in the Gwydir Valley installed a linear move irrigation system. The system incorporates 3 fields of 60 hectares each. Each field is 660 m wide by 900 m long. The system is designed to water 2 fields per season delivering 12.5 mm per day. There is the capacity to increase this application rate slightly with different nozzle selections.

Field design

The three fields are designed to drain similar to furrow irrigation fields but in some fields the fall is not as steep, with cells varying from 1:1100 to 1:3900. One field has been lasered to the nearest fall, resulting in a lot of side fall and very little down fall, and hence cotton in this field has been grown on the flat. Auscott did not limit the development of the linear irrigated fields and ensured that field development facilitated getting stormwater off.

The 2002/03 cotton season was preceded by a very dry winter. With a very dry soil profile Auscott initially had difficulty getting water into the profile using sprinklers. Socks have proved to be more successful at subbing up the profile. Consequently the first season the linear used approximately 2.3 ML/ha to get the crop established (1.5 ML/ha in pre-irrigation and 0.8 ML/ha crop establishment).

By comparison, pre-irrigation and crop establishment in 2003/04 only used 0.6 to 0.7 ML/ha. The operation of the machine has been much better as Auscott Midkin have learnt how to operate it and manage some of the initial practical problems associated with the machine. Auscott Midkin still had some problems watering up in 2003/04. There were difficulties in subbing up the top of the profile to meet up with rain moisture further down the profile. They found that the sprinkler set-up was producing droplets that were too big with too much of an impact on the soil. Other options for the sprinkler set-up included changing the nozzle to put out smaller droplets but then this would take longer to apply the same volume or spending more money on the sprinkler head so that the smaller nozzle could apply the same water. Auscott Midkin decided against either of these options and socks were used every second row. In 2003/04 one field under the lateral move irrigator was planted on the flat, with small furrows for the socks to run in placed in the field during cultivation. This is working quite well, with no extra waterlogging during January rain when compared to the field planted on hills. In the future, cotton will be able to be planted directly into wheat stubble on the flat, greatly reducing seed bed preparation passes and loss of moisture associated with these passes.

Labour and maintenance

Fuel costs associated with running the lateral move are approximately \$15/ML. Labour requirements have initially been higher, as these included watching and learning about the machine. This should decrease in the future but there will still be some labour requirement. The big labour saving should come in the reduced need for tractor passes to prepare a seed bed if flat farming is successful.

Auscott Midkin feels that water scheduling tools, particularly capacitance probes (C-probes), are a must with lateral move irrigators as decisions are constantly being made. A problem with C-probes is that the lateral move applies a narrow channel of water, so probe placement is important. In the future Auscott Midkin will place probes in the dry and wet furrow and the row. C-probes will also be spread down the field (approximately 3) so they can monitor water use at both ends of the field to see if the lateral move is working satisfactorily.

2002/03 season	Furrow irrigation	Linear move irrigator
Yield (bales/ha)	11.4	11.1
Pre-irrigation & crop establishment (ML/ha)	1.7	2.3
In crop (ML/ha)	6.7	4.3
Difference (ML/ha)	1.8	
Rainfall	148	
IWUI (bales/ML)	1.36	1.68

2003/04 season	Furrow irrigation	Linear move irrigator
Yield (bales/ha)	tba	tba
Pre-irrigation & crop establishment (ML/ha)	1.4	0.6
In crop (ML/ha)	6.2	4.0
Difference (ML/ha)	3.0	
Rainfall	319	

Pros and cons

Auscott Midkin believes the biggest advantage of the linear move irrigator will be during wet years, as some of the biggest yield losses in furrow irrigation occur from waterlogging, particularly when rain events follow irrigation. The advantages of the linear move irrigator can be attributed to no deep drainage and a lack of waterlogging. The lateral move irrigator is able to better supplement rainfall. There is also a lot more flexibility in the volume of water applied. Capacitance probes indicate full water use per day under the lateral move irrigator whether irrigating or not, while often, under the furrow system, there are periods of waterlogging following an irrigation event where the plants are not using water.

Another benefit Auscott sees in the lateral move system is the increased opportunity for in-crop fertiliser applications. Under the lateral move, Auscott applies some fertiliser upfront (approximately 85 units) with several additional applications (nitrogen and potassium) water run onto the field. Plant nutrition levels are monitored through petiole sampling as part of their nutrition management practice in the lateral move fields. There is also the potential for applying insecticides, although Auscott has not tried this yet.

Auscott Midkin rarely irrigates rotation crops, as furrow irrigation takes too much water. With this system there will be increased opportunity to supplement rainfall with irrigation for rotation crops, and at the same time fertilise crops to suit the potential of the season.

The implementation of the lateral move irrigator has not been without its problems. During the 2002/03 season Auscott Midkin identified some of the problems associated with it, with the biggest challenge being learning how to operate the machine. Initial problems were associated with ensuring the machine was steered straight. With beeline fields it is important that the machine be accurate in steering. Auscott did have to make some changes to the machine to improve the accuracy.

Another initial problem was that the lateral move started with no compaction under the wheels. Later in the season, with more passes of the lateral move, the wheel tracks were getting bigger and bigger and there was some cutting across the rows. As a result the machine was bogged several times. There was a need to create a compaction layer and wheel track for the wheels to run on, and ensure that water stays out of wheel tracks. The use of wider wheels running up the side of the furrows resulted in the cotton in these rows not growing as well and using less water. In 2003/04 Auscott changed the nozzle size next to the wheel tracks so 25% less water is applied around the wheels.

Rank growth has been a problem. In 2002/03 Auscott Midkin used high rates of Pix® to slow the crop's growth. Crop management in 2003/04 included going in earlier with more frequent Pix® applications, but this still has not been enough to control growth. Auscott will also try to regulate vegetative growth through moisture levels by drying the crop out a bit more, and making sure determinate varieties are used.



Problems Auscott has foreseen for future seasons include infiltration rates. With the socks there are large volumes of water over a smaller area. The profile has to be kept reasonably full, as application rates are limited by the capacity of the machine. As the lateral move runs back over the end of the field just irrigated, there may be problems with infiltration rates. Some options they are considering include sprinklers, or alternating the furrow, that is, swapping socks to the next row, allowing for partial rootzone drying.

Where to next?

Auscott Midkin will continue to monitor these fields to confirm the benefits of this irrigation system in terms of water use and yield. They will also look at variable rate application of water from the system to account for the fact the machine commences irrigating from the most recently wetted end of the field. The aim of this work would be to deliver more or less water as the machine moves up and down the field. Auscott Midkin will also be looking into the potential to operate the system via telemetry to minimise labour costs.

Things to consider...

Tim Richards (Midkin Agronomist) believes that linear move irrigators are definitely an option for new cotton developments, and if the cost of water continues to rise, can see them as a viable option for existing furrow irrigation areas. However, there are several things that require consideration when choosing a linear move system.

- What size machine suits the area you are trying to irrigate?
- Match the pump size to the amount of water you aim to apply: that is, ensure you can get the amount of water on the field.
- Consider pipe size – it is tempting to try and save costs by reducing pipe size but you will pay for it in other areas. For example, a smaller pipe size requires increased pressure and therefore fuel to be able to deliver desired water volume.
- Consider pros and cons of hydraulic versus electric systems, but both systems work.



Section 5

Managing soil and water

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5.1 Managing soils for irrigated cotton production

David Larsen

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Key points

- Farm management affects soil structure, which in turn affects plant available water.
- Good soil structure is essential in maximising water use efficiency.
- Soil pit observations, chemical testing and visual inspection will help soil management decisions.
- Irrigation system construction efficiency will be influenced by soil type.

Soil water availability depends on a number of soil properties, including texture and structure.

Soil texture is determined by the particle sizes that a soil is made up of. The proportion and type of the smallest particle, clay, is most important in determining how the soil behaves. Different clays and the cations found within clays affect:

- nutrient-holding capacity
- the capacity of the soil to regenerate, and
- the likelihood of soil problems when subjected to application of water.

Texture and clay type also influence how much of the irrigation water applied to a soil can be stored for use by the plant (Table 5.1.1).

Table 5.1.1. Soil type and amount of water available to plants between field capacity and permanent wilting point for well-structured soil (top metre)

Soil type	Plant available water capacity (mm)
Sand	70
Sandy loam	140
Clay loam	140
Heavy clay	150
Well structured clay	200

Source: *Irrigation scheduling of cotton*, CRC information sheet

Soil structure, which is strongly affected by farm management, further influences the amount of water available to plants. The history of tillage, compaction, wetting and drying, plant growth and soil biology and chemistry influence soil structure.

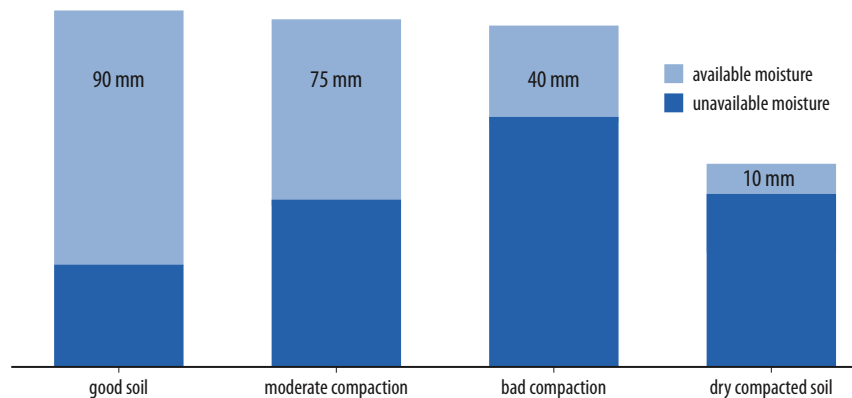
Pores compaction and plant available water

An interconnected network of macropores is required for good water and oxygen entry to the depth of the root zone.

Disruption to the interconnectivity of pores and reduction of the total pore space by compaction from farm implements and dispersion in unstable soils affects the amount of water that is available to plants between irrigation events.

Compaction is more about loss of root pathways than lowered soil water storage. This is why a compacted soil shows only a small decrease in the total amount of water actually stored in the profile when measured with a sensing probe, but water available to plants is much reduced (Figure 5.1.1).

Figure 5.1.1. Changes to plant available moisture with compaction (cracking clay example, top 60 cm)

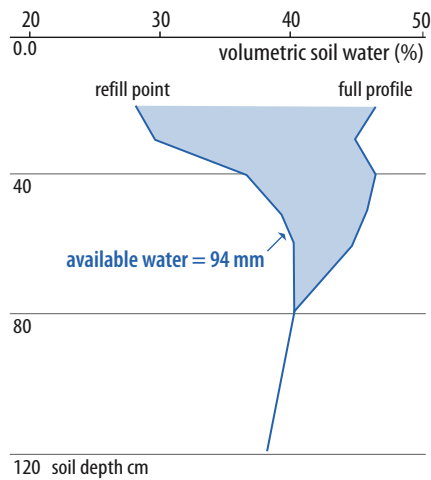


Source: from *Cotton production during drought 1995*

Normally roots follow the path of least resistance when exploring the soil for nutrients or water — the path generally follows natural crack lines, especially in cracking clay soils or biopores (old root channels, faunal tunnels, and so on). As soil compaction increases, there are fewer pores, and roots have to push through soil where pores have been destroyed. There is a maximum force that roots can exert on a soil, and as the soil dries and its strength increases it becomes impermeable to roots. If the soil is well structured with numerous pores, plant roots can still explore a large area of soil by following these cracks or pores.

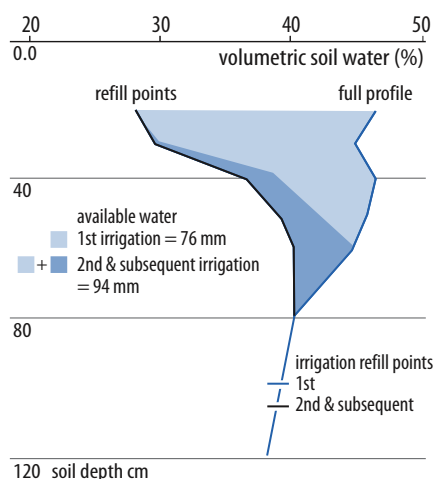
The next three diagrams (Figures 5.1.2, 5.1.3 and 5.1.4) from the SOILpak manual show patterns of water extraction from a well-structured cracking clay soil, a soil with a moderately compacted layer and a heavily compacted soil. Note that the availability of water within the profile can change between irrigation events. As the soil is wet, strength decreases, and there is opportunity for roots to penetrate compacted zones: the extent to which they do this is related to the degree of compaction. Heavily compacted soils may show marginal increases in extraction between each irrigation event.

Figure 5.1.2. Well-structured soil, extraction pattern



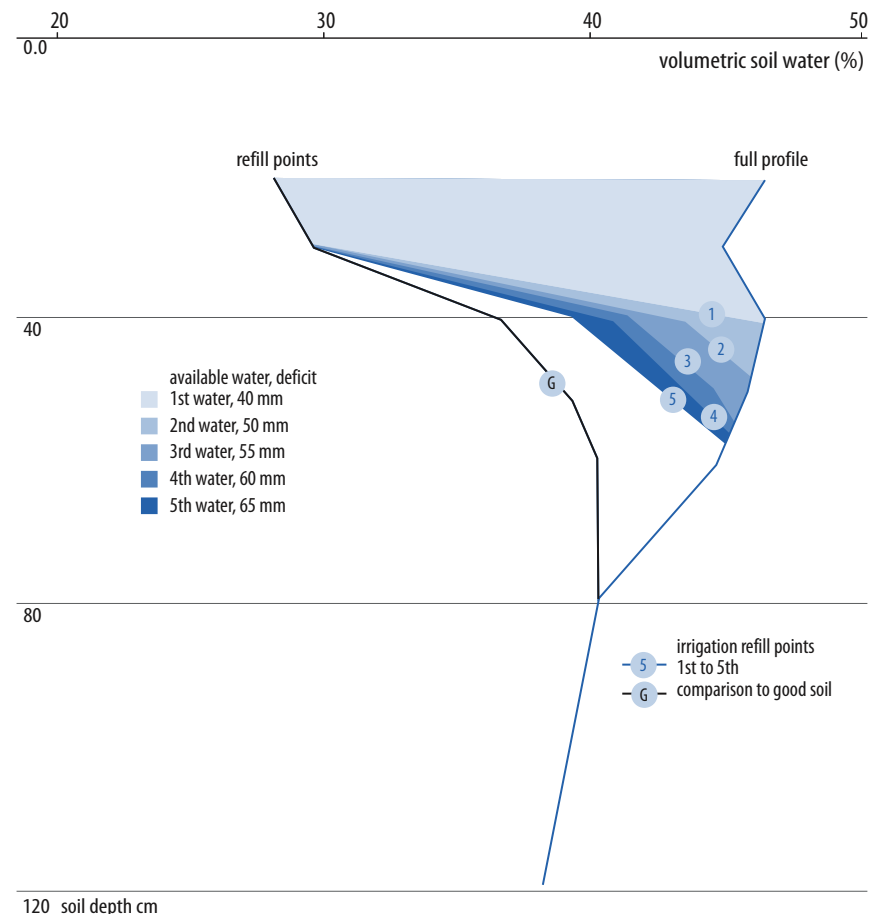
The soil water profiles in Figure 5.1.2 show typical extraction pattern from a well-structured soil. The soil is able to provide the plant with 94 mm of water. Extraction has taken place down to 80 cm. The right-hand line is the amount of water in the profile after irrigation, the line on the left being the amount in the soil when the plants are starting to show signs of requiring water.

Figure 5.1.3 Moderately compacted soil, extraction pattern



This profile in Figure 5.1.3 shows what can happen in a soil that has a light compaction layer that roots are able to penetrate after the first irrigation. The plants before first irrigation are showing stress at a water deficit of 76 mm, with water extraction only to 60 cm depth. Following the irrigation, the plants begin to extract water beyond 60 cm to a deficit of 94 mm, indicating that the roots have penetrated a compaction zone.

Figure 5.1.4 Heavily compacted soil, extraction pattern



The profile in Figure 5.1.4 shows what may happen with severe compaction. The diagram shows 5 subsequent refill points as the season progresses. Following each irrigation, the crop is able to utilise more water as it penetrates the compaction zone, however the crop is never able to extract as much as a crop on a well-structured soil (the G line).

Managing the soil environment

Do I have a soil problem that needs to be addressed?

Simple soil observations can be made to determine if you have soil structural problems. The manual *SOILpak for cotton growers* is a valuable source of information on what to look for in soils if you suspect a problem. Part C of the *SOILpak* manual ('Diagnosing soil condition') outlines simple methods of diagnosis.

Major problems that interact with irrigation include:

Compaction

- A problem common to all soil types in the Australian cotton industry. Over recent years the use of permanent beds and minimum tillage systems has lowered the incidence of this problem, but wet harvests and movements in plant beds with time can reintroduce the problem.
- Cracking clay soils are particularly vulnerable to compaction damage if trafficked when the soil is moist. If traffic has occurred under these conditions, observations should be made to determine the extent of damage and whether remedial measures are needed.
- Compaction can be managed, and, if confined to limited areas away from the water infiltration and rooting zone, its effects can be minimised.
- Use a visual inspection using a spade or backhoe pit to determine if a problem exists.

Sodicity

- This soil problem caused by high levels of sodium adhering between clay particles is inherent in some Australian cotton soils – the problem can be increased or induced by using irrigation water that is high in sodium levels. Sodicity leads to excessive swelling of the soil and dispersion and breakdown of soil structure. On the surface this can lead to crusting, with associated problems of poor plant establishment and lowered infiltration. At depth it can lead to massive soil structures with reduced pore space that increase problems with infiltration and waterlogging.
- It is possible to address surface sodicity problems with the addition of calcium-based soil amendments such as gypsum and lime. Sodicity at depth can be more of a problem.
- Management should avoid bringing this soil to the surface with tillage operations.
- Use data from a soil test to determine if a problem exists.

Salinity

- In some regions salinity from accumulation of salts within the root zone is a problem. When watertables rise to within 2 m of the surface, problems can be encountered. When salt accumulates in the root zone it lowers the amount of water available to plants. Plants become water stressed even if the soil is not dry. Cotton is fairly tolerant of salinity, but rotation crops, especially legumes, can be very susceptible.

- Management to counteract salinity includes lining leaky storages and supply channels. Crop irrigations should be scheduled according to actual crop requirements. If hotspots within the field can be identified, different management on these areas may reduce the salinity problem.
- Soil test data indicate salinity. Regular soil testing will indicate rising or falling salinity levels (see *WATERpak* Topic 5.3).

Low organic matter levels

Low organic matter levels can lead to a lowering of soil stability during rapid wetting, especially in soils that also have a problem with sodicity. Organic matter helps bind the soil in stable aggregates, especially when wetting happens very quickly, as is common with surface irrigation. Organic matter can also partly overcome the effects of sodicity. Soil management practices to enhance organic matter retention include retaining stubble within the field (either standing or incorporated) and the use of minimum tillage principles.

Soil test data can indicate if your organic matter levels are falling or rising over time.



Management issues for soil types common in the Australian cotton industry

Grey and brown cracking clays (vertisols)

In the Australian cotton industry most cotton is grown on this soil type. Features of these soils in terms of irrigation include:

- a high storage capacity for water
- easily damaged if trafficked or worked wet
- self-mulching (repairing)
- generally low through-drainage

To manage grey and brown cracking clay soils:

- Be mindful of soil moisture content when working. Use the plastic limit test.
- Controlled traffic limits compaction. Think about traffic wheel patterns in unusual situations.

Controlled traffic has advantages on this soil type - compacted zones in wheel tracks can even be advantageous for support of machinery when the soil is moist.

The key to managing grey and brown cracking clay soils is to be careful of moisture conditions when the soil is worked or driven upon.

A simple test to show if the soil is too wet for working is the **plastic limit test**. Roll some soil from a given depth in your hand. If you can form a ball and then roll a rod shape of 3 mm diameter without the soil crumbling, then the soil is wetter than the plastic limit. Working soil at this moisture content will only remould the soil, destroying pores and creating smeared layers with few pores and high soil strength that makes it difficult for plant roots to penetrate.

To determine if a tillage operation can be completed safely, use the plastic limit test at intervals through the soil profile to the proposed maximum depth of tillage. Don't till into depths that are above the plastic limit.

If there is no option but to traffic the soil when it is wet, for example during a wet harvest operation, think about where wheels will be travelling with respect to existing wheel tracks: that is, try to maximise the number of non-trafficked furrows.

Researchers have shown that it is possible to overcome the effects of compaction by adding up to 10% more nitrogen and increasing the irrigation frequency. Water use efficiency suffers in this case and in limited water years there is an opportunity cost associated with the extra water and extra nitrogen required to grow a crop on a damaged soil.

Cracking clay soils are prone to waterlogging because when they are wet, the soil swells and has a tendency to block pores. Soil management to overcome this problem includes:

- ensuring that there is adequate slope on the field to drain excess irrigation or rainwater. Also, ensure the field is level, with no hollows to collect water.
- building hills or beds high. If waterlogging conditions exist lower in the furrow there should still be an area above the water level that is better drained and aerated for at least a proportion of the crop roots.

Addressing compaction

Limited compaction: the current crop may act to remove some of the damage by promoting the shrink swell cycles in the soil. Watch the crop closely for signs of water stress: crops grown on a compacted soil may show signs of stress more quickly than those grown on undamaged soil.

More serious compaction: may be addressed by biological tillage, that is, growing an actively rooted crop such as wheat to dry the soil and promote swell shrink cycles. Note that the more active the root system and the more wet dry cycles the soil is exposed to, the better the result.

Severe compaction: may be addressed by mechanical tillage when the soil is drier than the plastic limit. The tillage can be targeted at specific zones. Use a spade or backhoe pit to determine the existing problem (see SOILpak Part C); for example, a compacted bed shoulder that is causing water infiltration problems could be addressed at nitrogen application time with a curving gas knife.

Sodic soils

Lack of stability of wet aggregates in sodic soil leads to the problems associated with this soil type. In sodic soils, clay dispersion and increased swelling in the subsoil block pores and reduce pore space. This stops or reduces water and oxygen entering the soils, leading to waterlogging problems. Following dispersion of nonstable aggregates (clods) into their individual constituents of sand, silt and clay, surface sealing blocks pores.

Some sodic soils, although initially stable, can become dispersive after being worked at high moisture contents. Soil management for these soils aims at restoring stability to aggregates or clods to prevent their dispersion when wet.

There are simple tests to check if your soil is dispersive. The ASWAT Test (see SOILpak Chapter C4) involves leaving air dry crumbs of soil in distilled water for a period and checking to see if a milky solution of dispersed clay is formed. The stability of the soil following wet working can be deduced by using the same test but using a piece of soil that has been moistened and then reworked before testing.

Sodic soils can also be problematic when building water storages and irrigation systems, as they are prone to tunnelling if compaction of the embankments is inadequate. Tunnelling occurs as water moves through small pathways in the embankment and dispersed particles move with it. If the wetting event is so fast that the clay doesn't have time to swell to fill the resulting pores, tunnelling can occur that can lead to bank failure. If a storage is to be made of this soil type, special attention should be paid to compaction at the correct moisture content and possibly lining the storage with non-dispersive soil (see Topic 2.5).

Management to avoid surface sealing problems

- Some soils have a stable surface layer overlying a sodic dispersive subsoil. Tillage operations can raise the dispersive soil to the surface, creating problems. Be careful when working this soil type.
- Be aware that tillage can create a problem with surface sealing – some marginally stable soils, if tilled at too high a moisture content, that is, above the plastic limit, can become dispersive. Always attempt to till when the conditions are right for your soil.

- Organic matter in the soil acts as glue that holds soil aggregates together. Try methods to maximise organic matter in the soils and to minimise its breakdown. Good organic matter levels can partially overcome the effects of sodicity.

Will gypsum work?

The addition of gypsum can overcome some of the effects of sodicity at the surface. Note however that gypsum will not necessarily work on all soils. If dispersion is identified as a problem, further soil tests should be carried out to see if the soil would respond positively to the addition of gypsum. A soil may be gypsum responsive if it has an exchangeable sodium percentage (ESP) of greater than 5. Calcium to magnesium ratio of less than 2 can also aggravate sodicity problems when the soil is near an ESP of 5. In a responsive soil, gypsum will improve surface aggregation (for better seedling emergence), decrease dry soil strength (to give easier tillage), increase water entry (with consequent longer irrigation intervals) and lengthen the time over which soil physical conditions are suitable for unimpeded root growth.

If the soil does not have inherent chemical stability, the presence of organic matter can compensate. Soil management should aim at maximising organic matter in the soil.



Red soils (loam topsoil)

Red soils lack the regenerative capacity of cracking clay soils. Soil structural problems that will self-repair with cracking clays with a wet/dry cycle will not self-repair on a red soil. Damage to red soils should be addressed before sowing.

A soil management bonus of red soils is that they drain quickly and can be trafficked more quickly than clay soils after irrigation or rainfall events.

Soil problems associated with red soils include:

1. Infiltration problems due to hard setting. This hard setting is brought about by a combination of factors that are associated with this soil type including the particle size make-up. The different sized particles found in loam soils can easily pack together, limiting pores for water and oxygen entry.
2. Red soils often do not have enough stable swelling clay (non-sodic) at the surface to encourage self mulching and deep cracking.
3. Low organic matter levels mean that the soil can collapse or slake on wetting (see point 1 above).
4. Rapid surface drying requires irrigation management aimed at watering up rather than planting to moisture.
5. Where red soils are on very permeable subsoils – for example if they are located over recent alluvium – rapid movement through the profile and beyond the root zone results in loss of water from the crop. Aim to manage irrigation to minimise this loss in order to reduce water use and lower the potential for irrigation salinity.
6. Red soils have a very narrow tillage window. The soils can be compacted if too wet and due to low inherent strength they can be reduced to dust if tilled when they are too dry. Avoid the use of disk ploughs and rotary hoes under dry conditions.
7. Where sodicity is also a problem there can be naturally restrictive subsoil layers that prevent irrigation water entry.

Management of red soils

Address problems on red soils before growing a crop as there is limited self-regeneration potential in these soils. Any restrictive layers should be disrupted, keeping in mind that there is a limited moisture window when this can be done without causing damage.

If the soil is in good structural condition, maintain it this way by using minimum tillage, surface mulches, including planting into standing cereal stubble, slow wetting irrigation systems and addition of soil conditioners such as gypsum to maintain the soil structure.

Overcoming red soil problems

Use mulches to minimise the collapse of soil aggregates into micro-aggregates from raindrop impact (this is called **slaking**). Slaking increases as initial water content of the soil decreases and rate of wetting increases, and so slow irrigation delivery methods such as drip and overhead sprinklers (with reduced droplet size and fall distance) can be an advantage.

Slaking under furrow irrigation has been minimised by starting the irrigation with normal discharge siphons, then switching to smaller diameter discharge siphons.

Sow into standing cereal stubble to improve infiltration via stable biopores (old root channels). Anchored stubble in the rows also slows down the rate of water movement, increasing the time the water is in the furrow and moving down biopores. When retaining stubble cut it into small lengths to prevent clogging of machinery. Roots should be left anchored.

Trials have been conducted on hard setting soils that showed improved water infiltration over a season. With conventional tillage the soils would not fill the profile following the initial watering. Using a retained stubble system a full profile was achieved with each irrigation. This lowered the irrigations required and increased water use efficiency.

Where fields contain a mixture of soil types including hard setting soils, retained cereal stubble in the systems ensured at least that the hard setting part of the field will receive a full profile.

Further information on the advantages and problems of planting into stubble can be found in the document 'Planting cotton into standing wheat stubble', available through the Australian Cotton CRC Technology Resource Centre or the Australian Cotton CRC website.

In red soils the short-term benefit of green manure crops can be as much from the production of stable biopores as from the increase in organic matter. Attempt to minimise soil disturbance, especially in the furrow and bed shoulders where biopore retention is important for water infiltration. Try to incorporate stubble with the least disturbance possible, as tillage itself helps speed soil OM breakdown.

Profile inversion using deep mouldboard ploughs can also be used in some cases where a hard setting surface overlies reactive clay. This is in the specific circumstance where the topsoil thickness is not more than 30 cm deep and the subsoil to be brought to the surface is not saline or sodic. The cation exchange capacity of the subsoil should be at least double that of the topsoil. A full soil survey should be done to ensure that this expensive operation would have results.

Deep ripping and chiselling when the soil is just below the plastic limit has been effective in some situations as an alternative to more expensive mouldboard ploughing.

Chisel ploughing furrows in the cotton season when the soil is dry may improve infiltration in the very short term, but there is a big risk of serious damage due to organic matter loss and dust formation from repeated working.

Increasing the time water remains at any given point on a red soil, whilst minimising the amount of tailwater return, is a key to maximising water intake on red soils. As well as the use of standing stubble, 'dammer-dyking' may be of benefit on red soils, especially if planting to fields where no cereal stubble exists. Basically this system involves a machine that places small stops at regular short spacings within the furrow to retain water longer in small puddles. This method is particularly useful under rainfall or overhead irrigation systems. When used in a furrow irrigation system the dams tend to fill quickly with silt unless the depressions are filled with a mulch.

Gypsum application can be of benefit if the clay content of the surface soil is at least 30% with a surface electrochemical stability index (ESI) of less than 0.05. The ESI is equal to electrical conductivity of a 1:5 soil water extract ($EC_{1:5}$) divided by exchangeable sodium percentage (ESP).

Anionic polyacrylamide applied at low rates (7 kg/ha) has been shown to improve seedling emergence and water infiltration in this soil type (see WATERpak Topic 7.1).



5.2 Applying water-run fertiliser

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Key points

- Water-run-urea is an effective means of applying N to cotton up to boll-filling.
- Use urea, not anhydrous ammonia, to reduce N loss.
- Other mineral fertilisers are not well suited to application in irrigation water.

Urea application

Urea is the preferred form of nitrogen for adding to irrigation water. Urea, being a soluble organic molecule, remains in solution in irrigation water and can be distributed evenly with the irrigation water throughout the field. The practice of using water-run urea at rates up to 80 kg N/ha early in the season has become popular and is common within the cotton industry.

The urea should be added to the irrigation water at a point where it can be dissolved and thoroughly mixed before being applied to the field; a culvert or drop structure is ideal. Obviously some N will be applied to the channel, and tailwater should be recirculated to avoid fertiliser loss and off-field impacts. Research has found similar recovery of water-run and soil-applied urea by cotton.

Water-run urea will be distributed through the profile with the irrigation water and is thereby made available for rapid crop uptake. Water-run urea can be applied using the following methods:

- Applying urea to dry soil, either by spreader or aircraft, then irrigating as soon as possible. (Losses can be high where urea is broadcast onto the surface of moist soil.)
- N Buggy type equipment that delivers a measured weight of fertiliser directly to the irrigation water flowing through an irrigation channel. The rate of fertiliser addition can be regulated according to the water flow rate.
- In some areas, urea solutions are available and can be delivered on-farm. A constant head tank containing a float-valve mechanism to maintain a constant flow of dissolved fertiliser into the channel is required. Changing the flow rate of the fertiliser solution or the irrigation water can vary the N application rate.

Anhydrous ammonia application

Although anhydrous ammonia can be injected into irrigation water, considerable volatilisation (loss) of ammonia can occur, particularly in windy conditions, where N losses of up to 25% per hour have been recorded. As a result the nitrogen may be applied unevenly, particularly on long fields, and the crop may respond poorly. Hence, this practice is not recommended.

Also, when anhydrous ammonia (NH_3) molecules are dissolved in water, they are transformed into ammonium ions (NH_4^+) that have a positive charge. Positively charged ions will be attracted to the negative charges that dominate the surfaces of the clay particles in our soils. Hence, the ammonium ions may be removed from irrigation water near the head ditch rather than being distributed uniformly down the furrow. Urea in comparison has no charge and is therefore distributed evenly wherever the water goes.

Other fertilisers

Most fertilisers are salts that dissolve when mixed with water and can be strongly adsorbed by the soil and organic matter, and may not be evenly distributed throughout the field and soil profile. This applies particularly to those nutrients that are held strongly to the soil, such as zinc and phosphate.

Fertilisers with drip and overhead irrigation

Applying fertilisers in drip and overhead systems is an efficient method of applying fertilisers. Under these systems, nutrients are applied evenly and without loss or contamination in distribution before they reach the soil and crop.

Weather conditions

In common with irrigation and other crop management decisions, the water-run operation should coincide with clear conditions during and following the application. Rain events during and following a water-run fertiliser application can move the fertiliser through the soil profile or off-field where it is not accessible by the crop.

For more information please refer to NUTRIpak.



5.3 Assessing and managing irrigation salinity: including EM surveying

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Key points

- Irrigation salinity is a significant but often hidden issue. Especially in the case of salinity, prevention is much better than cure.
- Irrigators need to understand the relationship between irrigation and the causes of irrigation salinity.
- Measure soil and water salinity levels on a regular basis to observe trends and identify problems.
- Irrigation salinity can be managed and quite often reversed.
- While cotton is quite tolerant of saline conditions, steps should be taken to minimise saline impacts on other crops and the landscape in general.
- EM surveys need to be ground-truthed with soil tests.

What is salinisation in agriculture?

Salinisation results from the accumulation of soluble salts in the root zone. These salts may be important dissolved salts including cations, such as sodium (Na), calcium (Ca), magnesium (Mg), and potassium (K), and anions such as carbonate (HCO_3), sulfate (SO_4) and chloride (Cl).

In the Australian environment, large quantities of stored salts have accumulated naturally from several sources, including:

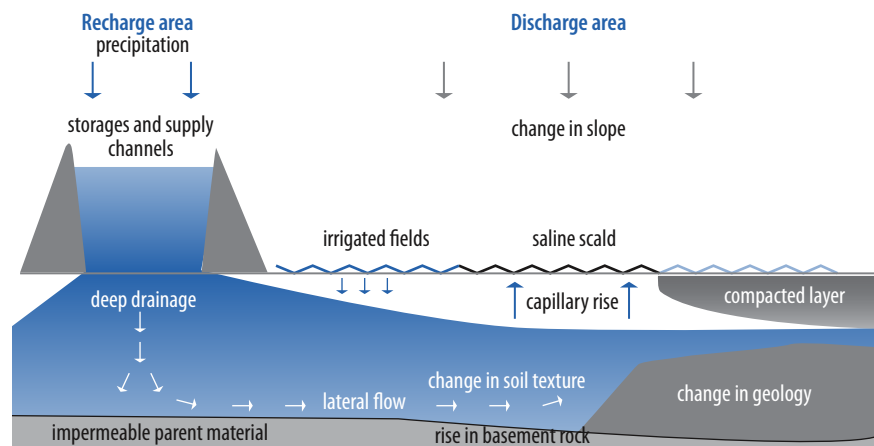
- cyclical deposition through rainfall
- weathering of saline materials, and
- salts stored in the soil or laid down as marine sediments in earlier geological times.

Areas of salinisation are primarily associated with the arid and semi-arid landscapes. These semi-arid and arid areas provide good climatic conditions but, unfortunately, the vagaries of rainfall render them mostly unsuitable for crop production. Irrigation overcomes this, but inefficient irrigation practices usually result in mobilisation of stored salts into the root zone. This is termed **irrigation salinity**.

In terms of agriculture, the other main type of salinisation is **dryland salinity**. Typically it occurs when native vegetation is replaced with pastures or cropping. As a result, less water is used, with the remainder draining beyond the root zone. The excess water (termed **deep drainage**) often recharges groundwater and may cause watertables to rise if the water is unable to flow vertically or laterally because of a change in texture or geology or other obstruction. Any salts stored between the root zone and the groundwater are mobilised in this process and brought to the surface. Through capillary action, salts accumulate and in time will be concentrated enough to cause a reduction in productivity. The capillary rise effect occurs when the dry soil above a watertable draws the groundwater up in much the same way as a sponge sitting on a wet surface soaks up water. The water then evaporates on the surface, leaving the salts behind both in and on the surface soils where they inhibit plant root growth. (See also SOILpak, page D4-5.)

As with dryland salinity, irrigation salinity is the result of significant changes to the hydrological balance in a given area. If irrigation plus rain exceeds evaporation, transpiration and run-off, then recharge of groundwater occurs. The result is excessive deep drainage, which can cause rising or perched saline watertables to appear. Figure 5.3.1 demonstrates how irrigation salinity can occur because of carrying out irrigation or constructing a water storage or supply channel on permeable soil types leading to recharge.

Figure 5.3.1. Schematic representation of irrigation salinity due to permeable soil types



Irrigation salinity occurs in the rice and horticultural areas of the Murrumbidgee and Murray valleys (Australia's oldest irrigation areas) and in cotton areas such as the lower Macquarie, Namoi and Darling river valleys. There is potential for it to become a problem in other cotton-growing areas. In addition, direct application of saline or sodic waters can cause irrigation salinity, since the salts are introduced in the root zone. This is a problem on the Darling Downs and a potential problem in other areas where poor quality groundwater is used.

In order to determine the threat and understand the causes of irrigation salinity, methods and techniques capable of providing this information are required at the field, farm, catchment and regional levels. The identification and measurement of both soil and water salinity are discussed later in this topic.

Cotton and salinity

Cotton is more tolerant of salt than most other crops, but salinity problems can easily get to the stage where cotton growth may be retarded. Some of the crops that may have to be grown in rotation with cotton are more sensitive to salt (for example, winter legumes).

from SOILpak for cotton growers – third edition, C7–1

Cotton is more susceptible to saline scald in early stages of development, a situation compounded by the fact that the highest salt concentrations are found at the top of row crop hills where the crop is planted. Yield decline for adult plants starts at around 7.7 dS/m, with seedlings starting to suffer at around 6.7 dS/m (12% less). A 50 % decline in yield of adult cotton is experienced at levels of 17 dS/m.

Table 5.3.1. Conductivities of saturated extracts and 1:5 soil-water suspensions at which yield decline starts for plants associated with cotton farming systems

Plant salt tolerance	Soil salinity rating	Saturated extract, EC _e (dS/m)	1:5 soil:water suspension, EC _{1:5} (dS/m)		
			Soil texture		
			Silt loam	Medium clay	Heavy clay
Sensitive (e.g. field peas)	Very low	<1.5	<0.16	<0.20	<0.26
Moderately sensitive (e.g. corn, lucerne, broccoli)	Low	1.5–3.0	0.16–0.32	0.20–0.40	0.26–0.52
Moderately tolerant (e.g. cowpea)	Medium	3.0–6.0	0.32–0.64	0.40–0.80	0.52–1.04
Tolerant (e.g. cotton, barley, wheat, sorghum)	High	6.0–10.0	0.64–1.05	0.80–1.33	1.04–1.72
Very tolerant (e.g. saltbush) {halophytes}	Very high	>10.0	>1.05	>1.33	>1.72

Source: modified from *SOILpak for cotton growers*

Field signs of soil salinity are located in SOILpak, section C7–3.

How can we measure salinisation?

On-farm monitoring of salinity levels of both soil and water is easily achieved with commonly available hand-held salinity meters. However, many people have not realised the full potential of these instruments in keeping track of the build-up of salts on the farm and in local waterways.

Salinity meters provide a quick and effective way of monitoring salinity on the farm and in waterways. They are cheap, easy-to-use, and are highly recommended for all irrigators.

The salinity meter is a small and simple battery-powered device that is used to measure the salt content in a solution. This allows a quick and reasonably accurate reading of the amount of salt in water and in soil samples through a simple field test.

By dipping the salinity meter into a solution and measuring the solution's ability to conduct electricity between the electrodes of the meter, you can determine the amount of dissolved salts present. Salts increase the conductivity, so readings increase as salinity levels increase.

The meter then gives a digital readout of the electrical conductivity (EC) of the water, which can be converted to common units of measure for salinity.

Regular testing of water supplies is very important, particularly if bore water is being used for irrigation. Salinity can vary considerably over short periods, and has a profound effect on the growth of plants, especially salt-sensitive varieties.

Table 5.3.2. Common units of measurement for salinity

1 dS/m = 1 mS/cm = 1000 EC (μ S/cm) = 640 ppm **So, to convert ...**

	From this unit	To this unit	Do this
1 decisiemen per metre (dS/m)	EC (μ S/cm)	dS/m	Divide by 1000
= 1 millisiemen per centimetre (mS/cm)	ppm (mg/L)	dS/m	Divide by 640
= 1000 EC (microsiemens per centimetre)	dS/m	EC	Multiply by 1000
= 640 parts per million in water (mg/L)	dS/m	ppm	Multiply by 640

Soil salinisation

In the past, soil salinity assessment involved observing the soil condition (for example, waterlogging, friable soil structure, bare and salt-encrusted surface soil) or plant growth (for example, poor or stunted growth). Whilst this approach provides an approximation, more information is required. This is because soil salinity may reduce crop yields by as much as 25% without any visible symptoms and so salinity might be well advanced by the time the need for control and amelioration is realised.

There are various methods and techniques that can be used to measure or assist in the assessment of soil salinisation, from laboratory measures to field techniques.

In the laboratory, a number of methods have been developed to prepare soil solutions for EC assessment. In Australia, two methods have been used extensively: a saturated soil paste extract (EC_e), and a suspended material preparation (EC_{1:5}). The prepared extract, suspension, or other preparation is then measured to determine its electrical conductivity (EC). These are always expressed at a standard temperature of 25°C so comparisons can be made under varying climatic conditions.



How to texture soils and test for salinity

Testing a soil sample is a reliable way to assess how salts are affecting plant growth. Even though it is quicker and easier to test water samples, a soil salinity test shows the soil conditions around plant roots, taking into account the influence of soil texture. Identifying current soil salinity conditions and recording salinity trends will help you recognise and predict soil salinity problems.

To perform the test, samples of soil will be required from the crop root zone. If possible, take a sample from below the root zone as well. Aim to take samples from different soil types in an area using electromagnetic (EM) maps with high and low conductivity areas, aerial photos showing waterlogged and saline areas, cut and fill maps showing saline or sodic subsoils and visual signs such as crop variations and remnant vegetation.

Note that soil salinity will be highest before the rain break or before commencing irrigation, so test soils then. Also note that the test result will be artificially high if gypsum (a calcium salt) has been recently added.

The soil salinity field test

Soil salinity can be measured by a simple field test. The test is reasonably accurate in indicating if salts may cause yield losses or soil management problems, but is not as accurate as laboratory analysis.

Commercial soil tests include salinity as one of the properties tested. The field test for salinity is also called an $EC_{1:5}$ ('EC one-to-five') test because a ratio of 1 part soil sample to 5 parts distilled water is used to find the salinity of the sample.

The three steps in a soil salinity test are:

1. Assess the texture of the soil sample.
2. Measure the salinity of a solution made up of distilled water mixed with the collected soil.
3. Multiply the test result by the conversion factor based on soil texture to get soil salinity (EC_e), which shows how soil salinity will affect plant growth.

In simple terms, a given amount of salt in sandy soils will be more concentrated in its effect on plant roots than an equivalent amount in clay soils. This is because sandy soils hold less water to dilute the salts than clay soils (they have a lower available water content). Find the multiplication factor for your textured soil sample on the conversion factor table (Table 5.3.3) below.

Table 5.3.3. Coefficients for converting $EC_{1:5}$ (S/m) to an approximate value of EC_e (S/m) based on soil textural properties

Texture class	Textures	Clay (%)	Coefficient
Sands	Sand, loamy sand, clayey sand	<10	-
Sandy loams	Sandy loam, fine sandy loam, light sandy clay loam	10-20	11
Loams	Loam, loam fine sandy, silt loam, sandy clay loam	25	10
Clay loams	Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	30-40	9
Light clays	Light clay	35-40	9
Light medium clays	Light medium clay	40-45	8
Medium clays	Medium clay	45-55	7
Heavy clays	Heavy clay	<50	6

Source: after Daniells and Larsen 1991

Water salinity

Surface water tests provide a reading that is accurate only at the time of testing. The salinity can change sharply in a short time due to evaporation or rainfall, so water needs to be tested regularly.

- River water supplies can change, with good quality water often being interspersed with slugs of higher salinity water flowing downstream.
- Groundwater tends to be more constant in the short term. Groundwater should be checked on farm for watertable depth and salinity levels, and more importantly for any changes.

Test wells, observation wells and piezometers are an easy way of measuring the level of the local watertable, and can highlight potential salinity hazards on your property before they become a problem. They measure the free water depth to the local watertable, and give an indication of what is happening to the local watertable.

They are best located:

- in problem drainage areas
- on low parts of the farm
- on light permeable soils (especially areas of prior stream or old watercourses)
- in a non-irrigated areas adjacent to irrigation
- next to large storages and supply channels
- where signs of salting are occurring
- in areas you suspect may have high watertables.

Testing water salinity

Some points to consider when testing water for salinity are:

- Make sure that the water sample is mixed thoroughly prior to testing.
- Rinse the sample container with sample water before collection.
- When sampling from a storage, collect a sample from entry points, and several locations around the storage.
- When sampling from a channel or river, collect a sample from near the middle of the flow and near your pump intake.
- When sampling from a bore, collect a sample from a turbulent area near the discharge pipe, after continuous pumping for at least 30 minutes.
- When testing water from a testwell or piezometer, bail out the water in the pipe and allow fresh groundwater to enter prior to testing.
- Salinity meters should read zero in the air and if not they need to be calibrated.

Crop production can decline if the salts in irrigation water exceed certain levels. It may be difficult to recognise salinity problems in the paddock because there can be a significant yield decline before the signs of salinity are obvious. There may be no obvious plant symptoms or signs of salt on the surface. Some early visible signs for most irrigated plants may be:

- slow or patchy germination and establishment
- stunted growth
- burnt leaf tips. The whole plant may start to lose its vigour and healthy green appearance and appear yellow or bronzed (especially if it is also waterlogged).

In cases where salinity is severe, salt-tolerant plants such as sea barley grass or couch may become more evident.

Table 5.3.4. General water quality benchmarks (in dS/m)

Water type	dS/m
Distilled or rain water	0
Desirable limit for people	0.83
Environmental impacts may occur	1.5
Safe limit for people	1.56
Limit for mixing herbicides	4.7
Seawater	55+

The effects of water salinity on plant yield, where the water of a set salinity level is used for the whole irrigation season, are shown in Table 5.3.5.



Table 5.3.5 Tolerance of crops and pastures to water salinity and root zone soil salinity

Soil type	Water salinity limits for surface irrigation (in dS/m)						Root zone soil salinity (in dS/m)	
	Well-drained soils		Moderate to slow draining soils		Very slow draining soils		Up to 10%	25%
Yield reduction	Up to 10%	25%	Up to 10%	25%	Up to 10%	25%	Up to 10%	25%
Pasture legumes								
Strawberry clover	2.1	4.0	1.4	2.6	0.7	1.3	2.1	4.0
Lucerne (most varieties)	2.0	5.4	1.3	3.5	--	--	2.0	5.4
Lucerne (salt tolerant varieties)	3.6	5.9	2.4	3.9	--	--	3.6	5.9
Pasture grasses								
Phalaris	4.2	8.0	2.8	5.3	1.4	2.6	4.2	8.0
Perennial ryegrass	5.6	8.9	3.7	5.8	1.8	2.9	5.6	8.9
Tall wheatgrass	7.5	13.3	5.0	8.8	2.5	4.4	7.5	13.3
Saltbush	12	20	8.0	13	4.0	6.6	12	20
Puccinellia	16	22	10.6	15	5.3	7.3	16	22
Winter crops								
Wheat	6.0	9.5	4.0	6.3	2.0	3.1	6.0	9.5
Canola	6.5	11	4.3	7.3	2.1	3.6	6.5	11
Barley	8.0	13	5.3	8.6	2.6	4.3	8.0	13
Summer crops								
Grain sorghum	1.0	1.5	0.7	1.0	0.3	0.5	1.0	1.5
Maize	1.7	3.8	1.1	2.5	0.6	1.2	1.7	3.8
Soybeans	2.0	2.6	1.3	1.7	0.6	0.8	2.0	2.6
Sunflowers	5.5	6.5	3.6	4.3	--	--	5.5	6.5
Cotton	7.7	12.5	5.1	8.3	2.5	4.2	7.7	12.5

Plants can be watered for short times with saltier water, if fresh irrigation water is available later to flush away the salt and the groundwater is deep enough to allow adequate leaching. Saline water can also be shandied with better quality water to reduce the effects of salts and sodium in irrigation water. However, shandying will diminish the useability of good quality water and should only be used if the quantities of good water far exceed the quantities of poorer quality water.

The values listed in Table 5.3.5 can vary with:

- stage of plant growth: plants are much more susceptible to salinity at germination and seedling stages.
- soil type: influences potential for leaching of salts. If salts cannot leach away from the surface and plant roots it will cause more damage. Water moves through heavier soils (clays) more slowly, so salts in the water are more likely to affect plant growth.
- method of irrigation: spray irrigation concentrates salts and chlorides on leaves and can cause leaf scorching. **Use caution when irrigating with sprays if the water salinity is above low levels.** Leaching of salts is lower under drip irrigation systems but still possible.

Some tips on using saline water

- Use the best quality water when establishing crops, as plants are much more salt sensitive when germinating and when young (especially lucerne and clover).
- The best time to use poorer quality water is in the late summer–autumn period for pre-watering winter crops. Older, well-established plants are more salt tolerant than young plants, winter cereals are more salt tolerant than most other crops and there is less accumulation of salts in the surface soil over the season.

- Avoid filling storages with saline bore water. This water tends to have more salts than channel or freshly recycled water. These salts will build up in time (through evaporation) in the storage, causing the water to become saltier, increasing the leakiness of the storage, and damaging the clay lining. If the bore water is sodic (contains too much sodium), then the clay lining is more likely to slake or disperse: muddying the water in the storage, and possibly breaking down the clay lining and banks.

Management and remediation of irrigation salinity

In order to minimise salinity impacts and to improve affected sites, land needs to be managed according to its level of soil salinity. Irrigators need to know their soil types, watertable depths (especially around storages and major supply channels), their current salinity levels for soil and water and the potential risk for further degradation due to salinity.

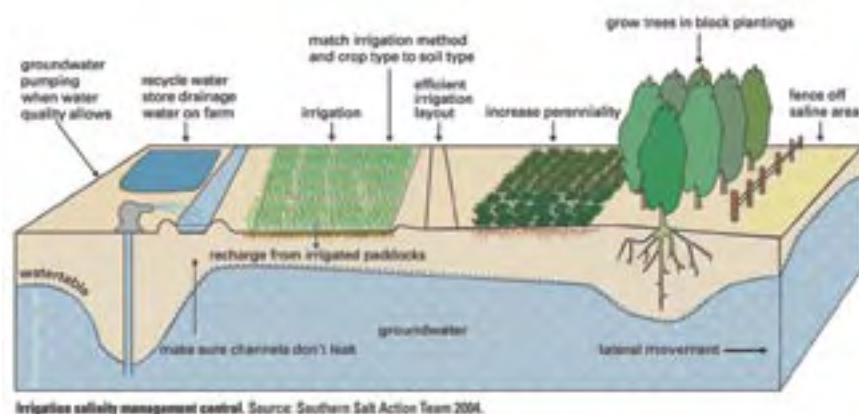
The land that is most suited to agricultural production has low (0 to 2 dS/m) to moderate (2 to 6 dS/m) levels of root zone salinity. This land has little to no effect on production at the low end and minor yield losses at the high end. This is due to mobilisation of salt into the root zone through capillary rise. There is risk however of further salinisation and visual indications will point to this.

Land that requires protection measures is land with high to extreme levels of root zone salinity, that is, 6 to 15 dS/m and over. Surface salts will affect all plants, and at these levels there is probably a shallow watertable. Change in species composition to highly salt tolerant plants and the appearance of bare patches will be evident. Land at this level of salinisation requires the establishment and maintenance of a perennial groundcover. Irrigated crops can be used to leach away surface salts if there is no shallow groundwater but the land has a high risk of further salinisation. Soils over 15 dS/m are considered extreme, and sites affected have extensive scalding. Most vegetation dies out, leaving only salt-tolerant plants (halophytes). Regeneration of these sites is difficult and requires careful management and protection.

In all cases irrigations need to be scheduled to match plant water requirements at differing stages of the season. The plant requirements continually change due to climatic conditions, rooting depth, stage of growth and are also influenced by soil type. The irrigation water applied should match this crop need in both the amount applied and when it is required. Excess drainage through over-irrigation needs to be prevented if irrigation salinity is to be avoided or reduced in salt prone areas. In areas where it is difficult to manage surface irrigation and its excess drainage, then more precise irrigation methods such as drip and spray could be considered.



Figure 5.3.2. Irrigation salinity management control



Irrigation channels and storages should be monitored for leakage. Leaks should be fixed where possible. In worse case scenarios, channels should be re-routed and storages used for short-term storage only, split or even abandoned. Groundwater pumping and subsurface drainage are both methods that are currently used with success to control the impacts of irrigation salinity in some irrigated areas of Australia. At this level of remediation, early prevention is much easier and cheaper.

Early prevention focuses on the correct design of systems, whole farm planning, sound irrigation management, good understanding of the mechanics of salinity and vigilant monitoring for changes in saline conditions.

Irrigators should concentrate their resources such as irrigation water, diesel, seed and fertiliser onto the land suited to agricultural production instead of onto land with higher levels of salinity. Land with low to moderate levels of salinity will give a higher economic return.

On the land best suited to production, ensure that the irrigation-based agricultural systems used maximise the amount of soil water they use, avoid leakage to the watertable beyond the root zone and hence prevent potential salinity problems. Where shallow watertables exist, plant salt-tolerant deep-rooted perennials to draw down the watertable. Also plant trees in targeted areas to intercept lateral groundwater table flows and also draw down shallow watertables.

Land management practices such as effective irrigation management, surface and subsurface drainage, and maintaining groundcover can be used to reduce soil salinity levels. The aim is to maintain soil salinity at a level where agricultural production can occur.

Investigation of large areas using EM technology

Generating soil information at the field level is time-consuming and labour intensive, and costs of the resulting soil analysis can soon add up. Therefore, only limited soil information can be collected. In specific investigations such as soil salinity assessment, irrigation storage or channel site selection and determination of irrigation and drainage efficiency, more detailed quantitative soil information is required to manage soil salinity, permeability or related problems.

Electromagnetic (EM) induction instruments, which measure the apparent electrical conductivity (EC_a) of soil, have successfully been used to estimate various soil variables and properties. These include assessing soil salinity and estimating deep drainage, clay content, depth to clay, nutrient status and moisture content. The reason for the wide application is the ability of the EM instruments to respond to various soil attributes including changes in clay content, soil texture, moisture content and salinity.

Over 120,000 hectares of rice country in southern NSW has been tested by EM surveys for clay content and hence permeability between 1998 and 2003. Most new irrigation storages are also EM surveyed as standard practice.

To improve the efficiency of EM data collection, global positioning systems (GPS) data are also collected to link the collected values with an exact location.

The most commonly used EM device is the Geonics EM31. The meter measures apparent electrical conductivity (EC_a) to a depth of 6 metres from the soil surface. Other devices are the EM38, which is used mainly for salinity investigation to shallower depth in the soil profile, and the EM34, which looks at soil clay and salt content variations to depths of 15 metres. Additional information on EM devices and their application is found in SOILpak, page C7-5.

Practical applications of EM surveys

The two case studies of EM application described below are from the irrigated cotton-growing areas of northern New South Wales.

The first is a field in the Namoi Valley experiencing minor cyclical salinity.

The second field, which is located in the Gwydir Valley, has perennial problems with a shallow watertable.

The EM survey helps identify likely causes of soil salinity and clay content in each cotton field studied, and adds value to limited soil information, helping identify where soil samples could be taken to enhance interpretation.

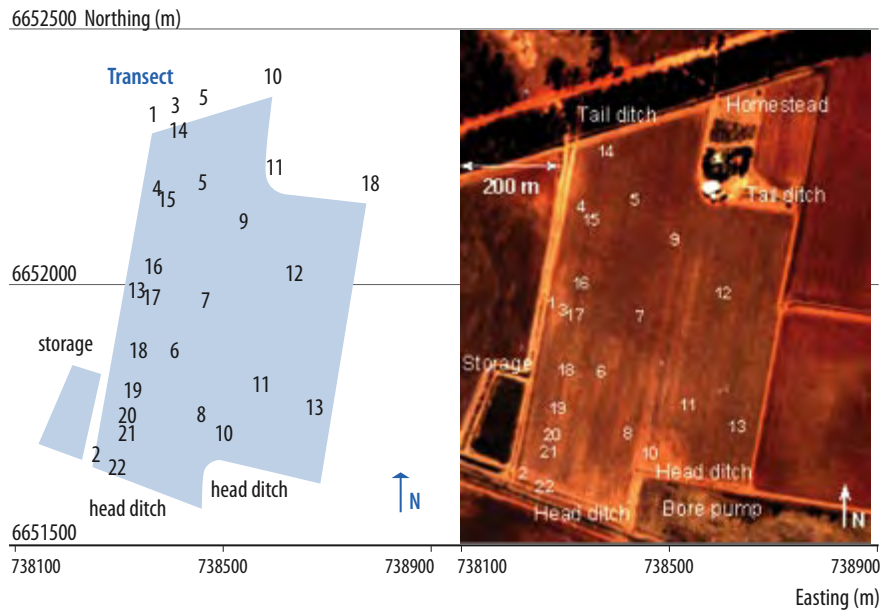
Case study 1, EM application

The first case study is located in the lower Namoi valley near Wee Waa. Figure 5.3.3 shows an aerial photo of a field that is experiencing problems with a shallow watertable and minor soil salinity. The head ditch is located at the southern end of the field next to the water storage.

An EM survey was undertaken to ascertain the extent of waterlogging and soil salinity and the likely causes. Eighteen transects were traversed in a north-south direction in this 29 ha field, recording 20,000 EC_a measurements with the EM38 and EM31 instruments. Twenty-two soil profiles were sampled to a depth of 2.0 m for calibration. Samples were obtained at 0.3 m increments.



Figure 5.3.3. Aerial photograph, location of transects and sampling sites, Case study 1

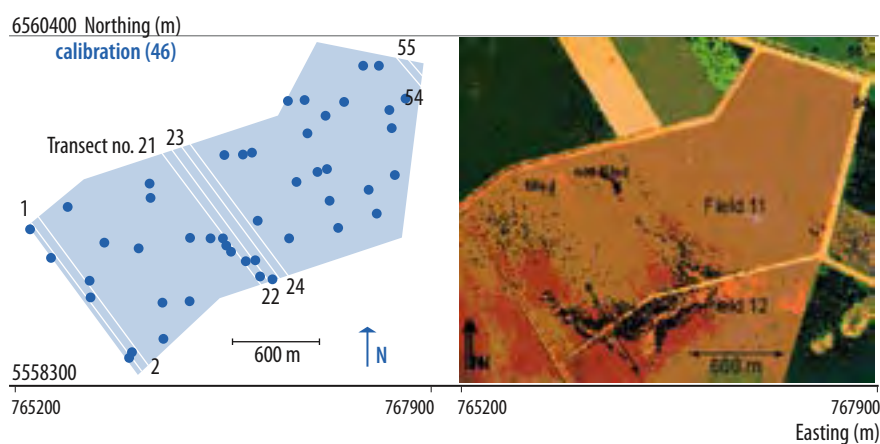


Case study 2, EM application

The second case study is located in the lower Gwydir Valley north-west of Moree. The problem experienced in this field is the presence of a shallow watertable which is causing waterlogged conditions in the middle sections and near the head ditch. Figure 5.3.4 shows the irrigation layout. Again, the head ditch is located at the southern end of the field. A large supply channel and the head ditch of the southern field run parallel to the head ditch of the field.

Fifty-five transects were travelled at a spacing of 48 m. In this field of 240 ha, 27,000 EC_a measurements were made with the EM instruments. The EM survey took two days to complete. A total of 46 soil profile sites were chosen at low, intermediate and high values of soil EC_a for calibration. These were sampled to a depth of 1.5 m.

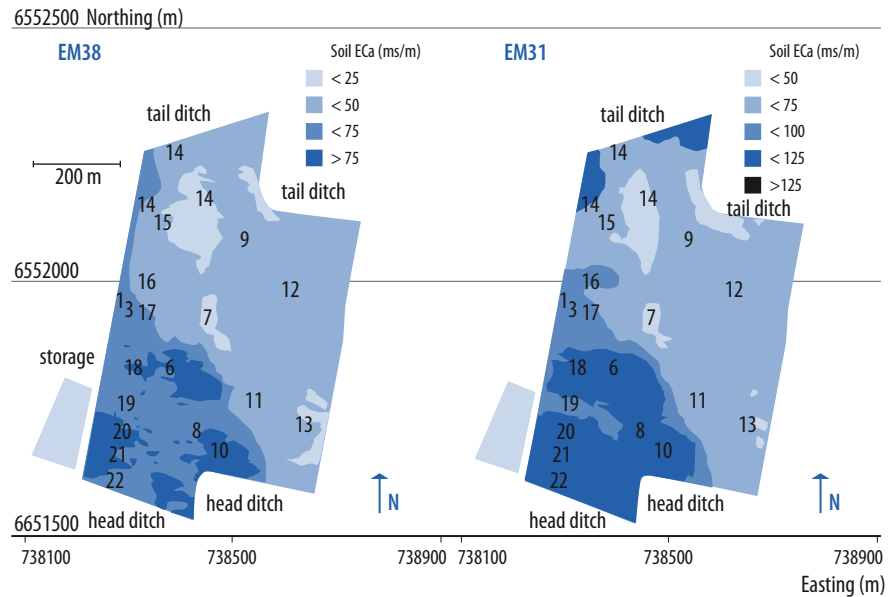
Figure 5.3.4. Aerial photograph, location of transects and sampling sites, Case study 2.



Spatial distribution of soil EC_a

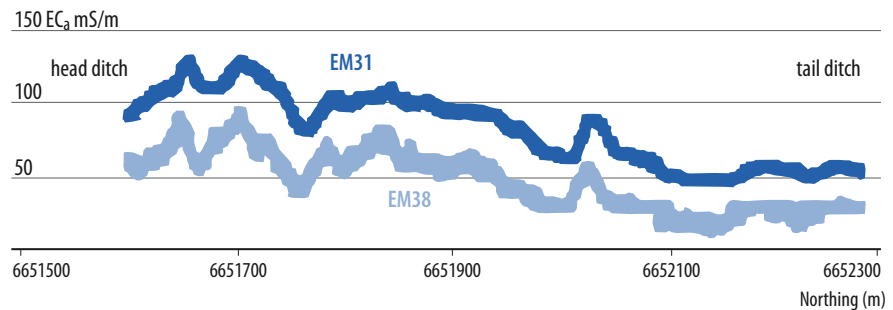
Figure 5.3.5 shows the spatial distribution of EC_a as generated by EM38 and EM31 in Case Study 1. Both instruments show that in the south-west corner, near the head ditch and eastern storage wall, EC_a is higher (for example, EM31 > 125 mS/m) than at the northern or tail ditch end (EM31 < 75 mS/m). This is consistent with where waterlogging is apparent.

Figure 5.3.5. Spatial distribution of EC_a , Case study 1: a) EM38; and, b) EM31



It is also evident that a sharp drop in EC_a occurs approximately halfway between the head and tail ditch. This drop in soil EC_a is shown more clearly in Figure 5.3.6, along transect 3.

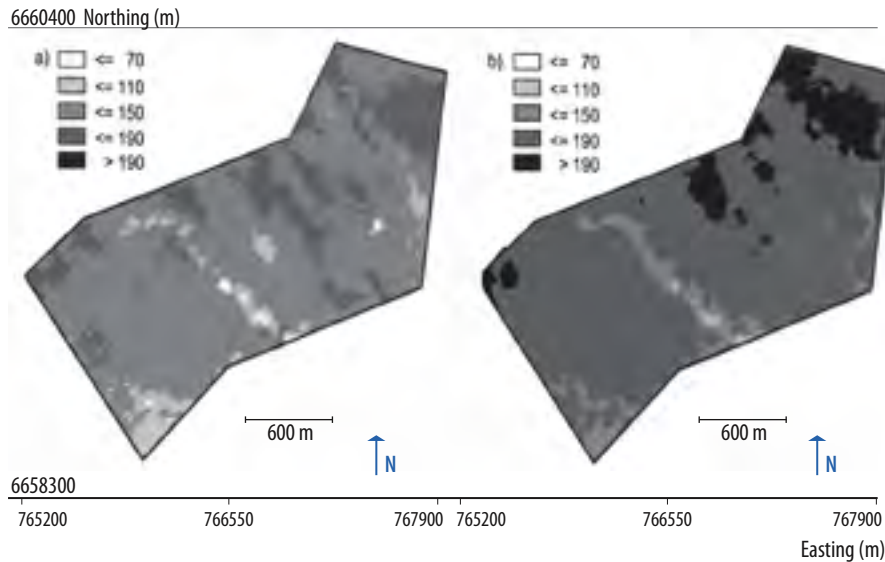
Figure 5.3.6. Spatial distributions of soil EC_a along transect 3, Case Study 1.



What is also apparent in Figure 5.3.5b is a small band of low EC_a (that is, <100 mS/m) which lies perpendicular to the eastern storage wall at an approximate Northing of 6651750 (sample site 19). This lower band of soil EC_a is more evident in Figure 5.3.6 for both EM instruments (that is, Northing 6651750).

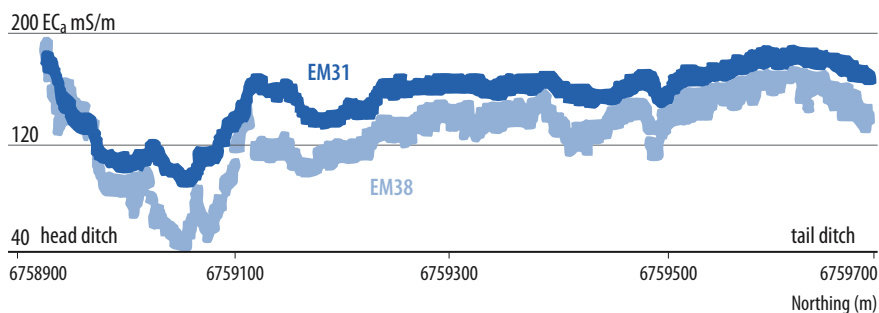
The spatial distribution of soil EC_a generated at Case study 2 is shown in Figure 5.3.8 for the EM38 and EM31. In the north-eastern part of the field, larger values of EC_a (>185 mS/m) were generally obtained with the EM38 and reflect areas where heavy clay profiles exist. Similar, EC_a patterns were obtained with the EM31.

Figure 5.3.7. Spatial distribution of EC_a across Case Study 2 for: a) EM38; and, b) EM31 in vertical mode of operation



The lighter shaded areas in Figure 5.3.7 ($EC_a < 110$ mS/m) indicate parts of the field where a prior stream travelled and where sandier soil types are apparent. This suggests both instruments are primarily responding to clay content and soil mineralogy and hence strongly reflect geology and geomorphology. This is more clearly illustrated in Figure 5.3.8, which shows the spatial distribution of soil EC_a recorded along transect 22 at Case Study 2. The location of the sandier prior stream material is evident between the Northings of 6758900 and 6759100. Further away soil EC_a generally increases and reflects the more clayey soil of the alluvial plain.

Figure 5.3.8. Spatial distributions of soil EC_a along transect 22, Case Study 2.



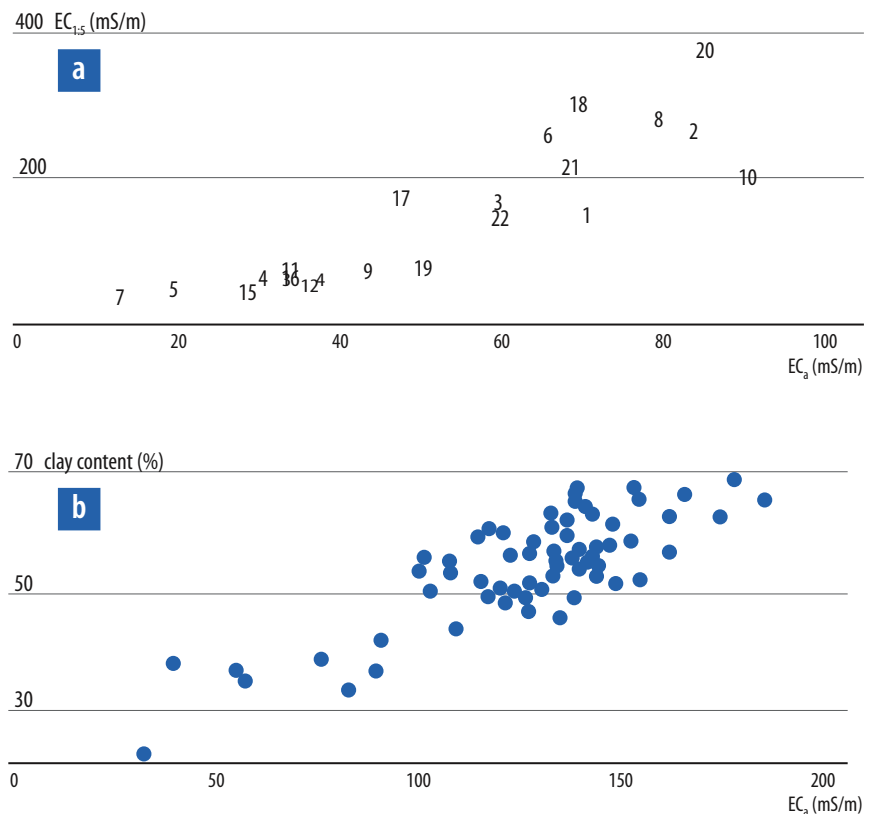
Interpreting soil EC_a

In order to confirm these field observations and determine which soil attributes influence EC_a , average profile values for clay content (%), soil moisture (field moisture %), ECEC (cmol(+)/kg) and soil salinity ($EC_{1:5}$ – dS/m) were determined from the samples collected in each case study. These average profile values were compared with soil EC_a using simple linear regressions.

At Case Study 1, soil EC_a was generally not correlated with average field moisture or clay content. Figure 5.3.9 (a) shows that a reasonable relationship exists between EC_a and $EC_{1:5}$. The low salinity profiles are generally located in the northern half of the field, near the tail ditch. The more saline profiles characterise the southern half near the water storage and where soil EC_a was also much larger. Significantly site 19, which is located in the southern half of the field and lies adjacent to the northeast corner of the storage, does not belong to this group of more saline/high soil EC_a profiles. It is apparent from Figure 5.3.5 that this site does lie within the lower band of soil EC_a as measured by the EM31 and EM38, however.

By comparison, soil EC_a at Case Study 2 was most strongly correlated with average soil clay content and to a lesser extent cation exchange capacity (cmol(+)/kg) and field moisture content (%) to a depth of 1.5 m. The relationship between EC_a and clay content is shown in Figure 5.3.9.

Figure 5.3.9. Relationship between soil EC_a as measured by the EM38 and average a) soil $EC_{1:5}$ at Case Study 1, and b) clay content at Case Study 2.



At the first case study site, the field is experiencing perched watertables and modest saline soil conditions. This is affecting irrigated cotton production. The probable cause of the problem originates from the storage dam, which has either been constructed poorly or includes soil types which are unsuitable. Further investigation is required and should be targeted at the north-west corner of the storage dam. This coincides with the lower band of soil EC_a apparent in Figures 5.3.6 (b) and 5.3.7. The reason for this is that lower soil EC_a coincides with lower soil salinity ($EC_{1:5}$) as evidenced at site 19. This suggests that the salts have been leached. It is most likely that the movement is lateral through this band of lower soil EC_a because in the adjoining areas soil salinity is quite high at some depths ($EC_{1:5}$ of 6 dS/m). Once the area of leakage has been determined, the dam wall can be reconstructed or lined with impermeable clay membranes.

At the second case study site, the field is similarly experiencing a perched watertable. The problem appears to be due to the location of the supply channel and head-ditch of this field on top of a prior stream channel. Because of the sandy nature of the soil, the supply channel and head ditch are extremely permeable. At the time the EM survey was undertaken, the field was in fallow. However, a shallow watertable was evident when soil samples were taken near the head ditch. The likely management required in this area includes lining the channel with impermeable membranes or re-routing the location of the supply channel to a more suitable area on the farm.

In summary, the EM system that was developed and deployed provided preliminary soil EC_a information which could be used to determine suitable soil sampling sites. Once analysed for the various soil properties that affect EM instrument response, interpretations could be made as to the likely cause of soil salinity and irrigation inefficiencies in these two irrigated cotton-growing field in northern New South Wales.



5.4 Using poor quality water to irrigate cotton

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Key points

- Sources of poor quality water are usually bores or treated sewage effluent.
- Poor quality water is usually dominated by sodium and chloride which cause both salinisation and sodification, with some water having excessive bicarbonates, which cause very high alkalinity.
- Immediate consequences of salinisation are nutritional and osmotic stress on the crop, whereas sodification causes soil structural destabilisation leading to waterlogging.
- Poor quality water can be used for irrigation if appropriate management practices are put into place. These include:
 - Using a higher leaching fraction. This involves higher water application rates, and consequently reduced crop WUE.

- Improving soil structure and soil organic matter, and supplying nutrients to overcome imbalances caused by saline and sodic irrigation water. Improvements in soil structure can both alleviate waterlogging and facilitate leaching of Na and Cl ions.
- Avoiding irrigating with poor quality water during the most sensitive stages of crop growth.
- Using salt-tolerant cotton varieties. Some cotton varieties are more tolerant of salinity during their seedling stage than others.
- Diluting (or 'shandying') poor quality water with water of a higher quality is a common practice in the industry.

What is poor quality water and what are its consequences?

Until recently, most cotton growers did not need to consider the consequences of using poor quality irrigation water on cotton crops and soils. However, as availability of good quality irrigation water decreases due to a combination of drought and legislation, many cotton growers have begun irrigating with water of poor quality which in years gone by they would have used reluctantly. Others believe that treated water from sources such as sewage or industrial waste ('grey water') is cheap water which can be used with no detrimental effects on either crop or soil.

Chemically, such water is characterised by high salt (Na and Cl) concentrations and, less commonly, high nitrate and phosphate concentrations, high sodicity, and high alkalinity. Higher concentrations of K are also not unusual. As this water is recirculated, it tends to become turbid faster due to soil dispersion caused by the sodium. The dispersed clay particles in the water

also carry adsorbed nutrients and salts. Poor quality irrigation water is commonly bore water, treated sewage effluent or other industrial wastewater, although the quality of recirculated water is also poor as it contains both salts and nitrates picked up as it moves around the farm.

An example of the amounts of salts and nutrients which enter a cotton field in recirculated bore water and treated sewage effluent is given in Table 5.4.1. Assuming uniform concentrations and irrigation efficiencies typical of much of the cotton industry, about 60% to 70% of the salts and nutrients in irrigation water will be retained in the soil.

Table 5.4.1. Quality of treated sewage effluent (Narrabri, NSW) and re-circulated bore water (Merah North, NSW)

Irrigation date	pH	ECw dS/cm	K kg/ha	Ca kg/ha	Mg kg/ha	Na kg/ha	Cl kg/ha	NO ₃ -N kg/ha	SAR
Treated sewage effluent									
15-Oct-01	8.8	0.71	3.4	13.6	6.4	91.7	843	26.8	5.1
23-Dec-01	8.7	0.69	9.1	11.9	7.2	151.8	858	50.3	8.5
21-Jan-02	8.9	0.73	4.7	8.0	3.7	78.5	977	29.7	5.7
30-Jan-02	8.7	0.71	15.5	13.0	7.7	172.2	1047	46.2	9.3
18-Feb-02	9.2	1.15	8.9	11.2	6.1	119.3	1182	56.6	7.1
8-Mar-02	9.7	1.38	7.7	6.6	5.8	122.7	932	36.8	8.4
Seasonal total			49.2	64.3	36.9	736.2	5840	246.5	
Recirculated bore water									
19-Sep-00	9.1	0.43	2.1	14.1	13.6	54.4	1786	6.0	2.5
6-Oct-00	8.1	0.35	1.6	14.5	8.8	36.6	1626	43.9	1.9
13-Dec-00	8.2	0.52	2.4	12.6	8.2	86.9	1562	15.5	4.7
28-Dec-00	8.1	0.40	2.3	15.1	11.4	59.5	320	57.2	2.8
9-Jan-01	8.2	0.40	1.9	17.0	11.8	56.3	249	4.5	2.6
18-Jan-01	8.2	0.41	2.0	13.8	12.0	68.5	238	2.6	3.2
29-Jan-01	7.8	0.46	2.0	17.0	11.9	72.2	399	31.1	3.3
16-Feb-01	8.2	0.34	2.4	13.1	9.0	41.2	178	37.6	2.1
21-Feb-01	7.7	0.68	3.3	17.1	16.3	94.7	195	16.0	3.9
Seasonal total			20.0	134.3	103.0	570.3	6552	214.4	
River water (Namoi River)									
12-Oct-00	8.7	0.45	5.3	20.4	22.3	41.9	32	29.2	1.5
5-Jan-01	-	0.58	6.6	37.9	21.6	40.0	749	6.8	1.1
19-Jan-01	7.6	0.41	3.7	21.9	18.6	34.9	309	2.8	1.3
Seasonal total			15.6	80.2	62.5	116.8	1090	38.8	
7-Nov-02	8.5	0.27	2.1	15.6	14.2	20.9	249	2.8	0.9
17-Dec-02	8.3	0.25	2.9	11.4	12.3	20.5	245	1.1	1.0
15-Jan-03	8.2	0.28	3.1	16.9	14.6	21.5	199	15.4	0.9
29-Jan-03	8.2	0.21	2.1	13.6	10.3	12.8	167	3.1	0.6
19-Feb-03	8.2	0.27	3.5	12.5	15.6	21.5	217	9.2	1.0
Seasonal total			13.7	70.0	67.0	97.2	1076	31.6	

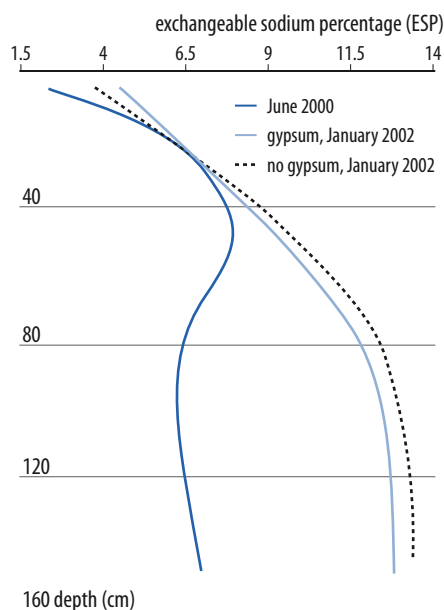


Notes: Values are an average of 3 fields sampled from the head ditch. For comparison, qualities of river water used at ACRI during the 2000-01 and 2002-03 seasons are also shown.

Nutrient entry to the field (in kg/ha) has been calculated on the basis of an irrigation rate of 1 ML/ha. (EC_w is the electrolytic conductivity of the water, a measure of its salinity, and SAR is the sodium adsorption ratio, a measure of its sodicity. As a general rule of thumb, irrigation water which has $EC_w \leq 0.4$ and $SAR \leq 4$ is considered to be good to excellent).

Irrigating with poor quality water, then, can result in soil salinisation, sodification and nutritional stress. Figure 5.4.1 shows an example where soil profile sodification was caused by irrigation with treated sewage effluent.

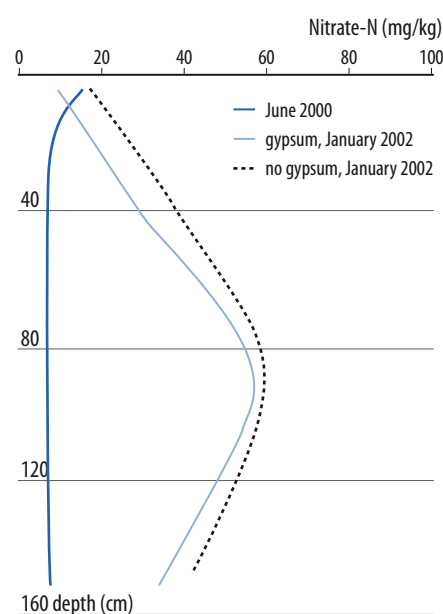
Figure 5.4.1. Effect of gypsum and time on ESP



Note: although gypsum was added, it was not sufficient to prevent sodification.

In addition, excessive amounts of nitrates and phosphates in the irrigation water can move into the watertable and cause pollution of drinking water sources. Figure 5.4.2 shows an example where nitrate in irrigation water (treated sewage effluent) was not used by the cotton crop but has moved deep into the soil profile.

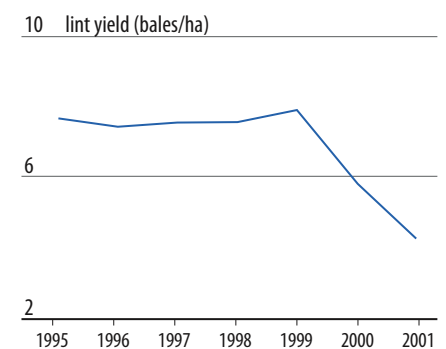
Figure 5.4.2. Effect of gypsum and time on nitrate N concentration



Soil salinisation will result in osmotic (salt-induced water deficiency), nutritional and toxic stresses in crops, whereas sodification causes nutritional stresses, toxicities and soil structural destabilisation. The latter will lead to poor root growth and waterlogging (see SOILPak for more details).

Commonly seen nutritional stresses are K and P deficiencies, and Na and Cl toxicities. Long-term irrigation with poor quality water usually shows up in cotton crops as stunted growth, premature senescence and declining yields (Figure 5.4.3).

Figure 5.4.3. Change in average cotton lint yield at Merah North, 1995-2001. Irrigation water quality deteriorated after 1999



In many fruit crops, Cl toxicity shows up as burns and necrotic lesion on leaves, but in cotton, at the concentrations seen in Australia, Cl toxicity is more likely to be seen as stunted growth due to N deficiency, even though there may be sufficient nitrate-N supplies in the soil. This is because Cl can block uptake of nitrate-N by the cotton crop.

With some sources of poor quality water, such as treated effluent, which has high concentrations of K (for example, about 45 to 60 kg K/ha/season) compared with irrigating with river water (usually less than 10 kg K/ha/season), K deficiency is less likely to occur. P concentration is also high in treated effluent, so P deficiency is also less likely to occur.

Managing poor quality irrigation water

Avoid irrigating with saline water during periods when cotton is sensitive to salinity

As young cotton between 2 and 10 weeks after sowing is very sensitive to salinity and the mature crop is relatively insensitive, either river or bore water of low salinity or stored rainfall should be the preferred source of water for early season irrigation. Alternatively, 'shandying' of poor and good quality water may be attempted.

As the crop matures and becomes more tolerant of salinity, water of higher salinity can be used for irrigation.

Include a leaching fraction when irrigating

If you are using saline water, a leaching fraction of the order of 20% is recommended for most clay soils. This means that an additional amount of water of the order of 20% over that required by the crop is needed to allow the salts which come in with irrigation water to be leached out of the crop's root zone. Consequently water use efficiency of saline water-irrigated crops is lower than when good quality water is used. The disadvantage of using a leaching fraction is that nutrients in irrigation water are also leached out of the root zone.

Manage soil to improve and maintain good soil structure

Good profile soil structure will facilitate leaching of salts which come in with poor quality irrigation water. Management practices which improve soil structure are explained in detail in SOILpak. Briefly, these practices are:

- Using soil amendments such as gypsum, lime or lime/gypsum mixtures, synthetic polymers such as polyacrylamide (PAM), or organic amendments such as composts.
- Using suitable rotation crops to improve subsoil structure. In sodic or saline-sodic soils, rotation crops which are tolerant of sodicity and salinity should be used. Cotton and cereal crops such as wheat, sorghum or forage sorghum can tolerate levels of salinity and sodicity which most grain legumes cannot. Leaching of salt is, therefore, less with most grain legumes. Other crops tolerant of salinity and sodicity are tall wheat and couch grass, barley and Egyptian and Persian clovers. In extreme situations, saltbush and bluebush can be used.
- Minimum ('permanent beds') or zero tillage, particularly when combined with controlled traffic systems, improves soil structure more than conventional tillage systems.

As with using a leaching fraction, the disadvantage of improving soil structure is that nutrients can be potentially leached out of the crop root zone.



Retain salts and nutrients in a 'filtration' field

Saline irrigation water may be passed through a cotton field sown into standing wheat stubble (Figure 5.4.4). As infiltration is higher with standing stubble, salts and nutrients are retained in the field by being moved into the soil profile, and not circulated with recycled irrigation water throughout the entire farm. That is to say, the water which leaves this field is hopefully cleaner than that which entered it (Figure 5.4.5). The salts which were retained in field (Figure 5.4.6) are then leached out of the cotton root zone over time.

Figure 5.4.4. Cotton sown into standing wheat stubble near Narrabri, NSW



Figure 5.4.5. Run-off water from adjacent plots of cotton sown into standing or incorporated wheat stubble (left) standing stubble (right) stubble incorporated

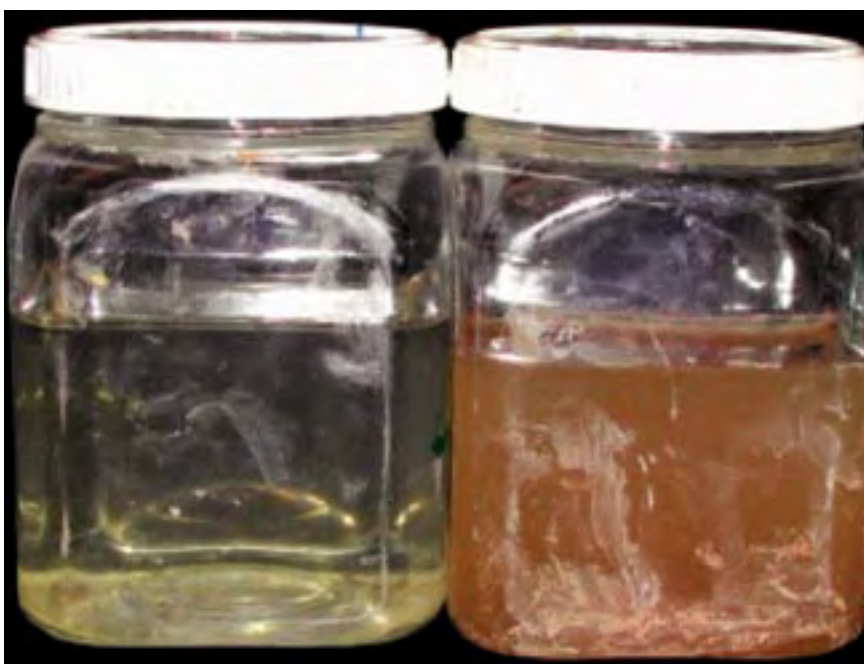
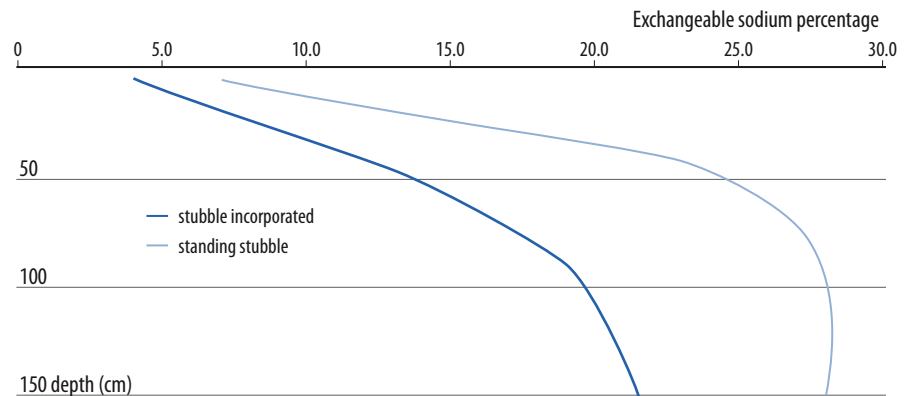


Figure 5.4.6. Exchangeable sodium percentage in adjacent plots of cotton sown into standing or incorporated wheat stubble, November 2001, near Boggabri, NSW



Some problems can occur, particularly in clay soils, with waterlogging. This can be overcome by retaining the stubble in the furrows only until the start of the irrigation season. At this point, except for a 1 to 4 m buffer of standing stubble in the furrows at the tail drain end of the field, the point of a sweep is run through the furrow to clean out the stubble from the bottom 10 cm. This facilitates water flow through the field. The retained buffer is sufficient to slow water flow just enough to sediment out dispersed clay. Excess salts and nutrients adsorbed onto clay particles are deposited in the furrow and do not move off field with run-off. Figure 5.4.7 describes this operation.

Figure 5.4.7. Clearing standing wheat stubble from furrows with sweeps.

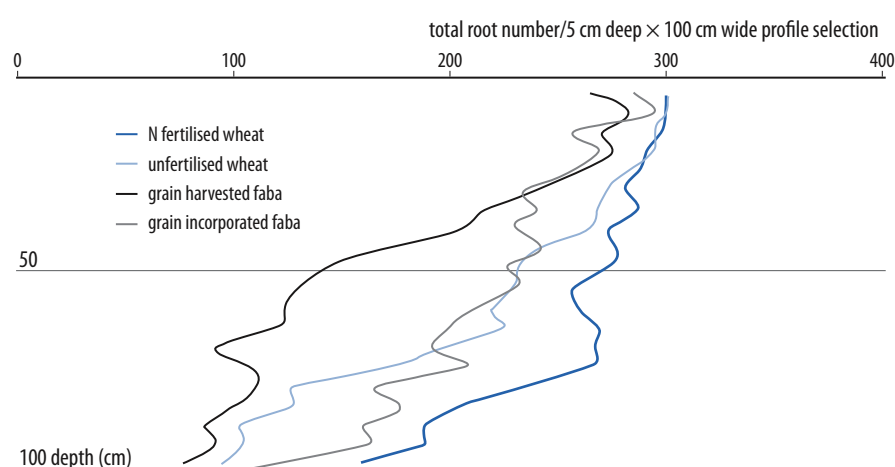
(A) Uncleared furrow with standing stubble , (B) Side view of sweep used in operation, (C) Standing stubble being cleared from furrow , (D) Cleared furrow with 2-m buffer



'Sop' up excess nutrients with cereal rotation crops

Cereal crops can extract excess nutrients, particularly nitrates, which have been leached below the cotton root zone. The N taken up by the cereals are released on decomposition of the wheat stubble during the following cotton season. Efficiency of N uptake is improved by fertilising the wheat crop, as this improves wheat root growth and allows the root system to extend into the deeper soil horizons (Figure 5.4.8). Figure 5.4.8 shows that root density of fertilised wheat is higher than that of either unfertilised wheat or grain legumes.

Figure 5.4.8 Root densities in a 100 × 100 cm profile face under wheat and grain legume crops in a gray clay near Wee Waa, NSW. November 1995



As an example, at the bore-irrigated site described in Table 5.4.1, a wheat crop, sown after cotton in May 2001 and fertilised with 60 kg N/ha as urea, extracted 113 kg of N/ha from the depths below 60 cm. The equivalent fertiliser (anhydrous ammonia) value of this N (assuming a cost of \$700/t) was \$96.50/ha.

Concluding remarks

Poor quality irrigation water is enriched with salts and nutrients, and consequently its long-term use can cause reductions in cotton growth and soil degradation. These consequences can be minimised or avoided by vigilant crop and soil management, but this does involve additional costs. Treated sewage effluent and other industrial wastewater which superficially appear to be cheaper than river and bore water have hidden costs in terms of crop and soil management.

For more information please refer to Qld NRM & DPI Notes in the back of this Manual.



5.5 Case study, water quality monitoring: Dirranbandi

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Cotton CRC, Qld DPI&F, Goondiwindi

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Key points

- Simple, inexpensive water sampling enables cotton growers to monitor the quality of irrigation water that is delivered to their crops and farms.
- Water quality fluctuates daily and annually and is influenced by the nutrient load in the soil, sediment load in the water and management practices.
- The quality of water sampled from on-farm storages along the Balonne River at Dirranbandi during the 2001/02 season was good.
- Water quality varies considerably from site to site, depending on soil type.
- The salinity (EC), sodicity (SAR), chloride and nitrate levels recorded in the samples were all classed as 'very low' or 'low' according to the national ARMCANZ & ANZECC guidelines. The levels of phosphorus in the samples just exceeded national guidelines, but pose no threat to irrigated crops.
- Irrigators and dryland farmers need to minimise sediment run-off on their farms to ensure the water quality of river systems is maintained in the long term.

Growers and consultants across the industry display a keen interest in the volume of water required to grow a crop and how this water can be best utilised to maximise water use efficiency.

But what about the quality of the water applied?

- Is the water quality conducive to good crop growth, or will it have a toxic effect on plant health?
- How will the water quality affect the sustainability of the farm ?
- How will run-off from the farm affect river health?

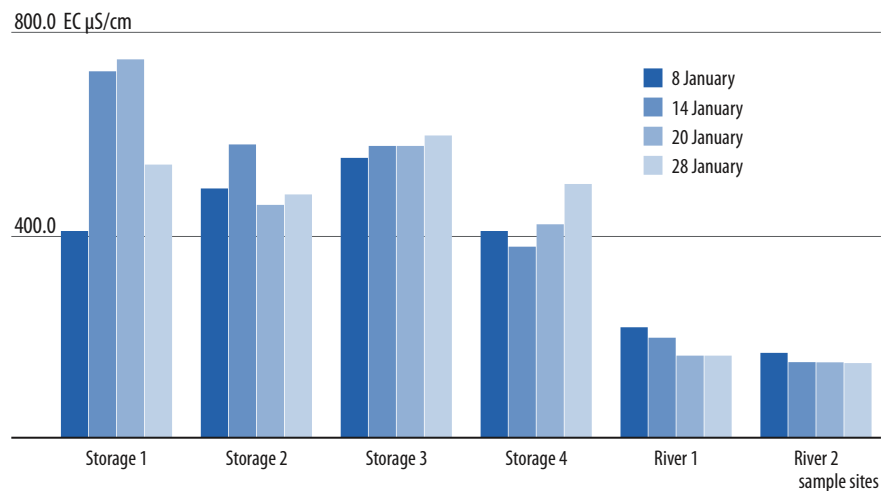
The quality of surface water varies over time and between locations, and may affect the suitability of the water for irrigation. For this reason it is important to monitor the quality of water used for irrigation. The WATERpak topics 6.1, 6.2 and 6.3 outline the variability in water quality over seasons in river systems. Water quality also fluctuates within a single season.

This case study shows the variability detected in water quality over a six week period in the 2001/02 summer at Dirranbandi. Water samples were collected from four on-farm storages (labelled S1 to S4) throughout the Dirranbandi district and from two sites along the Balonne River (labelled R1 and R2), one upstream and one downstream of Dirranbandi. The nutrient and salinity levels of these irrigation water samples were analysed.

Salinity

The salinity level of the Balonne River, measured by electrical conductivity (EC), was much lower than the on-farm storages and remained relatively constant (Figure 5.5.1). The lower electrical conductivity for the river may be explained largely by the fact that EC has a significant negative association with flow. This means that a flow in the river results in the dilution of ions in solution, thus decreasing the EC.

Figure 5.5.1. Electrical conductivity of storage and river water



The EC of most storages increased throughout the sampling period. This is due to the concentrating of salts due to drainage, evaporation and the removal of water from the storages for irrigation.

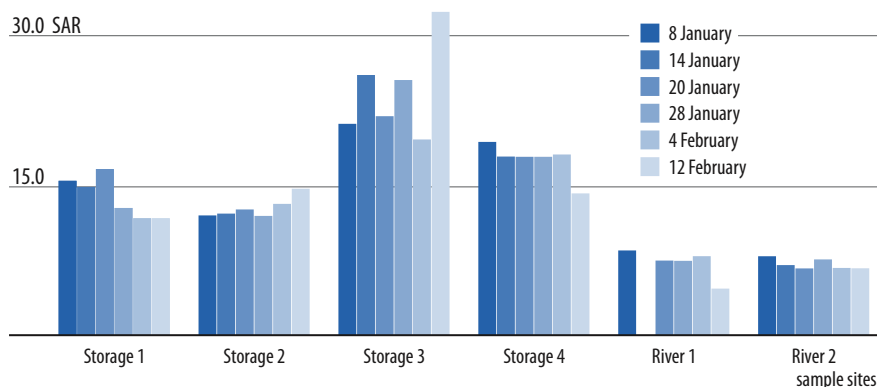
Differences in the storages can be explained using recent soil tests from the farm. The sodium and calcium content of the soil on one farm is almost double that of the other water levels. The majority of the samples (91%) were classed as a very low (<650 $\mu\text{S}/\text{cm}$) salinity hazard for irrigation water according to national water quality guidelines, indicating that the water is suitable for irrigation of sensitive crops and will pose no threat to soil salinity.

The average EC of the water in the Balonne River for both sample sites was 170 $\mu\text{S}/\text{cm}$, which is low relative to studies in other cotton-growing valleys that report ECs between 306 $\mu\text{S}/\text{cm}$ and 1565 $\mu\text{S}/\text{cm}$ in the Liverpool Plains (Wood 1997), 227 $\mu\text{S}/\text{cm}$ and 1626 $\mu\text{S}/\text{cm}$ in the Gywdir (Montgomery 2002), and up to 800 $\mu\text{S}/\text{cm}$ in the Namoi River (DLWC 2001).

Sodicity

The sodium adsorption ratio (SAR) is a measure of the proportion of sodium ions in the soil or water solution relative to other cations (magnesium, calcium and potassium). The SAR of the river water is much lower than the on-farm water storages. The SAR of the storages varied, with 42% of the storages falling in a high sodicity class (8-14) and 58% in a very high sodicity class (>14) (Figure 5.5.2).

Figure 5.5.2. Sodium adsorption ratios of storage and river water

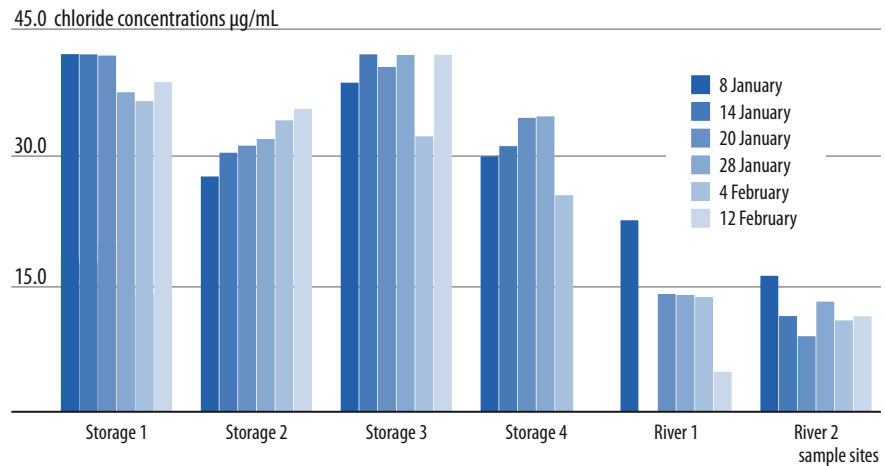


The difference between the SAR of storages is consistent with the soil test results, which explains why S3 had a much higher SAR value. Irrigating with sodic water will affect soil structure, resulting in soil dispersion and reduced water infiltration. WATERpak Topic 5.4 explains management strategies when irrigating with sodic water.

Chloride load

Chloride is essential for plant growth, although high levels of chloride can cause damage to the crop's foliage and increase the uptake of cadmium from the soil, which can be toxic. All samples had concentrations less than 175 µg/mL (Figure 5.5.3), which indicates that the water is suitable for irrigation of chloride-sensitive crops such as cotton. The chloride level in the river was almost half the values recorded throughout the Gwydir Valley by Janelle Montgomery (2002).

Figure 5.5.3. Chloride levels in storage and river water

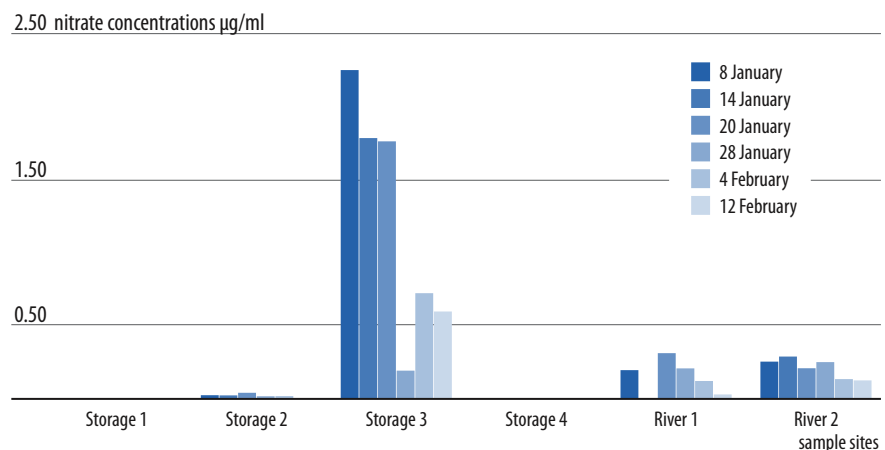


Nitrate load

Nitrate occurs naturally in water and is usually present in river water at concentrations below 1 µg/mL. Levels higher than this are generally related to the use of nitrogen fertiliser, manure, intensive livestock production or urban wastes.

The national guidelines for irrigation water suggest that nitrate levels in irrigation water should be in the range of 25 to 125 µg/mL. During the observation period, nitrate levels were below these levels (Figure 5.5.4). No nitrate was detected in Storage 1 or Storage 4, and only low levels in Storage 2. Storage 3 recorded a much higher nitrate level (2.25 µg/mL), which is a direct consequence of the addition of nitrogen fertiliser to the water prior to sampling.

Figure 5.5.4. Nitrate levels in the storage and river water



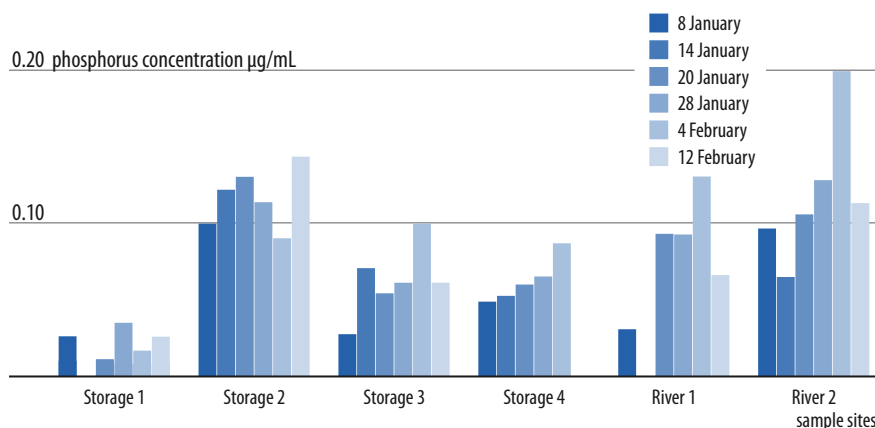
The two river sites recorded maximum nitrate values of approximately 0.3 µg/mL. These levels are similar to those presented from other water quality studies in cotton-growing regions. The majority of samples collected throughout the Gwydir Valley showed nitrate levels between 0 and 1 µg/mL (Montgomery 2002).

Phosphorus

Generally, the concentration of phosphorus in the river water was higher than that in the on-farm storages. This is because phosphorus binds tightly to sediment particles and there are often more sediment particles in river water (Montgomery 2002).

Figure 5.5.5 shows that Storage 1 had the lowest phosphorus concentration, while Storage 2 had the highest concentration. This pattern is consistent with soil test results from these farms. Using a Colwell P soil test, soil P levels of 2 mg/kg were measured on the Storage 1 farm compared to the farms of Storages 2, 3 and 4 which measured 36, 26 and 25 mg P/kg respectively. The levels of phosphorus in the river water increased during the sampling period.

Figure 5.5.5. Phosphorus levels in the storage and river water



High phosphorus levels in water do not generally affect plant growth although, if microbial activity is healthy, they may cause algal growth that may block irrigation equipment (Montgomery 2002). The majority (76%) of the samples from the storages and river exceeded the maximum standard of 0.05 µg/mL for irrigation water that has been set in the ARMCANZ guidelines.

The phosphorus levels in the Balonne River are comparable to other river systems within cotton-growing areas in Northern New South Wales and Queensland. Studies by DLWC have recorded median values of 0.1 µg/mL in the Narrabri Creek at Narrabri and 0.445 µg/mL in the Peel River at the Bective Reserve.

Action for the grower

This project highlighted that every on-farm water storage, even those within close proximity of each other, were different in terms of water quality. Monitoring the salinity of storage and river water using an electrical conductivity meter will give you an indication of the level of salinity in the water and any changes that occur over both the short and the long term.

It is very simple and inexpensive to measure the electrical conductivity of a water sample. It costs about \$100 to buy your own meter to measure salinity levels.

For more information about monitoring the electrical conductivity or nutrient content of your irrigation water, contact your Cotton CRC Industry Development Officer.

References

DLWC 2001, *Water quality in the Namoi Catchment*, NSW Department of Land and Water Conservation, Sydney.

Montgomery J 2002, *Water quality in the Gywdir Valley water courses*, University of New England and the Cotton Co-operative Research Centre, Armidale.

Wood J 1997, *1996/1997 report on nutrients and general water quality monitoring*, NSW Department of Land and Water Conservation, Sydney.



Section 6

Catchment-scale impacts

6.1	Catchment water quality and cotton: northern NSW case study	265
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6.1 Case study, catchment water quality and cotton: northern NSW

Warwick Mawhinney
DIPNR, Tamworth

Key points

- Since monitoring of pesticide residues in surface water began in 1991, the most commonly detected insecticide has been endosulfan.
- Restrictions on endosulfan use, and further emphasis on the cotton industry's integrated pest management system (IPM), best management practice strategies and the introduction of genetically modified and insect tolerant cotton varieties, have resulted in a reduction in the detection of endosulfan residues.
- Atrazine is the most commonly detected herbicide and since 1992 the most commonly detected pesticide in groundwater is atrazine. Atrazine is not used for cotton production and is more commonly used in dryland grain crops.
- Irrigators should monitor the quality of the water that they pump into storages to ensure they are not salinising their own land.
- Some degree of contamination of surface and groundwater will always occur in agricultural areas. Our common aim should be to minimise the impact.

Australia is a dry continent, and we are all aware of the value of good quality water. It protects public health, supports economic production and maintains a healthy river ecosystem. Water quality is largely determined by land use, geology, climate, riparian vegetation and stream flow.

Alteration of the landscape since European settlement has resulted in marked changes in catchment conditions. Since then, land use has had an increasing impact on water quality. Agricultural activities such as land clearing, broadscale cultivation, irrigation and grazing can increase levels of turbidity, salinity, nutrients and pesticides in our waterways.

Water quality within cotton-growing regions of northern NSW is being monitored by DIPNR. These results show the levels of insecticides (in particular endosulfan) are decreasing, while herbicides continue to be detected at numerous sites throughout the region.

A review of water quality in rivers of North-West NSW

The Central and North West Regions Water Quality Program (CNWRWQP) was jointly funded by the then Department of Land and Water Conservation and the water users of the Macintyre, Gwydir, Namoi and Macquarie valleys. The project commenced in the early 1990s and focused on the impacts of agriculture on water quality. Nutrients, salinity, turbidity and up to 34 agricultural chemicals were monitored, at a number of sites, over a ten-year period.

Pesticides

The detection of pesticides (including insecticides, herbicides and defoliants) in surface water is of great concern to water managers and the community as a whole, as the effects of long-term, low dose exposure of humans and the environment to pesticides are largely unknown.

Spray drift, vapour transport and run-off are the main pathways for pesticide transport into river systems (Mawhinney 1998, Raupach et al. 2001). Spray drift and vapour

both contribute low level but almost continuous inputs to the riverine ecosystem during the peak spraying season. Spray drift occurs when pesticide droplets, while still in the air, move away from the target area into neighbouring environs. The likelihood of pesticide drift is influenced by weather conditions, the method of application, equipment used and crop structure. Therefore it is important that these factors be considered before spraying.

Run-off tends to provide occasional high concentrations of pesticide contamination. Pesticides in run-off can be dissolved in the water, bound within sediments or adsorbed onto suspended particles. One way to reduce the amount of pesticides in our river systems is to minimise run-off from agricultural land and associated sheet, rill, gully and stream bank erosion. Research by Rosewell (1988) has shown that the amount of run-off from even a short fallow is increased five times, compared to pasture, while soil erosion is magnified by a factor of

eight to 20 times. Poor soil structure increases run-off and erosion. The pulverising effects of cultivation and the loss of organic matter are the two factors that most disrupt the soil structure in agricultural systems.

The pesticides that were regularly detected through the CNWRWQP in the Namoi, Gwydir and Macintyre valleys, and the number of detections in each sampling year, are given in Table 6.1.1. The number of samples includes all sampling sites across each valley, not just those located in the main cotton-growing areas.

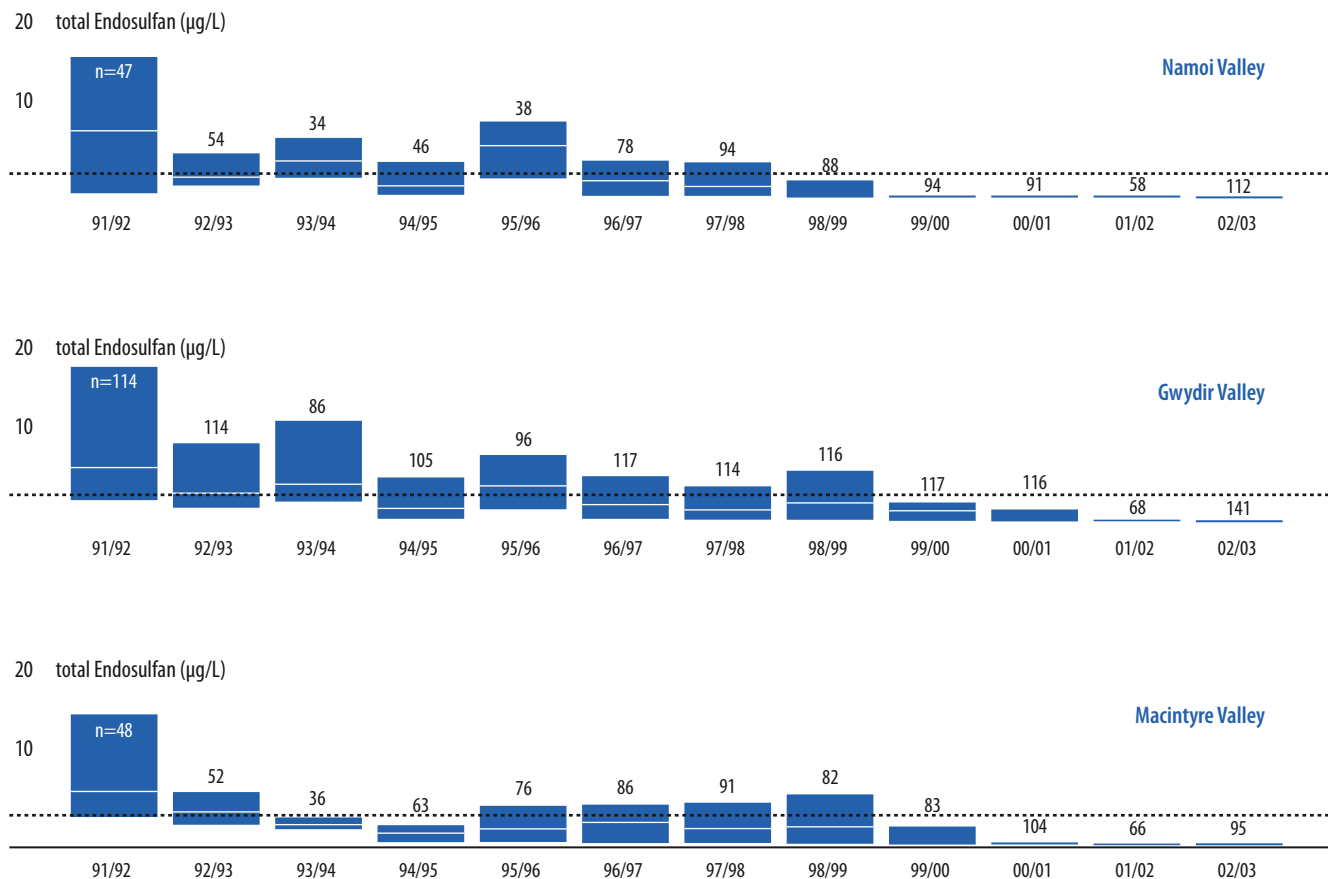
Table 6.1.1: Number and percentage of detections of common pesticides for all samples collected across all sites in the Namoi, Gwydir and Macintyre valleys from 1991/92 through to 2002/03

	Endosulfan	Atrazine	Diuron	Fluometuron	Metolachlor	Prometryn	Simazine	No. samples
1991/92	174 (59%)	136 (46%)	60 (20%)	16 (5.4%)	0	41 (14%)	ns	296
1992/93	194 (65%)	113 (38%)	28 (9.4%)	17 (5.7%)	0	32 (11%)	ns	299
1993/94	137 (65%)	71 (34%)	28 (13%)	19 (9.0%)	14 (6.7%)	15 (7.1%)	ns	210
1994/95	135 (48%)	106 (38%)	27 (9.6%)	10 (3.6%)	2 (0.7%)	12 (4.3%)	ns	281
1995/96	169 (58%)	178 (61%)	14 (4.8%)	2 (0.7%)	25 (8.6%)	23 (7.9%)	0	291
1996/97	207 (52%)	138 (35%)	24 (6.0%)	32 (8.1%)	21 (5.3%)	39 (9.9%)	0	395
1997/98	196 (49%)	86 (21%)	40 (10%)	70 (17%)	37 (9.2%)	48 (12%)	3 (0.7%)	404
1998/99	182 (46%)	131 (33%)	79 (20%)	73 (18%)	53 (13%)	31 (7.8%)	8 (2%)	400
1999/00	126 (31%)	177 (43%)	75 (18%)	66 (16%)	58 (14%)	35 (8.5%)	2 (0.5%)	413
2000/01	76 (17%)	184 (42%)	57 (13%)	86 (20%)	59 (14%)	25 (5.7%)	18 (4.1%)	438
2001/02	14 (4.8%)	81 (28%)	28 (9.7%)	21 (7.2%)	15 (5.2%)	17 (5.9%)	18 (6.2%)	290
2002/03	4 (1.1%)	69 (20%)	27 (7.8%)	18 (5.2%)	9 (2.3%)	10 (2.9%)	3 (0.8%)	348

ns = not sampled



Figure 6.1.1. Box plots of total endosulfan results by river basin from 1991/92 to 2001/02



The broken line represents the Australian and New Zealand water quality guideline trigger value (ANZECC and ARMCANZ 2000) for 99% ecosystem protection (0.03 µg/L). Each box represents the middle 50% of the data collected for each year. The middle line in each box represents the median (or 50th percentile) value, which is the most useful when assessing water quality data.

The most commonly detected insecticide in north-west NSW from 1991 to 2002 was endosulfan. From 1991 to 1999, about 50% of samples contained residues of endosulfan (Table 6.1.1). Endosulfan concentrations in the Namoi, Gwydir and Macintyre valleys from 1991 to 2002 are given in Figure 6.1.2. A similar contamination pattern is visible in all three valleys. The highest level of contamination by endosulfan occurred in the 1991/1992 growing season. This coincides with the rapid expansion

of the cotton industry and a relatively low awareness of best practice methods compared to today's standards. Levels dropped in 1994 and 1995 in response to the drought, as the area sown to cotton was greatly reduced, so that the amount of endosulfan applied was significantly less than previous years. In 1998/1999 endosulfan residues were detected in cattle. The result was the introduction of greater restrictions on endosulfan use, and further emphasis on the cotton industry's best management

strategy. Figure 6.1.1 shows how these two factors resulted in a dramatic reduction in endosulfan in the three valleys during 2000/2001 and 2001/2002. For the first time in ten years endosulfan residues were not detected in the Namoi River during the 2001/2002 spray season. The endosulfan monitoring results are also compared to the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC and ARMCANZ 2000) trigger value for 99% ecosystem protection (0.03 µg/L) as shown by the dashed

line in Figure 6.1.1. The 99% ecosystem protection level means that 99% of species are expected to be protected if the concentration remains below the trigger value. Only in recent years have endosulfan concentrations fallen below the guideline level across all three valleys.

Other insecticides detected through the CNWRWQP were chlorpyrifos, profenofos, dimethoate, propargite and parathion. The detection of these insecticides was more sporadic than that of endosulfan, due to different chemical properties and generally lower usage rates. However Muschal and Warne (in press) have demonstrated that occasional high concentrations of chlorpyrifos and profenofos can have a deleterious impact on the aquatic environment.

The broken line represents the Australian and New Zealand water quality guideline trigger value (ANZECC and ARMCANZ 2000) for 99% ecosystem protection ($0.03 \mu\text{g/L}$). Each box represents the middle 50% of the data collected for each year. The middle line in each box represents the median (or 50th percentile) value, which is the most useful when assessing water quality data.

The most commonly detected herbicide through the CNWRWQP was atrazine (this includes the active ingredient and the two major breakdown products hydroxy-atrazine and desethyl-atrazine). From 1991 to 1999, as many as 61% of samples contained atrazine or one of its breakdown products. Table 6.1.1 shows that, in most cases, the percentage of samples containing pesticide residues

dropped in 2001/2002. Other herbicides detected were diuron, fluometuron, metolachlor, prometryn and simazine. Metolachlor was most commonly detected in the Namoi Valley, while diuron, fluometuron and prometryn were more commonly detected in the Gwydir Valley. Little is known regarding the long-term impacts of herbicides on river ecosystems.

Salinity

Most landholders are well acquainted with the term salinity. Salinity is the presence of dissolved salts in soil and water and is a problem common to many parts of Australia. It may be caused by the presence of salt in underlying soil or bedrock, salt deposited due to past marine inundation of an area, or salt carried over the land surface from the ocean. Changes in land use can make this salinity problem worse. The replacement of native trees and grasses with annual crops and pastures, overgrazing and long fallows has increased the amount of water entering the watertable. During times of low rainfall, as the watertable falls, salts are concentrated in the soil. These salts can then be flushed into streams by run-off. Some streams may also be fed directly by saline groundwater. The most saline creeks and rivers in north-west NSW are located in the mid to upper parts of the catchment. Prolonged irrigation with saline water can exacerbate soil salinisation by providing salts in addition to those already present in the soil profile. Irrigators should monitor the quality of the water that they pump into storages to ensure they are not salinising their own land.

The most common measurement of salinity is electrical conductivity (EC), measured in microsiemens per centimetre ($\mu\text{S/cm}$). Electricity is conducted more easily (and therefore EC rises) as the concentration of dissolved salt increases. Figure 6.1.2 shows the median electrical conductivity at three sites, Namoi River at Bugilbone, Mehi River at Bronte and Barwon River at Mungindi, which are all located at the lower end of the major cotton-growing areas in each valley. In most years the Namoi Valley had the highest median electrical conductivity readings, while the Barwon River at Mungindi was consistently lower. The fluctuations from year to year are largely due to changes in flows due to rainfall, run-off and releases from storages.

The Australian and New Zealand water quality guidelines (ANZECC and ARMCANZ 2000) classify water with an electrical conductivity of less than $650 \mu\text{S/cm}$ as a very low salinity rating and being suitable for irrigating sensitive crops. These guidelines also provide trigger values, which are alert levels above which action should be taken to assess if there is potential impact on aquatic ecosystems. The generic trigger value for electrical conductivity in western NSW lowland rivers is $300 \mu\text{S/cm}$.

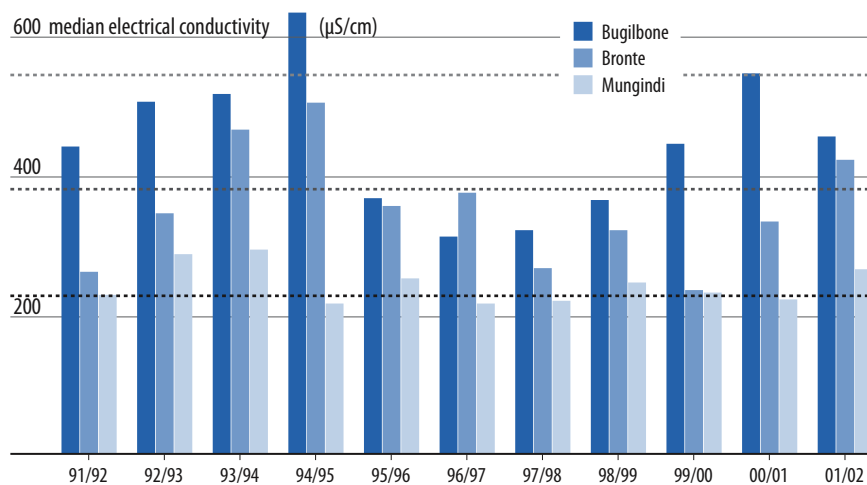
In addition to this trigger value, the Catchment Management Board Blueprints have set specific end-of-system salinity targets for the Namoi ($550 \mu\text{S/cm}$), Gwydir ($390 \mu\text{S/cm}$) and Border Rivers ($230 \mu\text{S/cm}$) catchments. The blueprints specify that these targets for each valley should not be exceeded more than 50% of the time. Since 1991, the Namoi River at Bugilbone



reached or exceeded the valley target four times and the Barwon River almost always reached or exceeded its target over the ten-year sampling period (Figure 6.1.2). Increased end-of-system salinity levels appear to be linked with low flows, as concentrations rose during the drought period of 1992 to 1995 and again in 2000 to 2002.

Figure 6.1.2. Median electrical conductivity ($\mu\text{S}/\text{cm}$) for three sites (Namoi River at Bugilbone, Mehi River at Bronte and Barwon River at Mungindi) located downstream of major cotton-growing areas and other land uses in each valley from 1991/92 through to 2001/02

Lines indicate Catchment Management Board salinity targets for the Namoi (---), Gwydir (----) and Border Rivers (----).



Nutrients

Sources of nutrient contamination include sewage treatment works, farm effluent, run-off from agricultural land, septic tanks, industrial effluent and urban storm water run-off. Phosphorus and nitrogen are the main nutrients of concern. Similar to pesticides, phosphorus and nitrogen can be dissolved in water, bound within sediments or adsorbed onto suspended particulate matter (for example, soil or organic matter). In north-west NSW, run-off from agricultural land is the main source of nutrients, with the movement of nutrients attached to suspended material the main transport mechanism.

High concentrations of nutrients are important factors in the formation of blue-green algal blooms. Nutrient levels do not actually trigger an algal bloom, but determine how large the bloom becomes. Other factors such as water temperature, turbidity and water turbulence are also important.

Blue-green algae can contain toxins which may cause severe dermatitis and conjunctivitis in people coming into contact with the algae through swimming or showering, and may cause stomach cramps, nausea, fever and headaches if consumed. Blue-green algae can also produce toxins that attack the liver and other internal organs and can act as neuromuscular blocking agents, leading to respiratory arrest (Chorus and Bartram 1999). Stock deaths in north-west NSW have been attributed to water contaminated by toxic blue-green algae.

The phosphorus and nitrogen levels in the Namoi, Gwydir and Macintyre valleys are not limiting to algal growth. This means there are ample nutrients available in the water for the formation of algal blooms when conditions are favourable. Every year we see algal blooms in the large storages in the region, usually over summer, and blooms in the Barwon-Darling have been well documented.

Off-farm impacts

Bowmer et al. (1995) and Napier et al. (1998) reviewed NSW and Queensland fish kill registers and media reports between the mid 1970s and 1995. Bowmer et al. (1995) concluded that *'despite all the difficulties in assessing the evidence, it is still clear that cotton pesticides are causing the majority of those fish kills that have been reported, and that endosulfan is the pesticide most often implicated'*. Napier et al. (1998) concurred with this conclusion. An assessment of risk posed by pesticides to aquatic

biota in rivers by Muschal and Warne (in press) determined that atrazine, diuron, fluometuron, metolachlor and prometryn posed either a low or moderate hazard to aquatic organisms. Their results also indicated that chlorpyrifos, endosulfan and profenofos posed a genuine risk to aquatic biota from acute exposures (brief exposure at high concentrations), and endosulfan also posed a risk from chronic exposures (continued exposure over a long period).

As endosulfan concentrations in the rivers have fallen in recent years, so too have the number of reported fish kills. Agricultural chemicals are not the only cause of fish kills: they can also be caused by the dramatic decline in water quality due to the 'first flush' effect. Many floods commence with an event characterised by high levels of sediment and nutrients at the very beginning of water levels starting to rise. This is often due to the sudden disturbance of the stream bed, and the purging of nutrients and poorly oxygenated water from standing pools. It is the toxic effect of these high concentrations of pollutants and low dissolved oxygen that appears to be the cause of recent fish kills, rather than chemical contamination. An example occurred in the Barwon River at Banarway Crossing in December 2002. In this instance a 'fresh' in the Moonie River flushed turbid, nutrient-rich and oxygen-depleted water into the Barwon River, resulting in more than a thousand dead fish.

Groundwater quality

Long fallowing, low water-use cropping and clearing of native vegetation have contributed to shallow, saline watertables, by increasing deep drainage of water through the soil profile. Shallow saline groundwaters can contribute to soil salinisation and can also leak downwards, contaminating deeper aquifers used for irrigation. This process is likely where excessive extraction causes long-term drawdown of groundwater levels. Consequently, groundwater quality and quantity issues are closely related, with hydraulic linkages meaning that maintaining good quality groundwater involves total groundwater management (Timms 1998).

Pesticides have been detected in groundwater in many different locations (Jiwan and Gates 1994a, 1994b, 1995; Timms 1997), with detections having a patchy and localised distribution. Since 1992 the most commonly detected chemical has been atrazine. Heavy black clays and proximity to cropping appears to be the major determinant for groundwater contamination by pesticides (Timms 1997). Observations in the field suggest that groundwater contamination by atrazine generally occurs in close proximity to sorghum crops. Atrazine has high water solubility, suggesting the predominance of diffuse contamination pathways through the soil profile. Isolated cases of low level contamination by diuron, fluometuron, metolachlor, simazine and trifluralin have also been found.



In addition, the contamination of bores by residues from abandoned chemical drums has been highlighted as a point source for chemical contamination. Chemicals with low water solubility and low mobility (for example, trifluralin) have been detected in such bores. Chemicals can leak directly into aquifers via backflow down the bore if drums are abandoned near poorly constructed bore heads, or during mixing and rinsing. The absence or poor maintenance of cement-lined mixing bays next to bores means that excess mixing waters drain into depressions close to or around the bore head and percolate directly to groundwater. This problem of point-source contamination is easily prevented with better farm management practices.

Once a pollutant enters an aquifer, depending on local groundwater conditions, it may either degrade, absorb onto aquifer materials or be transported laterally with groundwater flow. Unfortunately it is difficult to determine which mechanism is predominantly responsible for decreasing pesticide concentrations over time. Once an aquifer is contaminated either by chemicals or salinity, remediation of the aquifer is very difficult and very expensive. Prevention of aquifer contamination is strongly recommended.

Options to reduce the transport of pollutants off-farm

Improved surface and groundwater quality is possible, and the options to achieve it are not new. Most of the surface water quality problems are related to run-off. This is where improvements to land management and farming practices in a catchment area will achieve the best results. If run-off can be reduced, filtered by vegetation or stored on-farm, and then used before it can leak through the soil profile into shallow groundwater, many of the water quality problems could be solved.

The issue of groundwater contamination is complicated, mainly due to the lack of knowledge on agricultural chemical pathways through the soil profile. However, identified point sources of pollution, such as chemicals backflowing down bores and the over-extraction of deeper aquifers, can be addressed.

It must be remembered that some degree of contamination of surface and groundwater will always occur in agricultural areas. Our aim should be to minimise the impact. Management options that will achieve this goal include:

Adoption of best land, soil and vegetation management practices:

- maintaining at least 70% ground cover to reduce run-off and erosion;
- management of run-off through tailwater retention and prevention of tailwater releases (for example, 'blow outs');
- good soil management to improve organic matter content and soil structure; and

- good agronomic practices (for example, spray at optimum time, use certified seed).

Riparian vegetation management:

- exclude livestock from vegetated buffer strips along all creeks, rivers and major drainage lines (except for 'crash grazing', that is, a short period of intense grazing to keep rank growth in check, but not long enough for the animals to cause any damage along the riverside)
- install constructed watering points in stable areas to minimise streambank erosion and nutrient inputs by livestock
- maintain vegetated buffer strips down slopes of cropped paddocks and vegetated waterways to intercept and filter run-off water and minimise spray drift
- on-going maintenance of bore heads to prevent groundwater contamination by pesticides
- use of best management practices for chemical application to minimise the transport of chemical off-farm.

Water quality guidelines

For more information on National Water Quality Guidelines, see the following internet sites.

Guidelines for fresh and marine water quality www.erin.gov.au/water/quality/nwqms

Australian Drinking water guidelines www.health.gov.au/nhmrc/publications

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6.2 Case study, water quality in the Gwydir Valley watercourses

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Introduction

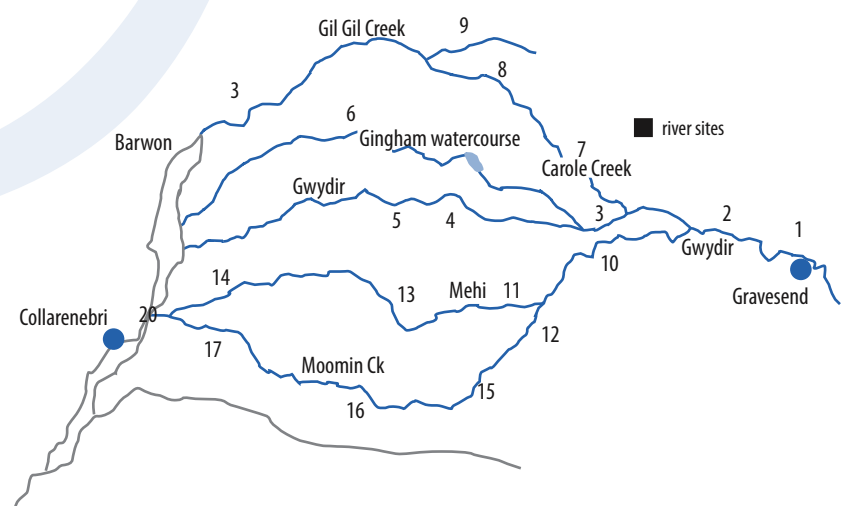
Irrigators are frequently accused of causing a deterioration of water quality in the Murray Darling Basin. For many catchments, such as the Gwydir in north-west NSW, little reliable information is available to assess the impact of irrigation on water quality.

The aim of this research is to measure the water quality (in terms of sediment, salts and nutrients) of the Gwydir Valley watercourses. By monitoring water quality above, within and below the irrigation area, any changes in water quality within the irrigation area can be examined to determine the impact of irrigation. Water quality data were also combined with river flow data to determine the quantity (load) of sediments, salts and nutrients that may leave the Gwydir Valley and enter the Murray Darling Basin.

Methods: Location

The Gwydir Valley River Catchment is located in north-west NSW. The Gwydir Catchment covers an area of approximately 26500 km² and is a part of the Murray-Darling Basin. Water from the Gwydir River supports a major irrigation industry, with 86,000 hectares licensed for irrigation. Water from Copeton Dam is delivered to irrigators whose farms are located along the Gwydir, Carole, Mehi and Moomin watercourses.

Figure 6.2.1. Location of water sampling sites (sampling Site 10 is Moree)



Sampling commenced in October 1998 and continued until July 2001. Water samples were collected weekly over summer, fortnightly during March, April, October and November, and monthly during the remainder of the year.

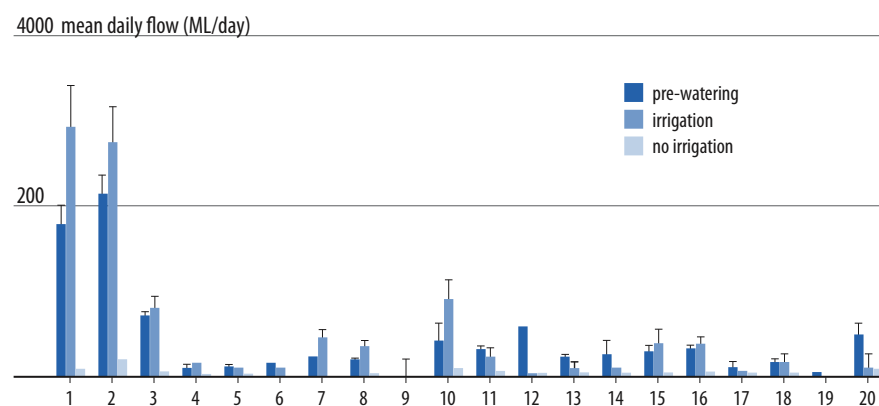
Results and discussion

Flow

Figure 6.2.2 shows the median daily flow at each sampling site, during each flow phase. The error bars represent the standard error of the median. Site 1 (Gravesend), Site 2 (Pallamallawa), Site 3 (Yarraman) and Site 10 (Moree) have a significantly higher flow compared to other sites within the valley. Site 1, located upstream of the irrigation area, has a median daily flow of 2950 ML/day during the irrigation phase, compared with Site 18 and Site 20, located downstream of irrigation area, which have median daily flows of 168 ML/day and 90 ML/day respectively. This difference in flow between the upstream and downstream sites is because the Gwydir has not yet split into the Mehi and Carole anabranches at the upstream sites. The flows decrease through the valley as the Gwydir splits into these anabranches and with the extraction of water for irrigation and stock and domestic supplies, along with evaporation and seepage losses. Furthermore, environmental flows from natural rainfall upstream or releases from Copeton Dam are accounted for in the flows at Site 1 and Site 2, but have no impact on flows at Site 18 and Site 20, as this water is directed straight down the Gwydir and Gingham watercourses (see Figure 6.2.1).

Flow during the pre-watering and irrigation phases are significantly higher than the no-irrigation phase with the release of water from Copeton Dam for irrigation purposes along with the increased likelihood of summer storms.

Figure 6.2.2. Median mean daily flow for each river site, during each flow phase (No 10 = Moree)



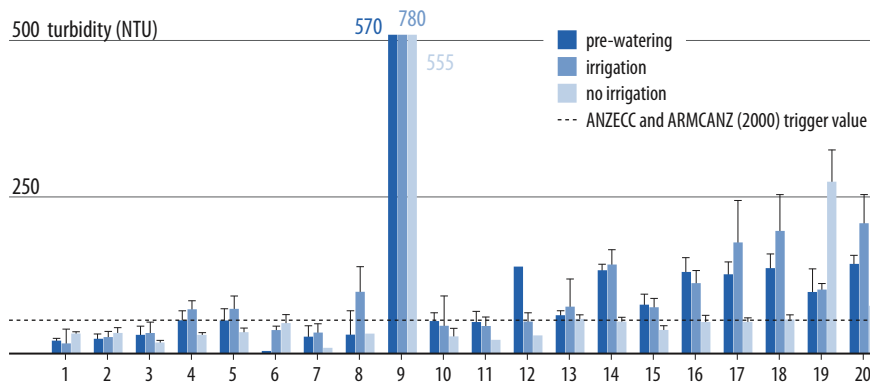
Turbidity

Median turbidity of all sampling sites within each flow phase is presented in Figure 6.2.3. All sites located downstream of Site 10 (Moree) exceed the ANZECC & ARMCANZ (2000) water quality guidelines for protection of aquatic ecosystems (50 NTU) and irrigation water (100 NTU). Median turbidity increases along the valley, with the highest median values at sites located at the bottom of the valley, Site 17 (Iffley), Site 18 (Galloway) and Site 20 (Collarenebri). This is a reflection of the cumulative effects of land use, streambank erosion and resuspension of sediments through the valley.

The turbidity of water at Site 9 is significantly higher than all other sites within all flow phases. This site is before any irrigation and is unregulated, and so only flows after run-off in the local catchment. Run-off, which causes soil erosion and therefore the transportation of particulate matter into the waterways, is a major contributor to turbidity.

High turbidity at sites lower in the valley reflect not only farming practices carried out on irrigated lands, which account for less than 4 per cent of the Gwydir Valley (North West Catchment Management Committee, 1997), but also land use practices associated with dryland farming (26 per cent), grazing (58 per cent of the Gwydir), timber (12 per cent) and other land use activities (<1 per cent) along the valley.

Figure 6.2.3. Median turbidity for each river site

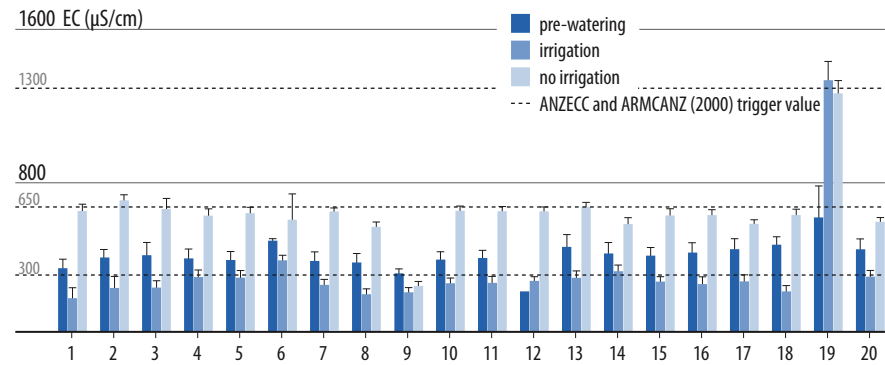


Irrigators are required to contain all water (run-off and tailwater) on-farm. Farms are designed to collect any water that runs off the fields and this water is stored in on-farm storages, which can be recirculated and used as irrigation water at a later date. Therefore, in theory, there should be no water coming off irrigation farms, and thus no input of sediments, salts and nutrients. However, during severe flood events, when farmers exhaust all water-holding infrastructure, or during a collapse of irrigation infrastructure (channels, banks or storages), some water could be released off-farm and make its way into the river system. It should be noted that, during such a flood event, the water spreads over the vast flood plains, making it impossible to determine the source of the sediments, salts and nutrients.

Salts

Median electrical conductivity (EC) mostly exceeded the ANZECC & ARMCANZ (2000) water quality guidelines for protection of aquatic ecosystems ($>300 \mu\text{S}/\text{cm}$), especially during the no-irrigation phase (Figure 6.2.4). EC has a significant negative correlation with flow (Nancarrow 1998), where an increase in flow causes a dilution of ions in solution, resulting in a decreased EC. Therefore, EC is significantly lower during the pre-watering and irrigation phase when flows are significantly higher. Most of the flow during January and February (irrigation phase) comes from releases of water from Copeton Dam. Gordon (2001) found Copeton Dam water to have a low EC and releases from Copeton to have a major influence on EC in the Gwydir river system throughout the year 1999/2000.

Figure 6.2.4. Median electrical conductivity



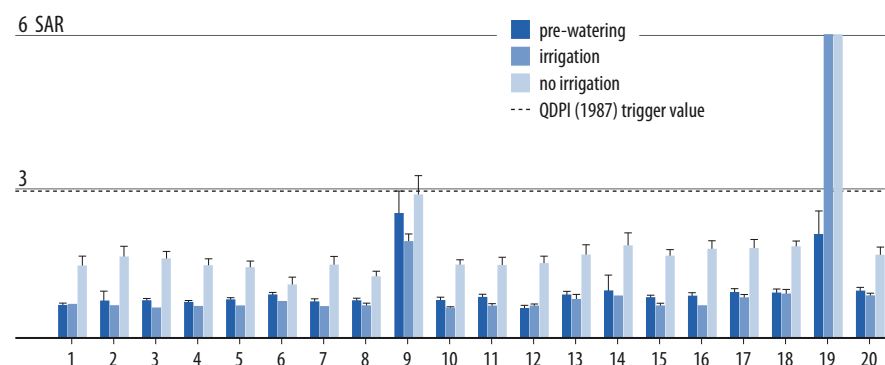
Median EC for all sites except Site 19 were classed with either a low (650–1300 $\mu\text{S/cm}$) or very low (<650 $\mu\text{S/cm}$) salinity rating for irrigation water. The EC at Site 19 is significantly higher than all other sites. This site is located at the end of the Gwydir River, where water only reaches during flood events, thus only flowing during flood events or local, run-off-producing rainfall events. It is a stagnant pond of water for most parts of the year where salts and nutrients accumulate and become concentrated due to the lack of fresh water flows, resulting in a high EC.

It can be seen that there is no significant increase in salinity moving downstream, indicating that irrigation is not influencing salinity in the rivers. Also, the release of irrigation water from Copeton Dam improves the salinity situation in the river due to the dilution effect causing a decrease in EC.

The median SAR for all sites within each flow phase are presented in Figure 6.2.5. The median SAR for all sites except Site 19 fall within a non-sodic classification (<3).

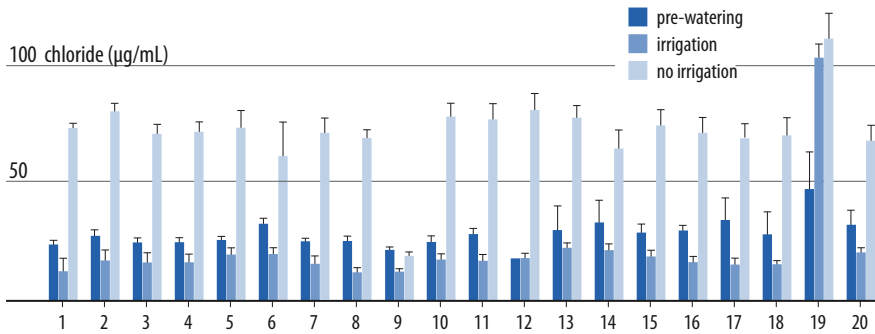
There is no significant difference between electrical conductivity (EC) and the sodium adsorption ratio (SAR) between the upstream (Site 1 and Site 2) and downstream sites (Site 18 and Site 20) within any of the flow phases.

Figure 6.2.5. Median SAR



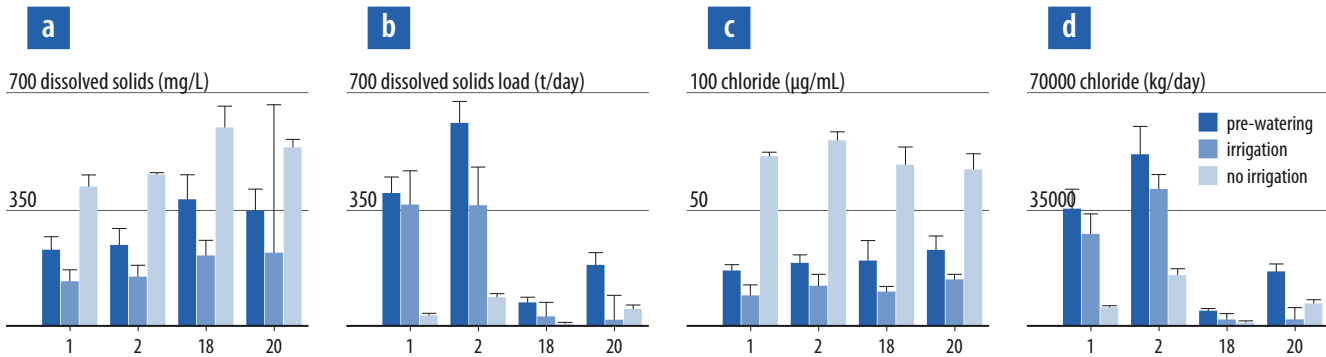
Chloride levels at all sites fall below the level of chloride affecting sensitive crops (<175 mg/ml) as shown in Figure 6.2.6. Chloride levels are significantly higher during the no-irrigation phase, as a result of the low flows during this phase.

Figure 6.2.6. Median chloride concentration for each river site, during each flow phase



Total dissolved solids (TDS) concentration is used as an estimate of salt concentration and consequently salt loads. Although there is no significant difference in salt concentration between the upstream and downstream sites, salt loads are significantly higher upstream as shown in Figures 6.2.7a and 6.2.7b. The median load of TDS during the irrigation phase for Site 1 was 353 tonnes/day, whereas a median of only 35 tonnes/day flowed past Site 18, and 23 tonnes/day flowed past Site 20 in the same year. Again, although there is no significant difference in chloride concentration between the upstream and downstream sites, the loads of chloride (kg/day) are significantly higher upstream as shown in Figures 6.2.7c and 6.2.7d. The load of chloride in the water decreases, with reduced flows downstream in the Gwydir Valley. The median load of chloride during the irrigation phase for Site 1 was 27 tonnes chloride/day, whereas less than 2.5 tonnes flowed past both Site 18 and Site 20 in the same year.

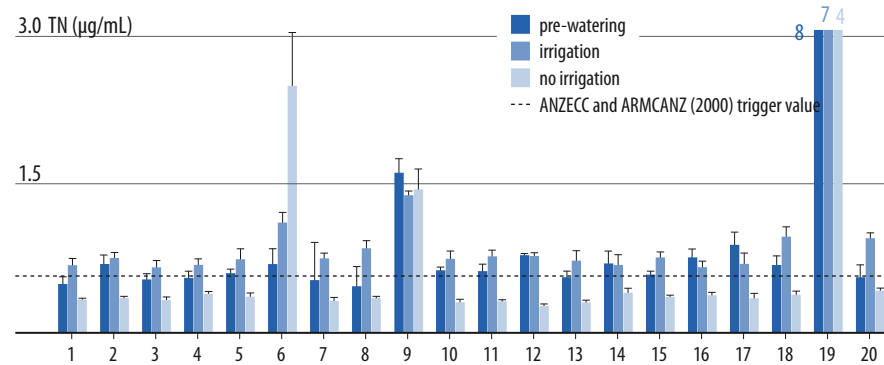
Figure 6.2.7. Salt parameters, upstream (Site 1, Site 2) and downstream (Site 18, Site 20) of the irrigation area: a) total dissolved solids concentration, b) total dissolved solids load, c) chloride concentration, d) chloride load



Nutrients

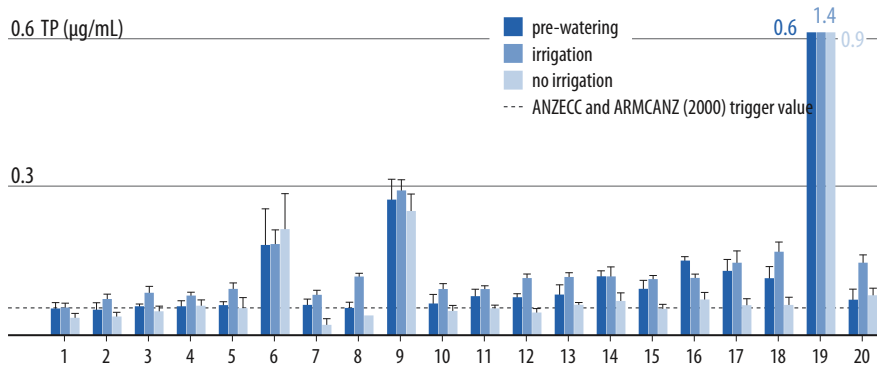
Figure 6.2.8 shows that the Gwydir River and its anabranches are relatively high in nitrogen. Median total nitrogen (TN) level exceeds the ANZECC & ARMCANZ (2000) guidelines for protection of aquatic ecosystems ($0.6 \mu\text{g/mL}$) at all sites within pre-watering and irrigation flow phases. These flow phases coincide with the time when nitrogenous fertilisers are used within the valley, along with the time when storm events are more likely, resulting in run-off and the possible transport of nitrogen into the river system. TN concentration at Site 6, Site 9 and Site 19 were significantly higher than other sites. Livestock grazing is common around each of these sampling sites, which may contribute to higher TN concentration. All sites except Site 19 meet the ANZECC & ARMCANZ (2000) guidelines for irrigation water ($<5 \mu\text{g/mL}$).

Figure 6.2.8. Median total nitrogen



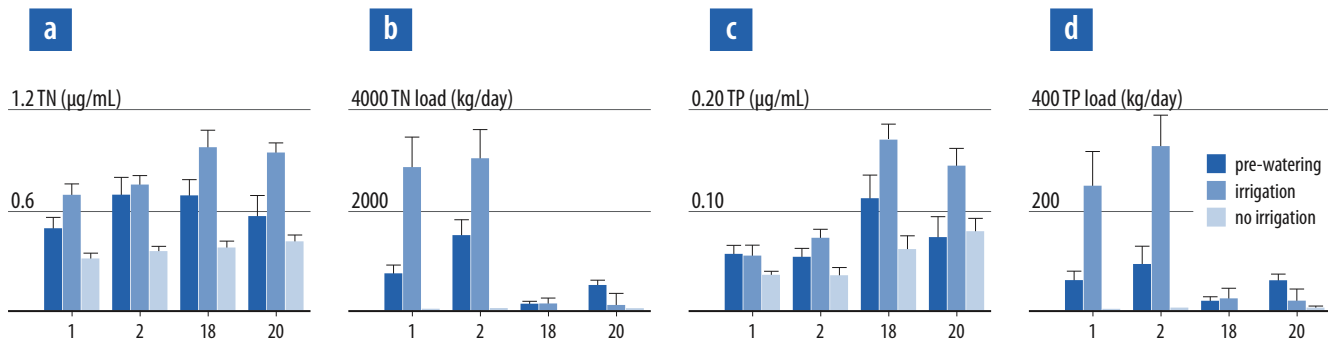
Median total phosphorus (TP) at all sites exceeds the ANZECC & ARMCANZ guidelines for protection of aquatic ecosystems and irrigation waters ($0.05 \mu\text{g/mL}$), as shown in Figure 6.2.9. Median TP is significantly higher during the pre-watering and irrigation phase for all sites except Site 6, Site 9 and Site 19. As phosphorus has a low solubility, it is rarely dissolved in run-off water, but is carried by suspended silt and clay particles (Mawhinney 1998). Site 9 and Site 19 only flow during flood or local rainfall events that produce run-off, therefore phosphorus would be carried into the river system bound to suspended sediment carried in the run-off water. Site 6 is located in the Gingham watercourse; grazing livestock that cause erosion to streambanks may be one factor causing higher TP levels at this site.

Figure 6.2.9. Median total phosphorus



The concentration of TN and TP is higher at the downstream sites. In contrast, the loads are significantly lower at the downstream sites compared to the upstream sites as shown in Figure 6.2.10. The difference in loads is a direct effect of different flows between the sites.

Figure 6.2.10. Salt parameters, upstream (Site 1, Site 2) and downstream (Site 18, Site 20) of the irrigation area: a) total nitrogen concentration, b) total nitrogen load, c) total phosphorus concentration, d) total phosphorus load.



The median load of TN during the irrigation phase for Site 1 was 2790 kg N/day, whereas a median of only 133 kg N/day flowed past Site 18 and 103 kg N/day flowed past Site 20 in the same year. This is similar to TP where the median daily load of TP was significantly greater at Site 1 with 249 kg P/day flowing past this site, compared with only 23 kg P/day flowing past Site 18 and 18 kg P/day flowing past Site 20 in the same year.

Conclusions

As irrigators are required to retain tailwater and run-off water on-farm, there should be little input of sediment, salts and nutrient from the irrigation industry. During flood events, some water could be released off-farm and make its way into the river system, but as irrigated land amounts to less than 4 per cent of the Gwydir Valley, the amount of water coming off these farms would be a very small proportion of total run-off in a major flood event. It should be noted that, during a flood event, as the water spreads over the vast flood plains, it is impossible to determine the source of the sediments, salts and nutrients.

All sites below Moree exceed the water quality guidelines for turbidity. Turbidity increases along the valley as a reflection of the cumulative effects of land use, streambank erosion and re-suspension of sediments along the valley. River water falls within a low (650 $\mu\text{S}/\text{cm}$ –1300 $\mu\text{S}/\text{cm}$) to very low (<650 $\mu\text{S}/\text{cm}$) salinity class for irrigation water. Although it meets the ANZECC & ARMCANZ (2000) water quality guidelines for irrigation water, it does exceed the guidelines for protection of aquatic ecosystems, although this is largely during the no-irrigation phase.

The median level of total nitrogen and total phosphorus in the river water within the Lower Gwydir Valley exceeds the ANZECC & ARMCANZ (2000) water quality guidelines for protection of aquatic ecosystems. The strategy of recirculating water and containing tailwater and run-off on-farm appears to be preventing higher

loads of nutrients, particularly nitrogen, from entering the river system. However, in times of exceptional flooding and inundation some contamination will occur. It is not possible to say that the elevated levels of nutrients in the rivers are a result of irrigation.

Irrigation water sent from Copeton Dam during the pre-watering and irrigation phase has two effects. Firstly, the increased flow rate dilutes the ions in solution, resulting in a lower EC and lower concentrations of nutrients in the irrigation water. Therefore, with regards to the water quality guidelines, the water quality at all sites improves in terms of salinity and nutrients. The second effect of increasing flows is the resulting increase in actual volume of salts and nutrients (that is, load). However, this quantity diminishes down the valley, resulting in much smaller quantities of salt and nutrients leaving the Gwydir Valley and entering the Murray-Darling Basin.

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6.3 Water quality in Queensland catchments and the cotton industry

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Key points

- In the Condamine Balonne Catchment, cotton contributes less than 5% of total nitrogen and phosphorus found in water.
- Total phosphorus levels in the Border Rivers catchment is generally low although it has been increasing over time in some tributaries.
- Total nitrogen levels have been generally below those likely to aid in algal bloom development. In the Condamine Balonne the levels increase with distance downstream from the headwaters – these have been attributed to the high nitrogen content of soils and run-off from upstream land use.
- Studies on cotton farms have shown that total phosphorus and total nitrogen levels increase in tailwater from irrigations.
- Cotton herbicides prometryn and metolachlor increased in detection frequency between 1993 and 2001.
- Atrazine (predominantly used on sorghum) was found in 80-90% of samples over 8 years.

- Since 1999 endosulfan has not been found in water samples in the QMDB.
- Storms and sediment are the two main factors affecting the movement of pesticides and nutrients off-site.
- Mean sediment concentration leaving cotton tail drains ranges from 3 to 9 g/L in storm and irrigation run-off.
- Typical annual soil loss leaving cotton tail drains ranges from 6 to 22 t/ha.
- Median EC values measured at all sites in the QMDB were below 700 $\mu\text{S}/\text{cm}$.
- The high-risk period for off farm movement of pollutants is pre- and post-plant when groundcover levels are below 30%.
- There are a number of practical management options available to farmers now that can dramatically reduce off farm movement of pollutants – for example, planting into stubble and the use of vegetative filters.

Introduction

The quality of surface and groundwater in the Queensland Murray-Darling Basin (QMDB) has significant social, economic and environmental implications for use. This includes its use as a water supply for human consumption, industry and irrigation, and as an ecosystem.

A healthy riverine system is defined as one having the ability to support and maintain a balanced, integrated adaptive community of organisms, and having a species composition diversity and functional organisation which is comparable to that of an undisturbed natural habitat of the region (ANZECC 1992). Catchments require a healthy water system to support human communities, agricultural production and the environment.

The cotton industry, like many industries, impacts on river health through off-site movement of soil, nutrients, insecticides and herbicides into waterways. The impacts of nutrient and pesticide contamination on the aquatic environment and human health have been well documented (Wardrop 1986, Sullivan et al. 1991, AIMS 2002, Chapman 1998). This has increased the level of scrutiny placed on the cotton industry to minimise off-site movement of these pollutants.

Pesticides

In 1999-2000 sampling, 29 sites across the region of NSW and Queensland were monitored for 34 agricultural chemicals. Endosulfan, atrazine, diuron, fluometuron, metolachlor and prometryn were detected. Atrazine was the most frequently detected herbicide, with the second most frequently detected chemical being endosulfan.

The CBWC pesticide-monitoring program was conducted at the following town weirs - Millmerran, Cecil Plains, Dalby, Chinchilla, Surat, St George and Dirranbandi in the Condamine Balonne River system. This work was continued in the later years through funding provided by the chemical company Syngenta. Cotton is grown upstream of all sampling locations and would therefore have the potential to contribute to contamination of the water bodies sampled.

Water samples were analysed for 52 pesticides. These chemicals included the alpha and beta isomers of endosulfan, as well as endosulfan sulfate and the breakdown products of atrazine - desethyl atrazine and hydroxy atrazine. Eight chemicals were detected in all five weirs: metolachlor, dieldrin, simazine, atrazine, atrazine desethyl, atrazine desisopropyl, prometryn. A byproduct of DDT (p,p-DDE) was detected on one occasion.

General findings from the study were:

- Metolachlor and atrazine were found in all weirs sampled.
- Metolachlor was found in 60% to 90% of all samples.
- Atrazine was found in 80% to 90% of samples in Dalby, Chinchilla and Surat weirs.

A summary of data from 1993 to 1998 for the two sites with continuous data for the period, Loudoun and Chinchilla Weirs, is given in Table 6.3.1.

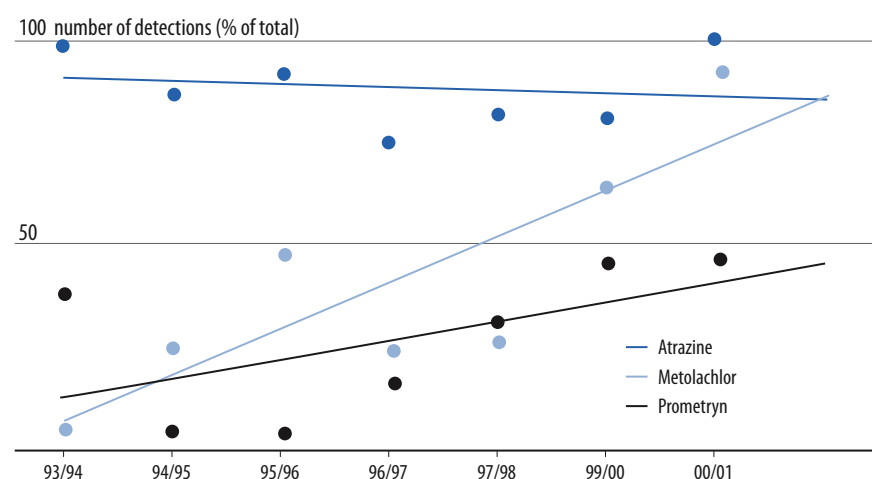
Table 6.3.1. Number of detections of simazine, atrazine, total endosulfan, prometryn & metolachlor for Loudoun & Chinchilla Weir across eight seasons

Chemical	Simazine	Atrazine	Total endosulfan	Prometryn	Metolachlor	Total no. samples analysed
93/94	0	18	12	7	1	18
94/95	0	20	4	1	6	23
95/96	0	21	7	1	11	23
96/97	0	18	6	4	6	24
97/98	0	18	2	7	6	22
98/99	NS	NS	NS	NS	NS	NS
99/00	0	9	0	5	7	11
00/01	5	13	0	6	12	13
01/—*	0	2	0	2	2	4

NS = Not samples *= Incomplete record

The herbicide atrazine, which is predominantly used on sorghum, was the most frequently detected, followed by metolachlor. Detections of atrazine remained constant across all seasons in 80-100% of samples (Figure 6.3.2).

Figure 6.3.2. Metolachlor and Prometryn detections have significantly increased from 1993-2001 with little change in the number of samples containing atrazine for the same period, remaining above 80% for Loudoun and Chinchilla Weirs.



The reduction in use of endosulfan by the cotton industry from 1999 has had a dramatic effect on detections in stream. For the past three seasons endosulfan has not been detected in any of the watercourses on the Condamine Balonne river system.

As in northern NSW, herbicides such as prometryn and metolachlor have significantly increased in detection frequency between 1993 and 2001. Both are herbicides used in the cotton industry.

Bed load sediment sampling for pesticides

Sampling of bedload sediments in all town weirs from 1998–99 found traces of endosulfan sulfate (a breakdown product of endosulfan) in three of the forty sediment samples collected. No pesticides were detected in any of the samples collected in February and October 2000.

Endosulfan sulfate was not detected in the sediment on more than one occasion at any site. This finding suggests that the pesticide is leaching back into the water and breaking down and not accumulating in the bedload sediments.

Groundwater sampling for pesticides

Groundwater bores were sampled at Millmerran, Dalby, Chinchilla and St George every 6 months in 1998 and 1999 to determine if there was any leaching of pesticides into the groundwater system (CBWC 2001). No pesticides were detected in any of the monitored bores. An additional bore tested on two occasions in 2001 in a cropping area close to Dalby had traces of a number of chemicals including endosulfan, metolachlor, trifluralin, atrazine, chlorpyrifos and prometryn. This is the first agricultural bore sample in the Condamine Balonne Catchment to show a positive detection to date.

Suspended solids (TSS) and turbidity

In the upper reaches of the Border Rivers Catchment turbidity is generally low (below 20 nephelometric turbidity units - NTUs), however median turbidity values increase to 120 NTU at the lower end of the catchment (McGloin 2001). High turbidity also occurs in some tributaries (for example, 325 NTU in the Weir River). Monitoring over the last 10 to 15 years has shown that turbidity levels have been increasing over time in the lower half of the catchment and in several tributaries (such as the Severn River (Qld), the Macintyre Brook, the Weir River and Oakey Creek).

TSS and turbidity in the Condamine Balonne River System increase with distance downstream, with turbidity levels ranging from 10–100 NTU and TSS 0–0.16 g/L in the uplands to 100–500 NTU and TSS (0.5–1.5 g/L) from Chinchilla to St George (CBWC 1999).

Unlike pesticides, it is difficult to isolate the direct cause of an increase in sediment and turbidity. However, studies by Noble et al. (1997) in the Emerald Irrigation Area found median sediment concentrations measured upstream (0.03 g/L) of the irrigation channel network increased to 1.76 g/L leaving the cotton farm, and reduced to 0.154 g/L downstream of the irrigation channel network. They reported that concentrations found leaving the fields were above those for any river site studied although concentrations leaving the network were comparable to many mid to lower catchment river sites.

Waters et al. (2001) and Carroll et al. (1995) found mean sediment concentration leaving conventional cotton farms ranged from 2.6 to 8.4 g/L in storm and irrigation run-off. Total soil loss for the season ranged from 6 to 22 t/ha.

The highest risk period is early in the season when groundcover is low and high intensity rainfall event occur. Therefore, where storm run-off is not contained, as in some dryland cotton farming systems, management actions such as vegetative filters are highly desirable to minimise their early season risk of increased run-off and sediment loads moving off-farm.



Total phosphorus (TP)

Nutrient enrichment of waterways in run-off from cropping areas can result in the growth of large masses of plant material. ANZECC's 1992 TP guidelines for the prevention of nuisance algal growth use an indicative range of 0.01–0.1 mg/L (milligrams per litre) for freshwater rivers and streams.

In the Border Rivers Catchment TP concentrations are generally low (0.025–0.1 mg/L) (McGloin 2001). Despite this, TP levels have been shown to be increasing over the last 10 to 15 years in several areas including the Macintyre River at Boggabilla, the Dumaresq River at Bonshaw, the Beardy and Severn (Qld) rivers and Tenterfield Creek. The Weir River (a tributary of the Macintyre/Barwon River) has a high median value (0.17 mg/L) but TP levels do not appear to be increasing over time.

In the Condamine Balonne river system, TP levels generally increase with distance downstream (0.1–1.0 mg/L). In general, TP concentrations increase with flow, TSS and turbidity and decrease with electrical conductivity. The association of TP with flow, turbidity and TSS suggests that the major inputs of phosphorus are attached to sediments or organic matter.

Typical levels of TP measured by Waters et al. (2001) leaving cotton farms were 0.97 mg/L. Noble et al. (1996) found in the Emerald Irrigation area that TP loads increased from (0.04 mg/L) upstream of cotton farms to (0.148 mg/L) in irrigation run-off water downstream of the cotton irrigation channel network. Downstream figures were below those measured in adjacent rivers in the basin.

Total nitrogen (TN)

TN guideline values are only indicative with respect to algal bloom development and are only one of a number of other factors influencing algal growth. The recommended range for freshwater rivers and streams, for the prevention of nuisance algal growth is 0.1–0.75 mg/L (ANZECC 1992).

TN concentrations in the Border Rivers Catchment are generally below the upper range for the prevention of nuisance algal growth (0.5–0.75 mg/L) (McGloin 2001). The only site with a median TN value that exceeds guideline values is the Weir River (1.2 mg/L). Nitrogen concentrations have been increasing over the last decade in the Weir River, the upper reaches of the Macintyre River, the lower Dumaresq River, the Macintyre Brook, the Severn (Qld), and the Beardy Rivers.

For the Condamine Balonne, TN concentrations generally increase with distance downstream. TN ranged from 0.1 to 0.9 mg/L in the headwaters and in the lower end of the catchment, while the Maranoa and the Warrego rivers TN ranged from 1.1 to 2.9 mg/L. The high TN observed in the lower end of the catchment can be attributed to the high nitrogen content of the soils and run-off from upstream land use.

Typical levels of TN measured by Waters et al. (2001) leaving cotton farms were 12.38 mg/L and Noble et al. (1996) in the Emerald Irrigation area found that median TN loads measured upstream (0.556 mg/L) and downstream (5.78 mg/L) of a cotton irrigation channel network resulted in an increase in TN in run-off water. Downstream figures were extremely high and suggest that there is a significant contribution of nitrogen in irrigation run-off water.

Electrical conductivity (EC)

EC measures the ability of a solution to carry an electrical current and is dependent on the presence and concentration of inorganic salts including sodium chloride, calcium chloride and magnesium sulfate. Salinity is defined as the total concentration of these ions and electrical conductivity is often used as an alternative measure of salinity (CBWC, 1999).

Surface water throughout the QMDB is generally of low electrical conductivity (less than 300 $\mu\text{S}/\text{cm}$). However, it should be noted that this does not indicate that these waters will not have salinity problems in the future, as salinity problems can take over fifty years to become visible in the landscape.

A number of tributaries in the Border Rivers Catchment have elevated EC levels (300–660 $\mu\text{S}/\text{cm}$) in comparison to all other sites – these include the Macintyre Brook, Oakey and Pike Creek which had medium salinity levels but no significant upward trend. This may indicate that this is a natural state for these tributaries. The Weir River, Pike Creek upstream of Glenlyon Dam and the Severn River (NSW) upstream at Strathbogie, have low EC levels, however these have been increasing since the early 1990s in the Weir and Severn (NSW) rivers and since the late 1950s in Pike Creek.

Median EC values measured at all sites in the QMDC were below 700 $\mu\text{S}/\text{cm}$. Hence water quality at all monitoring locations could be regarded as suitable for irrigation purposes (ANZECC & ARMCANZ 2000).

Minimising off-site movement of pollutants

The cotton industry has invested significant R&D funds over the past decade to address the issue of off-site movement of pollutants. Key findings from the work identified the high-risk period as early season and highlighted the importance of storms and sediment in moving pesticides off-site and the importance of groundcover in reducing movement (Simpson et al. 1996; Silburn et al. 1998).

Waters et al. (2000) demonstrated that there are a number of practical management options available to farmers now that can dramatically reduce off-farm movement of pollutants. Containment of pollutants on farm requires a whole farm approach. Techniques such as sumps, silt traps and vegetative filters are effective in collecting sediment once it has left the paddock. Crop rotations and stubble retention offers the most effective means of reducing 'off-site' movement of sediment bound pollutants for both irrigation and storms at this point in time. Cereal crops have been shown to be the most effective in terms of achieving high cover levels and having minimal impact on soil-borne diseases. To control chemicals which are more water-soluble is a separate issue again.

One technique alone will not address all the problems. An integrated approach which looks at the whole farm design and management is highly effective in reducing the associated risks of off-site movement of pollutants.

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Section 7

Investigative irrigation research

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7.1 Using PAM in irrigated cotton

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Key points

- Polyacrylamide (PAM) is used in irrigation to minimise soil erosion. Increases in infiltration and decreases in run-off concentrations of sediment and contaminant also typically occur.
- Rigorous scientific trials conducted on PAM use in the USA have been undertaken using drastically different furrow irrigation systems to those employed in the Australian cotton industry. The performance of PAM under these Australian conditions may be significantly different.
- It is essential to use soil moisture monitoring tools to understand your soil wetting patterns before deciding to use PAM, especially if the primary motivation for use of PAM is to increase infiltration.
- Analysing your furrow irrigation performance is also essential, as the slower advance rates experienced during PAM use are likely to increase total water use and decrease water use efficiency in all but low infiltration soils.

- When used in the right circumstances (for example, on soils with low infiltration rates), PAM can dramatically decrease sediments, nutrients and various contaminants in run-off and improve irrigation performance.
- When used incorrectly, PAM can dramatically decrease irrigation performance and increase water use.

Polyacrylamide (PAM) has been used extensively across numerous industries for many decades. Some of the current uses of PAM include:

- treating potable water
- dewatering sewage sludge
- food processing
- paper and adhesive manufacture (including food-grade paper products)
- cosmetic manufacture
- mining and drilling operations.

PAM is generally used as a settling agent. When added to a solution it flocculates (clusters together) fine particles which can then settle out of the solution. Hence, when added to irrigation water, PAM binds the fine clay and silt particles together. The resulting action is twofold: soil structure is stabilised, reducing the detachment and transport of sediment from the soil surface, whilst any detached particles are flocculated and can settle out of the irrigation stream.

There are actually hundreds of different formulations of PAM including cationic, neutral and anionic varieties with molecular weights ranging from 1 to 20 million. PAM used for irrigation is

mostly anionic, and may be provided in either fine granular, liquid or emulsion forms. Some cationic and neutral varieties are not suitable as they are not only less effective but may have environmental toxicity issues which are not present with anionic PAM when used at recommended rates. Appropriate PAM formulations are typically referred to as 'linear'. 'Crosslinked' or 'super water absorbent' PAMs have a different function and should not be used for erosion control purposes.

Typical application rates of PAM are in the order of 1 kg/ha for furrow irrigation and 4 kg/ha for sprinkler irrigation. Often subsequent irrigations require lower application rates so that the typical seasonal application ranges from 3 to 7 kg per hectare. Sufficient turbulence or agitation must be provided at the application point to dissolve granular PAM to the required concentration. The cost of agricultural PAM is approximately \$5 to \$15 per kilogram.

PAM effects for irrigation

Due to PAM's mode of action, its use in irrigation provides for two main effects. Erosion is reduced due to increased soil surface stability and a decreased amount of suspended solids whilst infiltration is increased as fewer soil pores are blocked by fine sediments.

Erosion

Trials in the USA have indicated reductions in run-off sediment of up to 94% through the use of PAM. The method of application involved dissolving 10 kg/ML of PAM in the irrigation water during the initial advance only. After run-off begins, PAM dosing is ceased. The resulting dose is generally 1 to 2 kg/ha. Where furrows were not disturbed, the erosion control during subsequent irrigations, without PAM application, was typically reduced by half.

The effectiveness of the PAM application for freshly formed furrows was found to vary according to inflow rate, PAM concentration, duration of furrow exposure and total amount of PAM applied. These variations may have dramatic impacts on the adoption of these results in Australia, as the test conditions involved short fields (175 to 264 metres) and flow rates in the order of 13 to 38 L/min: this contrasts with the much longer field lengths (~400 to 1600 metres) and higher flow rates (> 60 L/min) typically employed in the Australian cotton industry, where flow rates in excess of 200 L/min are not uncommon. The performance of PAM under these conditions may be considerably different.

Australian trials have indicated reductions in erosion from furrow irrigation events at flow rates of up to 120 L/min using either wheat stubble or PAM. Accordingly, levels of some contaminants, particularly endosulfan, were also effectively reduced using these erosion control methods. Other contaminants such as metolachlor, which are not as strongly associated with soil particles, were not effectively controlled. In a Warren trial, PAM applied in irrigation water was not effective in reducing soil erosion from subsequent rainfall events.

Infiltration

The effect of PAM in the above trials indicated typical increases in infiltration rates of 15% or more, with potential increases of up to 50% in clay soils. This increase in infiltration is reflected in the slowing of the advance of furrow irrigation water, and this is significant, particularly on the cracking clay soils that make up a significant portion of Australia's cotton-growing regions. Various studies over recent years have indicated that these soils typically have adequate infiltration rates: in fact, water use efficiency will often increase if the irrigation advance is speeded up through higher flow rates and shorter irrigation durations. The use of PAM in these situations is likely to reduce water use efficiency and increase the opportunity for deep drainage and waterlogging if the system is not adequately analysed beforehand.



However, in soils (hardsetting or sodic) with poor infiltration rates requiring long irrigation events, PAM can help to improve infiltration and reduce run-off losses and waterlogging problems. Where gypsum is used to reduce surface sealing, PAM may be used as an alternative treatment to help improve infiltration, reducing the amount of salt which would be added by the uninterrupted use of gypsum.

Environment

As well as decreasing sediment run-off from irrigated fields, studies have shown that using PAM in irrigation water decreases nutrient and pesticide loads in drainage waters. This is because pesticides are attached to the soil particles which are retained within the field. In addition, numerous microorganisms and weed seeds, typically removed in tailwater, remain in the field following PAM application. Minimising this movement results in significantly lower concentrations of pollutants in distribution systems and storages as well as in off-farm waterways.

When used at recommended rates, no significant negative impacts have been documented for crop species, soil microorganisms or aquatic macrofauna.

The movement of PAM from fields is minimal due to its attraction to sediment particles; as they settle out of the water stream, the PAM settles also. Trial results indicate that only 3% to 5% of the PAM applied to a field leaves in the tailwater, and this volume travels no further than 100 to 500 metres along the tail drain. PAM in soil gradually breaks down at about 10% to 20% per year due to physical, chemical and biological activities.

Important considerations

The biggest consideration facing the use of PAM in the Australian cotton industry is its effect on furrow irrigation water use efficiency. Recent furrow irrigation trials have indicated that, in many situations, water use efficiency is currently compromised through advance rates that are too slow, leading to poor uniformity, over-application and extended periods of waterlogging. PAM used in these situations would likely exacerbate the problem by slowing advance rates even further.

However there is quite probably potential for PAM use in some circumstances such as high slopes prone to erosion or soils with poor infiltration. The key is to gain an understanding of your situation before proceeding with PAM application. Soil wetting patterns (and potential infiltration issues) can be observed using soil

moisture measuring (SMM) tools (in Topic 2.10) whilst irrigation volumes and distribution uniformity can be investigated using the methods outlined in Topic 2.9. It is vital that such investigations are undertaken as the potential for PAM to decrease water use efficiency if used in the wrong situations is significant.

In circumstances where furrow optimisation suggests that optimum flow rates are high enough for erosion to be a significant issue, there may be potential to combine improved furrow irrigation practices and PAM application.

When using PAM, it is important to ensure that the first water to proceed down the furrow during the irrigation advance is of the correct PAM concentration. Any non-treated water that comes into contact with dry soil will start to degrade soil structure almost immediately, reducing the ability of PAM to stabilise soil structure and reduce erosion.

Case study: application of polyacrylamides in rural water use efficiency initiative demonstration sites

Irrigators in Queensland have undertaken several on-farm demonstrations of PAM use during the 2000 to 2003 summer irrigation seasons. The purpose of these demonstrations was to allow irrigators in the St George/Dirranbandi and Emerald regions to investigate the effect PAM had on improving infiltration and reducing erosion during cotton furrow irrigation events.

Due to lack of Australian research into the use of PAM in irrigated agriculture, irrigators and Rural Water Use Efficiency officers designed crude demonstrations (not rigorous trials) to monitor the effect of PAM treatments on fields with similar soil, design and management characteristics. The trials compared PAM treated and untreated fields or portions of fields. The following results are simply recorded observations from the demonstration sites, and should not be taken out of the context of these demonstrations.

In these demonstration sites, PAM was applied to irrigation water in the head ditch prior to siphons being started. The need for more investigation into application methods was highlighted due to some practical issues.

St George

During the 2000/2001 season, a crude comparison of irrigation advance times for PAM treated and untreated furrow irrigation events demonstrated that it took approximately two hours longer for PAM treated water to reach the end of the furrow. It is therefore inferred that infiltration can be increased on these hard setting soils through the application of PAM. The effect on total water use, distribution uniformity and water use efficiency was not measured.

Emerald

In the Emerald irrigation subregion, trials investigated likely improvements in water retention in the root zone (due to PAM) and the effect on waterlogging and potential yield reductions. Advance rates and the amount of tailwater were measured in treated and untreated sites. Continuous soil moisture monitoring was undertaken at several soil depths at both sites.

Observed outcomes included an average advance time increase of one and a half hours over the furrow distance of 375 m at the treated site. This implies an increase in infiltration due to PAM application. Less tailwater was measured at the treated site, potentially indicating that less sediment and nutrients left the field. Soil moisture monitoring at the treated site indicated prolonged waterlogging, which may have contributed to yield loss.



Case study: continued

Other investigations have demonstrated that PAM application may have been useful in ensuring even bed-wetting, thus assisting uniform germination and improved seedling establishment. In a demonstration of PAM on wheat an irrigator remarked on improved germination and seedling establishment, heavier seed heads, increased yield (0.25 tons/acre) and decreased water use (one whole irrigation) between a crop that was split into a treated section and a non-treated section.

Irrigators in the Emerald region are increasingly using PAM in their early irrigation particularly to save nutrients from being washed or leached away when the soil is still loose and fertiliser has just been applied.

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7.2 Regulated deficit irrigation and partial root zone drying

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Key points

- Farmers growing cotton under large mobile irrigation machines have greater and easier control over the volumes of irrigation water they can apply at any given irrigation compared with furrow irrigation. Consequently, with good knowledge and monitoring of soil moisture they can better maintain soil moisture within the range most agronomically acceptable for cotton and further reduce the incidence of waterlogging, rank growth and water stress.
- With further research conducted into RDI and the potential for PRD in cotton with the use of LEPA socks, greater benefits in water use efficiency in cotton production may be achievable.

Irrigation management of cotton involves a balance between vegetative and reproductive growth. Excessive vegetative growth can delay maturity and reduce final yield. Excessive leaf area, which increases shading on lower parts of the plant and the incidence of boll rot, may lead to yield losses. The efficacy of insecticides can be reduced because a thicker canopy reduces chemical penetration and an increased leaf area will also cause plants to have a higher rate of transpiration.

Two irrigation strategies that could be implemented to reduce excessive vegetative growth, maintain yield and reduce water use, leading to an improvement in water use efficiency, are regulated deficit irrigation (RDI) and partial root zone drying (PRD).

Regulated deficit irrigation

Previous research has confirmed vegetative growth of cotton is maximised when plants are maintained with a reduced soil moisture deficit. Maintaining a reduced soil moisture deficit keeps vegetative growth under control while boll growth and photosynthesis are unaffected. A reduced moisture deficit

therefore has been stated as the most agronomically desirable soil moisture level. Excessive water deficit/stress should be avoided, as it reduces photosynthetic supply: this will affect both vegetative and reproductive growth.

RDI may be implemented during part of the growing season by regulating moisture within a desired deficit range. RDI aims to optimise water use efficiency and therefore maximise the yield returned per unit of water applied. Any minor yield losses which may result from the implementation of a mild moisture deficit/stress under RDI is offset by the benefits of reduced water use leading to a reduction in excessive vegetative growth. A variety of crops have been found to benefit from a RDI strategy including maize, wheat, sunflower, potatoes, tomatoes and cotton.

The most desirable benefits associated with implementing a RDI strategy in cotton are:

- the reduction in excessive vegetative growth
- maintenance of soil moisture in the most agronomically desirable range
- an increase in water use efficiency, and
- the ability to better capture and use in-season rainfall events after an irrigation event due to the maintained deficit.

Furrow irrigation practices generally result in soil moisture returning to near field capacity after an irrigation event. This means that plants do not endure any moisture deficit for a certain time and that soil moisture levels are higher than the agronomically desirable range. Irrigation using drip, centre pivots and lateral moves are typically able to apply smaller quantities of water more frequently, and are therefore better able to maintain soil moisture at the mild deficit required to implement RDI.

Research is currently being conducted into the use of RDI in cotton grown with both drip and large mobile irrigation machines (LMIMs). Results to date have found improved WUE can be achieved through the implementation of a RDI strategy in cotton.

Partial rootzone drying (PRD)

Partial rootzone drying (PRD), as the name suggests, is the creation of simultaneous wet and dry (or drying) areas within the root zone. Only part of the root zone is irrigated and kept moist at any one time. PRD is implemented by irrigating one side of the plant row and allowing the other side to dry out. The irrigations are then alternated to the dry side after a set period of time and then back and forth thereafter after the same period of time.

The first research conducted in PRD investigated chemical root signalling between roots and shoots in apples. In these initial experiments, roots from individual plants were divided between two containers where one container was kept well-watered and the other left to dry out. It was discovered that when plants were grown under these conditions, roots located in the unwatered drying pot released elevated levels of the plant growth/stress hormone **abscisic acid** (Aba). In the presence of elevated levels of Aba it was noted that plants reduced leaf growth and stomatal aperture. This resulted in plants with a reduced leaf canopy and transpiration rate but still maintained yield and achieved an improvement in water use efficiency. It was also discovered when the irrigated side was not alternated, the plants reacted to the enforced conditions and over time returned to their pre-treatment stomatal aperture and growth rates. By alternating the side irrigated after

set periods of time, the signalling and associated reduction in stomatal aperture and growth rate was maintained, showing that alternation of the irrigation is critical in the implementation of PRD.

In Australia, most PRD work has been conducted in grapes and to a lesser extent in citrus and pears.

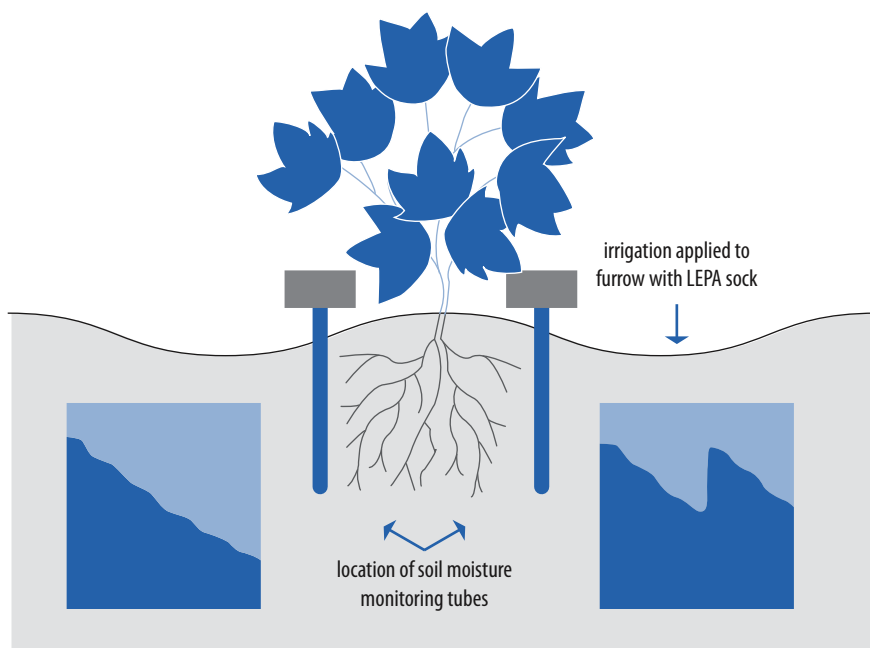
- PRD research conducted in grapes by the CSIRO in South Australia compared grapes irrigated on both sides and maintained close to field capacity with grapes irrigated on alternating sides with the alternation set occurring on a two-week interval. Grapes under PRD were found to have elevated levels of Aba and therefore a reduction in stomatal aperture compared to the well-watered control (Stoll 2000).
- In a similar trial there was found to be a consistent reduction in vegetative growth as measured by leaf area, pruning weight and shoot growth in PRD treatments (Dry, Loveys et al. 2000). It was also found that vines under PRD had a greater abundance of their roots at depth compared with the control, although no significant difference in total dry weight of the root mass was found.

In almost all experiments which have been conducted in grapes, there has not been a significant reduction in yield due to PRD treatments compared with fully irrigated plants. Yields were not even significantly reduced when almost half the irrigation water was applied under



PRD, when compared with standard regional irrigation practices (Chalmers, Kristic 200; Dry, Loveys et al. 2000)

Shown below is the author's impression of how PRD could be implemented in cotton. Water is applied frequently in small amounts with LEPA (low-energy precision-application) socks to one side of the cotton row. Graphs present in the figure show soil moisture over time. Soil moisture on the right-hand side increases after an irrigation event but soil moisture on the left-hand side continues to dry down. Irrigation placement is alternated to the furrow on the other side after a set period of time or at a target soil moisture level on the 'drying' unwatered side.



PRD is now commercially practised in vineyards and is continuing to be trialled in citrus, pears and peaches with promising results. Overseas, PRD studies are being conducted in crops including olives, citrus, tomatoes, aubergines, raspberries and cotton.

It has been suggested that deciduous plants adapted to drought tolerance respond best to PRD. Cotton, being of an indeterminate growth habit and well adapted to arid, dryland conditions, may show promise from a PRD strategy. To date PRD trials in cotton conducted in Turkey under furrow irrigation have furnished positive results. There is also work currently being carried out in Australia to investigate the use of PRD under centre pivots and lateral move irrigators in combination with LEPA socks which can be easily altered to the opposite side of the row after consecutive irrigation events. This allows for the implementation of PRD without any major expense or modifications needing to be made to the current machines.

The major questions still to be answered in evaluating PRD in cotton production involve:

- Can a soil moisture gradient sufficient to enable PRD signalling be created in the heavier soils commonly used to grow cotton?
- Will cotton plants under a PRD system react in a similar physiological manner to that which has been reported in other crops? Since abscisic acid is involved in the abscission process, it is suspected that the creation of a PRD system may increase fruit shedding and reduce yields.
- The regulation of stomatal conductance, as reported in other crops under PRD, may not occur in cotton: will the previously reported low stomatal response of cotton limit the potential savings in water use?

Conclusion

There are potential benefits and possible risks associated with the implementation of both RDI and PRD strategies in cotton. Irrigation with centre pivots, lateral moves and drip are most suited to implementation of these strategies.

Anecdotal evidence and some overseas research findings support the benefits of RDI in cotton.

Significant benefits in water use efficiency have been achieved from PRD in grapes. Research into PRD in cotton has only recently begun but is suggested to have potential benefits.

Before either RDI or PRD is implemented in cotton, knowledge of the predicted outcome and plants response to the imposed strategies need to be further researched and understood.

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Definitions

CI – chloride

ET – evapotranspiration (water evaporation from soil plus transpiration from plants)

ESP – exchangeable sodium percentage

Ksat – soil saturated hydraulic conductivity (measure of permeability)

LF – leaching fraction – the fraction of water (rainfall + irrigation) that drains below the root zone

SaLF – an equation for estimating steady state deep drainage (or leaching fraction) under irrigation from the rainfall, irrigation applied and soil properties (Shaw and Thorburn 1985)



Section 8

Glossary

8.1 Glossary

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8.2 Acronyms

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8.1 Glossary

alluvial: (soil) developed from recently deposited alluvium; usually too young to show the effects of soil forming processes: any layers in the soil profile are successive deposits rather than soil horizons.

bypass flow: the rapid movement of water down macropores ahead of a wetting front. It occurs even though the soil matrix surrounding the macropores is unsaturated (i.e. the water 'bypasses' the soil matrix). The result is that the soil profile is wet from the bottom-up despite the water being applied to the surface. The macropores through which bypass flow occurs include shrinkage cracks, cylindrical pores created by worms or roots and slickensides. It is also called preferential flow.

crop water use efficiency (CWUE) is a measure of lint yield per millimetre of water obtained from stored reserves in the soil, irrigation and rain.

cross fall: lateral fall across the field (that is, across the slope of land, as opposed to down the slope of the furrow)

cut-out: when the bolls are consuming all the available energy (carbon) generated through photosynthesis and therefore no new squares are produced.

deep drainage: drainage of water below the root zone.

evapotranspiration (ET): the sum of direct evaporation from the soil surface and transpiration, by which process plants give off water vapour through their leaves

exchangeable sodium percentage (ESP): the number of exchangeable sodium ions as a percentage of all exchangeable cations held by a soil. The critical ESP value above which dispersion occurs ranges from 2 to 15, depending on the amount of electrolyte in soil solution.

freeboard: height between bank and water surface in the distribution channel or storage.

gilgai country: a natural surface feature of humps and depressions found in some types of cracking clay

global positioning system (GPS): a network of satellites controlled by the US Department of Defence that is designed to determine a radio receiver's position in latitude, longitude and altitude. Differential GPS (DGPS) improves accuracy of the information via the use of a local base station.

headworks: main control structure in an irrigation scheme, that is, at the main dam in a catchment.

hydraulic conductivity: the rate of flow of water per unit gradient of hydraulic potential

indeterminate varieties: varieties that have no defined growth period, usually perennial species.

irrigation efficiency (IE): calculation of irrigation efficiency (IE) is similar to CWUE, but it takes into account water losses in the storage and distribution system.

leaching fraction: the fraction of infiltrated irrigation water that percolates below a plant root zone. When using this number, you need to specify the time over which the leaching fraction is measured and the depth interval over which it is calculated.

neutron moisture meter: a radioactive moisture sensor that is lowered down an aluminium access tube. It estimates volumetric soil water content through measurement of neutrons that are scattered by hydrogen atoms in soil water.

off-allocation: water flowing down the river which is available to be pumped without being debited to your water account.

plant available water capacity (PAWC): the maximum amount of water that a soil can hold in the root zone and later release to plant roots. Water held between 'field capacity' and 'refill point' is referred to as being readily available.

polyacrylamide (PAM): a settling agent used to flocculate soil particles.

porosity: the degree to which a soil is permeated with pores. The term refers not only to the fraction of the soil volume made up of pores, but also to the size and shape of the pores and the degree of connection between them.

rilling erosion: an erosion process on sloping land in which numerous and randomly occurring small channels only several centimetres deep are formed.

saturated hydraulic conductivity (Ksat): the saturated rate of flow of water per unit gradient of hydraulic potential.

Siemens: unit of conductivity.

slaking: collapse of aggregates in water to form microaggregates, due to the breakage of bonds formed, for example, by organic matter.

slickenside: shiny, striated stress surface found on clay-rich aggregates, formed by one mass of soil sliding past another during swelling and shrinking cycles.

slumping: collapse (of a furrow hill).

sodicity: an excess of exchangeable sodium, causing soil dispersion to occur.

soilcore: a sample of soil taken from down the profile.

squares: fruiting structures prior to cotton flowering.

stomate: a leaf pore.

'sub-up': the rate of lateral flow of water from furrows into raised beds or hills.

telemetry: direct transfer of information via radiowaves from the field to computer.

vapour pressure deficit: the differences between the amount of water vapour the air can hold at the current temperature and the amount it does hold. Units are kPa. Vapour pressure deficit is the driving force for evaporation.

vertosols: Australian term used to describe a soil which 'turns' (tills) itself (Latin *verto* – to turn). Vertosols have more than 35% clay throughout the profile, cracks greater than 5 mm at some time of the year, and the presence of slickensides. Vertosols lack distinct horizons.

water use efficiency: a measure of the efficiency of conversion of water into plant products.

'watering up': a full irrigation immediately after sowing.



8.2 Acronyms

Following is a list of acronyms that are used in the cotton industry or by Government, which may appear in this publication.

ABARE – Australian Bureau of Agricultural and Resource Economics

ACCRC – Australian Cotton Cooperative Research Centre (also Cotton CRC)

ACEC – Australian Cotton Exhibition Centre

ACGRA – Australian Cotton Growers' Research Association

ACIC – Australian Cotton Industry Council

ACRI – Australian Cotton Research Institute

ACSA – Australian Cotton Shippers Association

APVMA – Australian Pesticides and Veterinary Medicine Authority (formerly NRA)

AWM – Area Wide Management

BMP – Best Management Practices

Bt – *Bacillus thuringiensis* (crystal protein expressed in INGARD® and BOLLGARD II®)

CA – Cotton Australia

CCA – Cotton Consultants Australia Inc.

CGA – Cotton Growers' Association

CIE – Centre for International Economics

CRC – See ACCRC

CRCIF – Cooperative Research Centre for Irrigation Futures

CRDC – Cotton Research and Development Corporation

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DAFF – Department of Agriculture Fisheries and Forestry

DIPNR – Department of Infrastructure, Planning & Natural Resources (NSW)

ICAC – International Cotton Advisory Committee

IP – Intellectual Property

IPM – Integrated Pest Management

L&WA – Land & Water Australia

MDBC – Murray Darling Basin Commission

NRME – Department of Natural Resources, Mines and Energy (Qld)

NSW DPI – New South Wales Department of Primary Industries

QC – Queensland Cotton

Qld DPI&F – Queensland Department of Primary Industries and Fisheries

RCMAC – Raw Cotton Marketing Advisory Committee

TIMS – Transgenic and Insect Management Strategy committee

TRC – Technology Resource Centre (at the ACRI)



Section 9

Attachments (third party publications)

9.1	How much does it cost to pump? (NSW Agfact)	Peter Smith & Alan Richards
9.2	Is your diesel pump costing you money? (NSW Agfact)	Peter Smith
9.3	How efficient is your pump? (NSW Agfact)	Alan Richards & Peter Smith
9.4	Selecting an irrigation pump (NSW Agfact)	Bill Yiasoumi
9.5	Soil water monitoring: choosing the right device (NSW Agfact)	David Williams
9.6	Irrigation: water balance scheduling (DPI Note)	Graham Harris
9.7	Irrigation Water Quality (NRM WaterFact)	Robert de Hayr & Ian Gordon
9.8	Interpreting water analysis for crop and pasture (DPI Note)	Bill Mills
9.9	Sampling your water quality (NRM WaterFact)	Graham Herbert
9.10	Using conductivity meters in Agriculture (DPI Note)	Ian Walker
9.11	Siphon Table	David Wigginton
9.12	Leaking Farm Dams (NSW AgFact)	Bill Yiasoumi



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How much does it cost to pump?

Agfact E5.10, first edition, January 2003

Peter Smith and Alan Richards

Irrigation Officers, Tamworth and Paterson

Random tests of pumps in many NSW river valleys found that about half were not performing adequately, either because the wrong pump had been chosen for the job, or because the pump was worn.

If the pump is not doing its job, pumping costs are increased and productivity is reduced.

To contain costs, you need to monitor your energy usage regularly and repair and maintain the pump to operate efficiently.

Keeping track of your pump's costs is not difficult, and it may save you a lot of money and keep your irrigation system performing properly.

This Agfact describes a simple procedure to work out the pumping costs for your electric pump. When you have completed it once, you can perform quick checks to detect any change, and determine when repair is cost-effective.

One way of tracking pumping costs is to work out how much it **costs to pump a megalitre of water**. To do this, you need to measure:

1. the **power consumed** in kilowatts (kW)
2. the **flow rate** in litres per second (L/s).

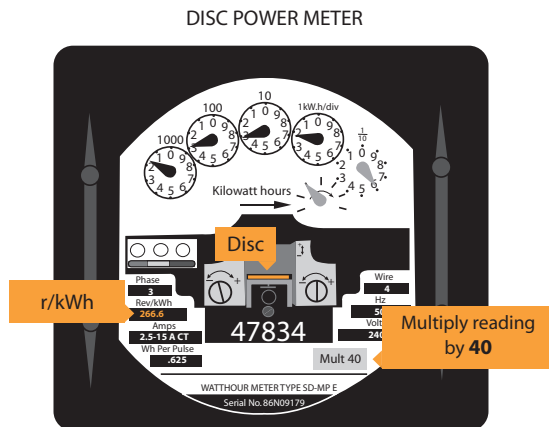
Combining these measures with the **cost of electricity** gives the pumping cost.



STEP 1. MEASURE THE POWER USED

You can measure the power used by reading your electricity meter. Currently, the three meters in common use are disc, multiple disc and electronic meters.

Disc meters



Reading a disc meter

Note the rating figure, the revolutions per kilowatt hour (r/kWh), marked on the electricity meter.

$$R \text{ (r/kWh as marked on meter)} = 266.6$$

Next, with the irrigation system set up in an average position and running, time the spinning horizontal disc on the power meter for at least 10% of R. (In this example, R is 266.6, so 10% is about 30 revs.)

$$N \text{ (number of disc revolutions)} = 30$$

$$T \text{ (time of test)} = 386 \text{ s}$$

In systems that consume large amounts of electricity, the disc may be geared down so it doesn't run too fast. If so, you will notice a multiplier 'M' is marked on the meter.

$$M \text{ (multiplier as marked on meter)} = 40$$

From this data you can calculate the power usage in kilowatts.

$$\begin{aligned} \text{Power usage} &= (N \times 3600 \times M) \div (R \times T) \\ &= (30 \times 3600 \times 40) \div (266.6 \times 386) \\ &= 42 \text{ kW} \end{aligned}$$

In this example, the pump uses 42 kW.

Perform this test regularly, over a season or between seasons, to check the pump's power consumption. If you find that it takes less time for the same number of disc revolutions than when you first tested the pump, the power use is higher, and you will need to find out why.

This comparison is only possible when the irrigation is set up in the same position as the initial test, with the same number of sprinklers, and with the pumping water level roughly the same.

If a very accurate result is needed, you need to monitor the system over all the irrigation positions for one complete cycle. In this case you need to record the total electricity used, the total hours of use and the total amount pumped over the period.

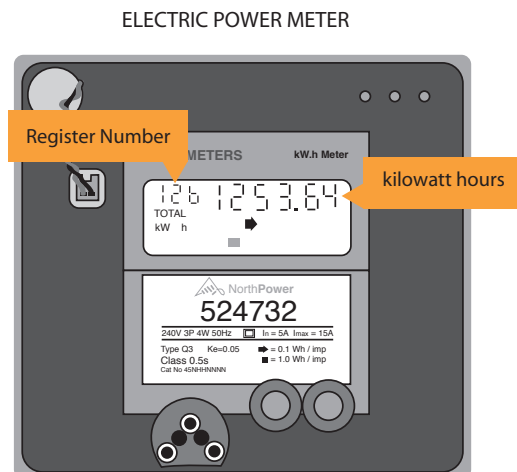
Multiple disc meters

If there are three meters, for example, one for each phase of a 3-phase power supply, measure the three meters individually and add the kW figures together.

Note: Measuring each meter separately gives an accurate answer. Rarely are three meters exactly the same.

Electronic meters

You may have an electronic meter that can measure and record the electricity used for the main rate, shoulder rate and the off-peak rate in separate registers. The various rates are switched 'on' and 'off' by the internal clock at the appropriate times.



The electronic meter records your electricity consumption in a time-of-use format. It may also have registers for the date, the time and for testing the display.

Each register has a 3-figure identification number: for example, the current off-peak kilowatts may be given register number '126'. You should check with your local energy authority what the display register numbers are for each of your rates.

The meter scrolls through each register at 4–6 second intervals.

- The register number appears, often in smaller numbers, on the LCD screen (in the diagram, in the top left-hand corner) and may have a short description underneath (for example: 126 — off-peak).
- The usage in kilowatt hours appears in the larger main display. It is usually a 6-figure number (for example: 1253.64).

When the present time rate usage is reached, the number may flash. Record this number. If none of the displays flash, record the readings from all the displays.

Let the pump run for at least 15 minutes before taking the next reading.

In systems that consume large amounts of electricity, there may be a multiplier programmed into the electronics. If so, it will be noted on the electricity supplier's bill for this meter as 'Mult' or 'M' and the display may read to a couple of decimal places. If there is a multiplier, run the pump for at least 30 minutes before taking the second register reading.

If the second reading has not changed, you are reading the wrong register.

Reading an electronic meter

1st reading (register 126) = 1253.64 kWh

2nd reading (register 126) = 1254.16 kWh

Multiplier stated on power bill = 40

Power usage between second and first reading

$$= (1254.16 - 1253.64) \times 40 \times 3600$$

$$= \frac{1800 \text{ (no. secs in 30 min)}}{1800}$$

$$= 0.52 \times 40 \times 3600$$

$$= 41.6 \text{ kW}$$

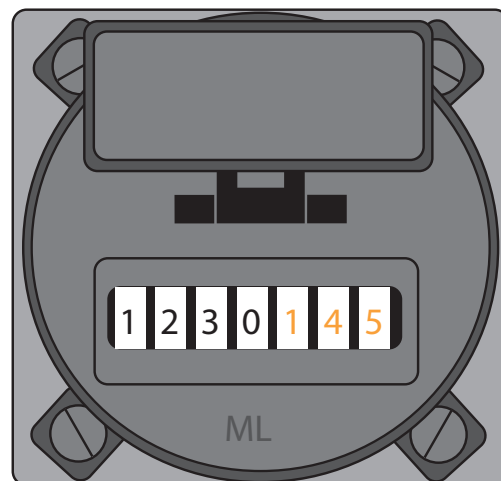
STEP 2. MEASURE THE FLOW RATE (Q)

The second measure needed to calculate pumping cost per megalitre is the flow rate of the system (Q).

The flow rate is the amount (or quantity) of water pumped in a certain amount of time, usually given in litres per second (L/s). It should be measured after the system has had sufficient time from start-up to be running normally.

Measure the flow rate by reading your water meter at the pump for preferably the whole irrigation cycle or at least half an hour and dividing the litres pumped by the time in seconds. (See 'Measuring the flow rate', below.)

WATER METER



Estimating flow rate by discharge

If no water meter is fitted or it is losing accuracy, the flow rate of a spray irrigation system where all the sprinklers are the same model and size can be estimated by measuring the sprinkler discharge.

Use several sprinklers: at least one at the start of the line, one in the middle and one at the end. Record how long each sprinkler takes to fill a container (for example, a 10-litre bucket or a 20-litre drum).

To find the flow rate of each sprinkler in L/s, divide the container volume (in litres) by the time taken to fill it (in seconds). You can then find the average for the sprinklers you measured.

To calculate the total flow rate of the system, multiply the average by the number of sprinklers operating. (See 'Estimating the flow rate by discharge', below.)

Measuring the flow rate

Water meter reading at start: 1108.345 kL

Water meter reading after 35 minutes: 1230.145 kL

$$\begin{aligned} \text{Flow rate (Q)} &= [(1230.145 - 1108.345) \times 1000] \div (35 \times 60) \\ &= 121\,800 \div 210 \\ &= 58 \text{ L/s} \end{aligned}$$

Estimating the flow rate by discharge

First sprinkler takes 9 seconds to fill a 10-litre bucket $= 10 \div 9 = 1.11 \text{ L/s}$

Middle sprinkler takes 8 seconds to fill a 10-litre bucket $= 10 \div 8 = 1.25 \text{ L/s}$

End sprinkler takes 7 seconds to fill a 10-litre bucket $= 10 \div 7 = 1.43 \text{ L/s}$

Average flow $= (1.11 + 1.25 + 1.43) \div 3 = 1.26 \text{ L/s}$

There are 46 sprinklers operating, so the total flow rate is $= 1.26 \times 46 = 58 \text{ L/s}$

STEP 3. CALCULATE THE POWER PER MEGALITRE PUMPED

From the power usage and the flow rate, the kilowatt hours per megalitre (kWh/ML) for your pump can be calculated.

This is called the 'calibration' value (the value used where electricity meter readings are read to determine water use).

STEP 4. CALCULATE THE PUMPING COST

Having calculated the power used to pump a megalitre, you need to know the cost per kWh from your supplier. Once you know the charge per kWh, you can calculate the cost of pumping.

Note: The charges per kWh may be difficult to work out exactly if your supplier has different rates for day or night, weekends, and so on. Contact your supplier for help to work this out.

Pump calibration (kWh/ML)

$$\begin{aligned} &= \text{kW} \div (\text{Q} \times 0.0036) \\ &= 42 \div (58 \times 0.0036) \\ &= 201.1 \text{ kWh/ML} \end{aligned}$$

Note: 0.0036 converts kilowatt seconds per litre to kilowatt hours per megalitre.

Pumping costs

If supply costs 12 cents per kWh:

$$\begin{aligned} \text{Pumping cost} &= 201 \text{ kWh/ML} \times \$0.12 \\ &= \$24.12 \text{ per ML} \end{aligned}$$

Conclusion

Try measuring your pump performance and calculating the cost of pumping. Worksheets for photocopying and using in the field are included at the end of this Agfact.

Keeping track of your pumping costs is not difficult. It may save you a lot of money and help you keep your irrigation system performing properly.

Related Agfacts

If you want to go a step further and measure how efficiently your pump is performing, see the companion Agfact E5.11 *How efficient is your pump?*

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Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing (January 2003). However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of New South Wales Department of Agriculture or the user's independent adviser.

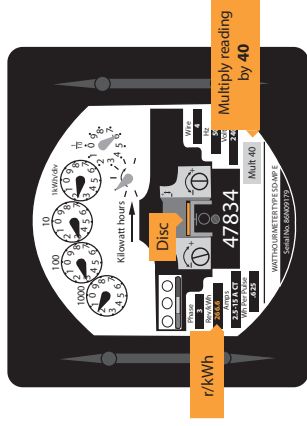
From the table below, select your irrigation system and compare your cost per megalitre with the typical figure.

Irrigation system	Total head (m)	Pumping cost/ML		
		@ 10c/kWh	@ 12c/kWh	@ 14c/kWh
Furrow (river)	10	\$4.52	\$5.43	\$6.33
Furrow (bore)	45	\$20.36	\$24.43	\$28.50
Pivot or linear move, low pressure	40	\$18.10	\$21.72	\$25.33
Drip/jet spray	50	\$22.62	\$27.14	\$31.67
Spray (river)	55	\$24.88	\$29.86	\$34.83
Spray (bore)	65	\$29.41	\$35.29	\$41.17
Traveller (river), medium pressure	85	\$38.45	\$46.14	\$53.84
Traveller (bore), medium pressure	90	\$40.72	\$48.86	\$57.00
Traveller, high pressure	120	\$54.29	\$65.15	\$76.00

Table 1 Pumping costs for typical irrigation systems

WORKSHEETS

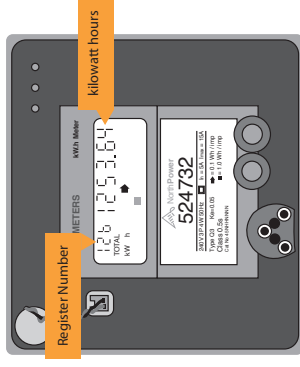
ELECTRICAL ENERGY CONSUMED - DISC METER



Worked example		Your readings		
Electricity meter		meter 1	meter 2	meter 3
1. R/kWh as marked on meter	= 266.60	R = ...	R = ...	R = ...
2. Multiplier as marked on meter	= 40	M = ...	M = ...	M = ...
3. Number of disc revolutions	= 30	N = ...	N = ...	N = ...
4. Time = 386 seconds		T = ...	T = ...	T = ...
5. kW per meter				
$= \frac{N \times 3600}{T} \times \frac{M}{R} = \frac{30 \times 3600}{386} \times \frac{40}{266.6}$		$= \frac{..... \times 3600}{.....} \times \frac{.....}{.....}$	$= \frac{..... \times 3600}{.....} \times \frac{.....}{.....}$	$= \frac{..... \times 3600}{.....} \times \frac{.....}{.....}$
= 42kW		= kW	= kW	= kW

WORKSHEETS

ELECTRICAL ENERGY CONSUMED - ELECTRONIC METER



Worked example		Your readings		
Electricity meter		meter 1	meter 2	meter 3
1. Register reading at start	= 1253.64	R1 = ...	R1 = ...	R1 = ...
2. Register reading at finish	= 1254.16	R2 = ...	R2 = ...	R2 = ...
3. Time between readings	= 1800 s (30 min)	T = ...	T = ...	T = ...
4. Multiplier as stated on power bill	= 40	M = ...	M = ...	M = ...
5. kW per meter				
= $\frac{(R2 - R1) \times 3600 \times M}{T}$	= $\frac{0.52 \times 3600 \times 40}{1800}$	= $\times 3600 \times$	= $\times 3600 \times$	= $\times 3600 \times$
= 41.6kW (42kW)		= kW	= kW	= kW
6. Flow rate (Q) = 58 litres per second		= litres/second	= litres/second	= litres/second
7. Pump calibration				
= $\frac{\text{kW used}}{Q \times 0.0036}$	= $\frac{42 \text{ kW}}{58 \times 0.0036}$	= $\times 0.0036$	= $\times 0.0036$	= $\times 0.0036$
= 201 kWh/ML		= kWh/ML	= kWh/ML	= kWh/ML
8. Pumping costs		@ cents/kWh	@ cents/kWh	@ cents/kWh
Cost @ 12 cents/kWh = $201 \times \$0.12$		Cost = ... $\times \$$	Cost = ... $\times \$$	Cost = ... $\times \$$
= \$24.12 per megalitre		= \$ per megalitre	= \$ per megalitre	= \$ per megalitre

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PRIMARY INDUSTRIES

Is your diesel pump costing you money?

Agfact E5.12, August 2004

Peter Smith
Irrigation Officer
Tamworth

Measuring the running costs and pump efficiency of diesel engine powered irrigation pumps

A random series of tests along the Murray, Hunter, Peel, Macquarie and Lachlan rivers found that about 50% of irrigation pumps were performing poorly. This was due to either incorrect pump selection or wear.

Poor pump performance means increased pumping costs, and possibly also reduced productivity because the pump is not delivering the correct amount of water to the crop.

Testing your pump will show if it is performing properly. This Agfact describes simple methods to work out your pumping costs and the efficiency of your diesel-powered pump.

PUMP EFFICIENCY

Pump efficiency is a measure of how well the pump converts diesel fuel to useful work moving water. The aim of careful pump selection and regular pump maintenance is to have the pump performing as efficiently as possible, because this gives the lowest running costs.

An acceptable efficiency for a centrifugal irrigation pump is above 65%. An acceptable figure for a turbine pump is above 75%. An efficiency figure below these means either the wrong pump was chosen for the job or the pump is worn and needs repair.

The key to containing your pumping costs is to regularly monitor your energy usage and check on any significant change that suggests pump maintenance is needed.

TEST PROCEDURE

There are two parts to testing the performance of your pump.

The first stage is to work out how much fuel is used to pump a megalitre of water. The information required is the amount of **fuel used** and the volume of **water pumped**. If you know how much you are charged for fuel, the cost of pumping can then be readily calculated.

The second stage is to work out the pump efficiency. The information required is the **fuel consumption** and the **total dynamic head** (or pump pressure). The efficiency can then be roughly calculated and compared to the manufacturer's specifications.

Both parts are explained below in a series of nine steps. When these steps are completed, you can perform quick checks from time to time to see if anything has changed, and you can estimate if the cost of repair is worth it.

A. WHAT IS THE PUMPING COST?

To work out the cost of pumping, you measure the **fuel used** and the **water pumped**. The fuel in litres (L) of diesel used to pump one megalitre (ML) is calculated from these figures.

Step 1. Measure the fuel used

To obtain a fairly accurate idea of consumption, the fuel used for an entire irrigation should be measured. This can be done by starting with a full tank and measuring how much is needed to refill the tank after irrigating, or by taking dipstick readings before and after irrigating.

DIPSTICK READINGS	
Start time (T1):	2.12 pm
First dipstick reading (F1):	1800 litres
Finish time (T2):	8.12 pm
Second dipstick reading (F2):	1638 litres

From this data you can calculate the fuel used per hour.

FUEL CONSUMPTION
$= (F1 - F2) \div (T2 - T1)$
$= (1800 - 1638) \div (8.12 - 2.12)$
$= 162 \div 6$
$= 27 \text{ L/h}$

This calculation, performed regularly over a season or across seasons, will be a useful check on general fuel consumption.

If you find that, with the pumping water level the same and with the irrigation set up the same, the energy consumption is now higher, you know straightaway something has changed and you should investigate further.

When comparing figures, be sure they are from the same operating set-up, that is, pump operating at the same revs, valves or gates opened the same amount, irrigation system in the same position, with the same number of sprinklers, and so on.

Step 2. Measure the flow rate (Q)

The flow rate of your irrigation system (Q) is the volume or quantity of water pumped in a certain time – for example, litres per second (L/s).

Flow rate is obtained by taking readings from your water meter at the pump over, say, half an hour and dividing the volume (litres L, kilolitres kL, or megalitres ML) pumped by the time.

WATER METER READINGS	
Reading at start:	1108.345 kL
Reading after 35 mins:	1286.845 kL



Water meter

FLOW RATE
$= (\text{final meter reading} - \text{start meter reading}) \times 1000 \times (60 \div \text{measured time})$
$= (1286.845 - 1108.345) \times 1000 \times (60 \div 35)$
$= 178,500 \text{ litres} \times (60 \div 35)$
$= 306,000 \text{ L/h}$
$= 0.306 \text{ ML/h}$

Step 3. Calculate the fuel per megalitre pumped

From its fuel usage and flow rate, the litres per megalitre (L/ML) for your pump can be calculated.

FUEL per ML
$= \text{fuel (L/h)} \div \text{water (ML/h)}$
$= 27 \div 0.306$
$= 88.2 \text{ L/ML}$

Calculating this figure a couple of times over a season or between seasons allows you to check your pump's performance. If the value changes, you should look for the reason.

Step 4. Calculate the pumping cost

To calculate the variable cost of pumping, you need to know the cost per litre of diesel. If diesel costs 65 cents per litre on farm:

PUMPING COST
= 88.2 L/ML x \$0.65
= \$57.33/ML

B. HOW EFFICIENTLY IS THE PUMP OPERATING?

The pressure or head and flow that a pump is supplying is called the **duty** or **duty point**. Pump efficiency varies over the range of possible duties for any specific pump.

You can roughly work out the efficiency of your diesel powered pump by using the cost of pumping, the specific fuel consumption of the engine, and the overall pressure, or total dynamic head (H), of the system.

CAUTION: Because this method includes both pump efficiency and engine efficiency, it is only a guide. We are assuming that the engine is in good running condition. If the results are very different from those expected, the problem may not only be with the pump: the engine may need some attention.

Overall pressure or **total dynamic head** is the pressure at the pump discharge plus the height from the water level to the centre line of the pump (the suction lift) and suction losses. (This figure is only approximately equal to the total dynamic head, because there are many variables which are difficult to measure.)

After working out your pump's duty and efficiency, you can then find your pump's duty point on the manufacturer's performance curves, and read the efficiency at which the pump was designed to operate. The two efficiency figures can then be compared to see if there is room for improvement and therefore possibly a reduction in costs.

(For surface irrigation systems, skip step 5 and 6 below. An adequate estimate of total dynamic head for surface systems is the vertical height in metres from source water level to the end of the discharge pipe, or, if the discharge is submerged, to the height of the water above the

discharge, that is, water level to water level, plus suction losses due to friction.)

Step 5. Determining total head

a. Measure discharge or delivery head

This is the pressure read from the gauge fitted at the pump when the system is at full operational pressure. This reading needs to be converted to equivalent metres of head.

TIP: New pumps usually have a pressure gauge installed but they often suffer physical damage quickly. A better method is to weld or braze a small nipple and gas cock onto the delivery side of the pump where you can temporarily install a pressure gauge whenever you want to take a reading. The gauge can be easily detached when not needed.

A change in pump operating pressure through the season or across seasons, when irrigating the same block or shift, immediately tells you something has changed. A sudden reduction usually indicates a new leak or a blockage on the suction side; a gradual reduction usually indicates wear of the impeller or sprinkler nozzles; and an increase usually suggests a blockage somewhere after the pressure gauge.

Pressure can be thought of as equivalent to a pipe of water of a certain height in metres. This is referred to as 'head' (H). At sea level, the pressure at the bottom of a pipe of water 10 metres high is about 100 kilopascals (kPa).

HEAD	PRESSURE
5 m	50 kPa
10 m	100 kPa
15 m	150 kPa
20 m	200 kPa
25 m	250 kPa
30 m	300 kPa

If your pressure gauge reads only in psi, convert to kPa by multiplying by 6.9.

CONVERTING TO kPa
70 psi
= 70 x 6.9
= 483 kPa
= 48 m head

b. Suction head

Suction head is the distance between the centre line of the pump and the source water level plus losses in the suction pipe if the pump is positioned above the water level. Typical suction head figures for centrifugal pumps are 3 to 5 metres unless there is an unusual condition.

Most problems with pumps positioned above the water level occur in the suction line, so ensure everything is right. Common problems include blocked inlet or foot valve or strainer, pipe diameter too small, pipe damaged or crushed, suction height too great, air trap at connection to pump.

Turbine and axial flow pumps must be submerged to operate, so they do not have any suction head.

Total pumping head
= discharge head + suction head
(for example)
= 48 m + 3 m suction head
= 51 m

Step 6. Engine derating (Dr)

Specific fuel consumption is the amount of fuel used per kilowatt-hour of energy produced by the engine. It is found by dividing the fuel consumption (L/h) by the power produced by the engine (kW).

For example, if this engine was producing 108 kW of power, the specific fuel consumption is $27 \div 108 = 0.25$ L/kWh.

Specific fuel consumption is about 0.25 L/kWh at sea level at 25°C for most large diesel engines (over 70 kW). For smaller engines it is about 0.3 L/kWh. A more accurate figure may be obtained from the engine manufacturer's performance sheets. Specific fuel consumption varies depending on altitude, temperature, general condition of the engine (especially the air filter), auxiliary fittings, and so on.

If the altitude is significantly above sea level, the power produced by diesel engines is less. If the diesel engine is, for example, 200 m above sea level, it will produce 99% of the power at sea level. For our calculations, this is expressed as a decimal, 0.99.

Derating factors (Dr) are shown in the table below.

DERATING FACTORS	
Sea level	100% (1.00)
200 m above sea level	99% (0.99)
400 m above sea level	98% (0.98)
600 m above sea level	97% (0.97)
800 m above sea level	96% (0.96)
1000 m above sea level	95% (0.95)

Step 7. Determine transmission losses (Df)

If the engine is not directly coupled to the pump, there is a loss of energy through the transmission.

This loss is taken into account by what is termed the **drive factor** (Df).

If the loss is 5%, then $Df = 0.95$.

For V-belt drives, Df is 0.90.

For gear drives, Df is 0.95.

If the pump is directly coupled, $Df = 1.0$.

Step 8. Calculate pump efficiency

Pump efficiency using a diesel engine can be estimated from the following calculation:

Efficiency (%)

$$= \frac{272 \times \text{pump head (H)} \times \text{L/kWh} \times \text{cost/L distillate}}{\text{cost/ML} \times Dr \times Df}$$

PUMP EFFICIENCY FACTORS	
Cost of fuel (Step 4)	\$0.65
Pumping cost per ML (Step 4)	\$57.33
Total head (Step 5)	51 m
Engine derating at 200 m (Dr) (Step 6)	0.99
Transmission loss (Df) (Step 7): gear drive	0.95
PUMP EFFICIENCY % CALCULATION	
$Pe (\%) = \frac{272 \times H \times L/kWh \times \text{fuel cost}}{\text{pumping cost} \times Dr \times Df}$	
$= \frac{272 \times 51 \times 0.25 \times 0.65}{57.33 \times 0.99 \times 0.95}$	
=	42%

Because this efficiency figure is approximate, use it as a guide only. If it is much worse than the value the manufacturer's performance sheets indicate, repair is probably needed.

Step 9. Calculating potential cost saving

Most centrifugal pumps are designed to operate at about 70% efficiency, and most turbine pumps are designed to operate at about 80% efficiency.

The pump in our example is only about 42% efficient. How much would be saved by improving the efficiency from 42% to 70%?

Our pumping cost is \$57.33 per ML. The improvement is calculated as follows:

COST SAVING per ML
$= \$57.33 - \frac{(\$57.33 \times 42)}{70}$
$= 57.33 - 34.40$
$= \$22.93$

If 900 ML are pumped during a season, the total cost saving is $\$22.93 \times 900 = \$20,637.00$.

If impeller wear is the problem, and the cost of replacement is \$8000, it would be paid for in about a third of a season, and after that the savings are increased profit.

Notice that a reduction in the pump efficiency figure of 28% (70% to 42%) causes an increase in pumping cost of 67% (\$34.40/ML to \$57.33/ML).

OTHER FACTORS THAT AFFECT COST AND PUMP EFFICIENCY

Pump speed

The manufacturer's pump performance charts are usually produced for specific pump speeds and impeller sizes.

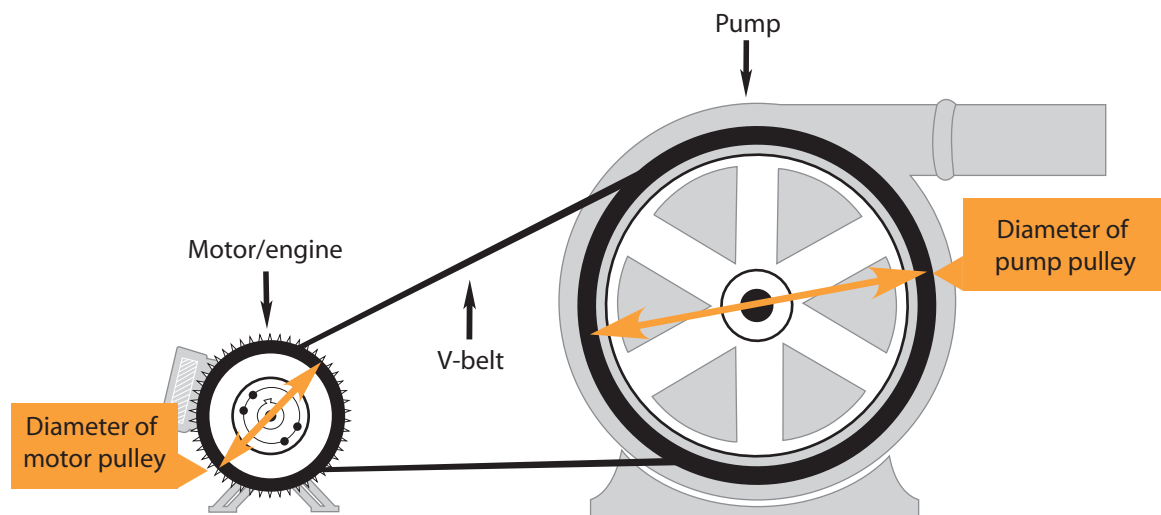
The pump speed must be known in order to interpret the manufacturer's pump performance charts. Because diesel engines can be set to run at any rpm within their range, it is essential to know the rpm. If a rev counter is not fitted, obtain a portable unit.

If the engine is not directly coupled to the pump, the speed is altered by the gearing ratio of the transmission. Gear drives normally have the ratio stamped on the identification plate. The ratio for a V-belt and pulley drive can be calculated from the diameter of the pulleys on the motor and the pump (see diagram below).

Impeller size

The manufacturers may offer impellers of different diameters for the same pump casing to give a different range of duties. The impeller sizes available are shown on the performance charts. You need to know the diameter of the impeller fitted to your pump to work out which performance curve applies to your pump.

Sometimes an impeller is deliberately reduced in diameter to a non-standard size to adjust the



pump's performance and obtain a specific duty, particularly in direct coupled units. Sometimes the impeller size is stamped on the pump's ID plate. If not, you need to find out the size by dismantling the pump and measuring it, or asking the person who made the change.

Impeller wear has the same effect as a reduction in size, that is, it reduces the pump flow rate and efficiency.

CONCLUSION

Keeping track of your pump's performance and costs is not difficult. It may save you a lot of money and keep your irrigation system performing properly.

TYPICAL PUMPING COSTS FOR DIFFERENT SYSTEMS

Irrigation system	Total head (m)	Diesel @ 45 cents per litre	Diesel @ 55 cents per litre	Diesel @ 65 cents per litre
Furrow (river)	10	\$6.00	\$7.00	\$8.00
Furrow (bore)	45	\$37.00	\$45.00	\$53.00
Pivot or linear move (river)	40	\$28.00	\$35.00	\$41.00
Pivot or linear move (bore)	70	\$40.00	\$49.00	\$58.00
Drip/jet spray	50	\$28.00	\$35.00	\$41.00
Spray (river)	55	\$31.00	\$38.00	\$45.00
Spray (bore)	65	\$37.00	\$45.00	\$53.00
Traveller (river), medium pressure	85	\$48.00	\$59.00	\$70.00
Traveller (bore), medium pressure	90	\$51.00	\$63.00	\$74.00
Traveller, high pressure	120	\$68.00	\$83.00	\$99.00

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Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing in July 2004. However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up-to-date and to check the currency of the information with the appropriate officer of NSW Department of Primary Industries or the user's independent adviser.

AGFACTS AGFACTS AGFACTS



NSW Agriculture

How efficient is your pump?

Agfact E5.11, first edition November 2003

Alan Richards, Irrigation Officer Maitland, and
Peter Smith, Irrigation Officer Tamworth

Random tests of pumps in many New South Wales river valleys found that about half were not performing efficiently, either because the wrong pump had been chosen for the job, or because the pump was worn.

If the pump is not doing its job, this can increase pumping costs and reduce productivity. To contain costs, you need to monitor your energy usage regularly and repair and maintain the pump to operate efficiently.

This Agfact describes a simple way to work out the efficiency of your electric pump. More information is given in the companion Agfact *How much does it cost to pump?*

When you have determined the pump efficiency, you can compare it to the manufacturer's figures to decide when repair or replacement is cost-effective.

IS THE PUMP EFFICIENT ?

The aim of careful pump selection and regular pump maintenance is to have the pump performing as efficiently as possible, because this gives the lowest running costs.

To calculate pump efficiency, you need to know the flow rate (Q; see also the Agfact *How much does it cost to pump?*) and the pump pressure, or total head (H) of the system. The pressure and flow that a pump is working at is called the **duty**. Efficiency changes with the range of possible duties for any specific pump.

When you have calculated the pump duty, you can compare it to the manufacturer's specifications shown in the pump's performance curves. By seeing the efficiency that the pump was designed to operate at, you can find out if you can improve its efficiency and thereby reduce pumping costs.

Pump efficiency measures how well the pump converts electrical power to useful work moving the water.

Pump efficiency = power output ÷ power input

An acceptable efficiency for a single impeller centrifugal irrigation pump, for example, is above 65%. A figure below this means either the wrong pump was chosen for the job, or the pump is worn and needs repair.



IRRIGATION ASSOCIATION OF AUSTRALIA

PUMP EFFICIENCY CALCULATIONS

Step 1. Measure power consumed

(See the Agfact *How much does it cost to pump?* for how to obtain these figures.)

$$\text{Power usage} = (N \times 3600 \times M) \div (R \times T)$$

Step 2. Measure flow rate

$$\text{Flow rate (Q)} = \text{litres pumped} \div \text{time in seconds}$$

Calculating duty in surface systems

For surface irrigation systems, an adequate estimate of total head is the height in metres from source water level to the end of the discharge pipe, or, if the discharge is submerged, to the height of the water above the discharge, plus suction losses.

Skip steps 3 and 4 if you are calculating pump efficiency in a surface system.

Step 3. Determine pressure head

Total head (H) is discharge head plus suction head.

Discharge head, or **pressure head**, is the pressure read from the pressure gauge fitted at the pump when the system is at full operational pressure.

Take this reading while you are measuring the flow rate.

Tip: use a temporary pressure gauge.

New pumps usually have a pressure gauge installed but they often suffer physical damage quickly. A better method is to weld or braze a small nipple and gas cock onto the delivery side of the pump where you can temporarily install a pressure gauge whenever you want to take a reading. The gauge can be easily detached when not needed.

A change in pump operating pressure through the season or between seasons immediately tells you something has changed:

- A sudden reduction usually indicates a new leak.
- A gradual reduction usually indicates wear of the impeller or sprinkler nozzles.
- An increase usually suggests a blockage somewhere.

Equivalent metres of head

The pressure gauge reading needs to be converted to equivalent metres of head.

Head (m)	5	10	15	20	25	30
Pressure (kPa)	50	100	150	200	250	300

If your pressure gauge reads only in psi, convert psi to kPa by multiplying by 6.9.

Example: 40 psi = $40 \times 6.9 = 276 \text{ kPa} = 27.6 \text{ m head}$

Overall pressure or total dynamic head is the pressure at the pump plus the height from the water level to the centre line of the pump (the suction lift) and suction losses.

Pressure can be thought of as equivalent to a pipe of water of a certain height in metres. This is referred to as 'head' (H). At sea level, the pressure at the bottom of a pipe of water 10 metres high is about 100 kPa.

Step 4. Determine suction head

Suction head is the distance between the centre line of the pump and the water level plus losses in the suction pipe. Typical suction head figures are between 3 and 5 metres. Add this to the pressure head to give **total head**.

Most problems with pumps occur in the suction line. Common problems include:

- blocked inlet
- pipe diameter too small
- pipe damaged or crushed
- suction height too great
- air trap at connection to pump.

Step 5. Determine motor efficiency

Electric motors have an efficiency value (Me): that is, they lose some of the energy going into them as heat. This energy loss changes with the size of the motor and the load on the motor, but you can assume an efficiency of 85% for motors up to 15 kW, and 90% above 15 kW.

Submersible motors are generally 4 points lower than other motors: for example, for a 22.4 kW 2-pole submersible, motor efficiency is 86%.

Step 6. Determine transmission losses

If the motor is not directly coupled to the pump, there is a loss of energy through the transmission.

Our calculations can include this loss by using a drive factor (Df). For example, if the loss of energy through the transmission is 5%, then the drive factor (Df) is 0.95.

- For V-belt drives, Df is 0.9.
- For gear drives, Df is 0.95.

Step 7. Calculate pump efficiency

$$\text{Pump efficiency} = (Q \times H) \div (\text{power used} \times \text{Me} \times \text{Df})$$

(Pump efficiency (Pe) is expressed as a percentage.)

This example includes the data from all the steps we have discussed:

Step 1.	
Power consumed	42 kW
Step 2.	
Flow rate (Q)	58 L/s
Step 3.	
Pressure at pump	276 kPa = $276 \times 0.1 \text{ m}$ = 27.6 m head
Step 4.	
Suction lift	4 m
Total head = pressure head + suction lift	= 31.6 m
Step 5.	
Motor efficiency	0.9 Me
Step 6.	
Transmission loss	0.9 for V-belt Df
Step 7.	
Pump efficiency	= $(Q \times H) \div (\text{power} \times \text{Me} \times \text{Df})$ = $(58 \times 31.6) \div (42 \times 0.9 \times 0.9)$ = 53.9%

Step 8. Calculating cost saving

A typical centrifugal pump is designed to operate above 65% efficiency.

The pump in this example is only about 54% efficient. If we checked the manufacturers' specifications for this pump, and found that this pump is designed to operate at 70%, we could now calculate the savings we could make if we repaired or replaced the pump.

If the pumping cost is \$24.12/ML, how much would be saved by improving the efficiency to 70%?

$$\begin{aligned}
 \text{Saving per ML} &= \$24.12 - (\$24.12 \times 54 \div 70) \\
 &= \$24.12 - \$18.61 \\
 &= \$5.51
 \end{aligned}$$

Notice that reducing pump efficiency by 16% (70% to 54%) increases the cost of pumping by 30% (\$18.61 to \$24.12).

For a season where 400 ML are pumped, the total cost saving would be $\$5.51 \times 400 = \$2204.00$

If impeller wear was the problem, then, with a replacement cost of \$1500, the improvement would pay for itself in less than one season. After that, the savings would increase the enterprise profit.

Pump speed

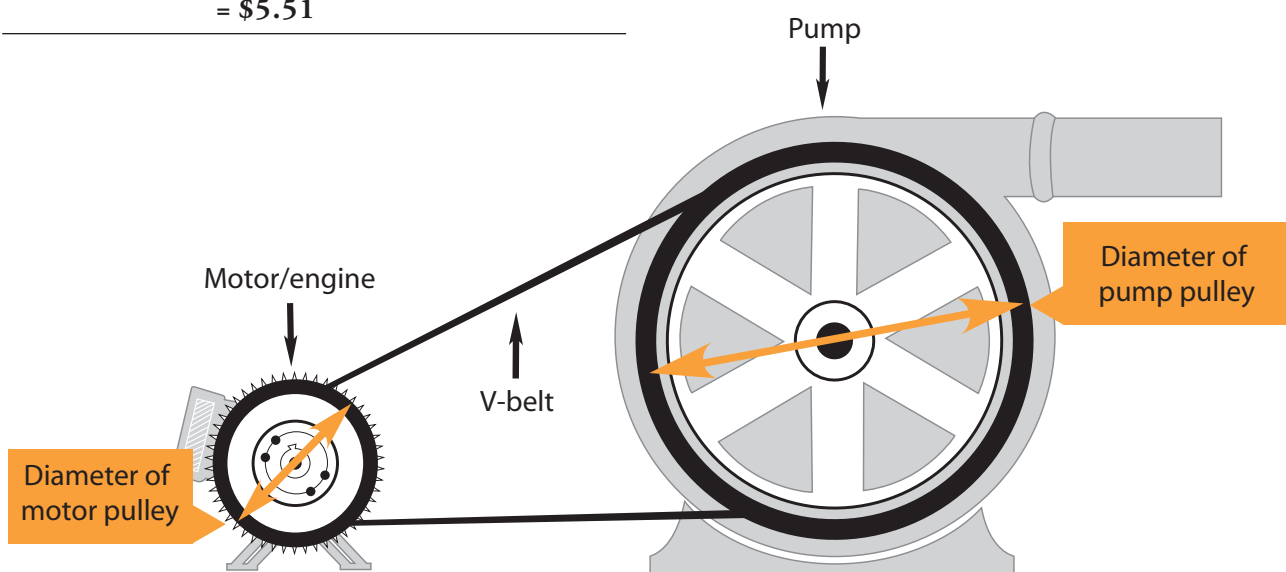
Two other variables affect cost and pump efficiency: pump speed and impeller size.

You must know the pump speed in order to read the pump curves. The curves are usually prepared for specific pump speeds and impeller sizes.

- If the pump is directly coupled to the electric motor, the speed is fixed by the speed of the motor: 2-pole motors run at 2900 rev/min and 4-pole motors run at 1440 rev/min.

Note: Because the speed of electric motors varies a little, it would be good to check your motor speed with a rev counter.

- If the motor is not directly coupled to the pump, the speed is altered by the gearing ratio of the transmission. Gear drives normally have the ratio stamped on the identification plate.
- The ratio for a V-belt and pulley drive can be calculated from the diameter of the pulleys on the motor and the pump; see diagram below.



$$\begin{aligned}
 \text{rev/min of motor} \times \text{diameter of motor pulley} &= \text{rev/min of pump} \times \text{diameter of pump pulley} \\
 \text{rev/min of pump} &= \text{rev/min of motor} \times \text{diameter of motor pulley} \div \text{diameter of pump pulley}
 \end{aligned}$$

PUMP EFFICIENCY WORKSHEET

	Worked example	Your readings
Power consumed	42 kW	
Flow rate (Q)	58 L/s	
Pressure gauge at pump:	276 kPa $\times 0.1 = 27.6$ m	
Suction lift:	5 m	
Total head (H)	= 27.6 + 5 = 32.6 m	
Motor efficiency (Me):	70 kW motor = 0.9	
Transmission loss (Df):	V-belt = 0.9	
Pump efficiency %	$Pe = \frac{Q \times H}{kW \times Me \times Df}$ $= \frac{58 \times 32.6}{42 \times 0.9 \times 0.9}$ $= 55.5\%$	

Impeller size

Impeller wear has the same effect as a reduction in size.

You need to know the size of impeller fitted to your pump to work out which performance curve applies to your pump. Sometimes the impeller size is stamped on the pump's ID plate. If not, you need to find out the size by dismantling the pump and measuring it, or asking the person who made the change.

Sometimes an impeller is deliberately reduced in diameter to adjust the pump's performance and obtain a specific duty.

To give a range of duties, manufacturers may offer impellers of different diameters for the same pump casing. Available impeller sizes are shown on the pump curves.

In conclusion

Worksheets are included with this Agfact to help you measure your pump performance and efficiency.

Keeping track of your pump's performance and costs is not difficult. It may save you a lot of money and keep your irrigation system performing properly.

Related Agfacts

Agfact E5.8 *Selecting an irrigation pump*

Agfact E5.10 *How much does it cost to pump?*

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PUMP EFFICIENCY WORKSHEET

Worked example		Your readings	Your readings
Power consumed	42 kW		
Flow rate (Q)	58 L/s		
Pressure gauge at pump:	$276 \text{ kPa} \times 0.1 = 27.6 \text{ m}$		
Suction lift:	5 m		
Total head (H)	$= 27.6 + 5 = 32.6 \text{ m}$		
Motor efficiency (Me):	70 kW motor = 0.9		
Transmission loss (Df):	V-belt = 0.9		
Pump efficiency %	$\begin{aligned} P_e &= \frac{Q \times H}{\text{kW} \times \text{Me} \times \text{Df}} \\ &= \frac{58 \times 32.6}{42 \times 0.9 \times 0.9} \\ &= 55.5\% \end{aligned}$		

Your readings	Your readings	Your readings
Power consumed		
Flow rate (Q)		
Pressure gauge at pump:		
Suction lift:		
Total head (H)		
Motor efficiency (Me):		
Transmission loss (Df):		
Pump efficiency %		



Selecting an irrigation pump

Agfact E5.8, 3rd edn, November 2003

Bill Yiasoumi

Irrigation Officer, Windsor

Farmers can select from a wide range of pumps for irrigation purposes. Some applications have special pump requirements, but there are many common considerations in the selection of an appropriate pump. Some of these are:

- discharge and pressure (or head) required
- suction conditions
- frequency of operation
- reliability required
- source of power available
- cost per unit of power
- capital cost, depreciation and interest charges
- physical constraints (for example, must the pump fit in a limited space such as a borehole?)
- shelter available (for example, will an electric motor need waterproofing?)
- potential for corrosion and wear
- facilities for maintenance.

The best pump for you depends on the type of irrigation system you have. The irrigation system and how you operate it will determine the pump performance you require. Descriptions of pumps and their performance will help you to select a suitable pump for your situation.

TYPES OF PUMPS

Pumps are classified in two main categories, based on how energy is given to the water.

The two types are:

- rotodynamic pumps (for example, centrifugal pumps, mixed flow pumps, mixed flow bore hole pumps and axial pumps)
- positive displacement pumps (for example, piston pumps, and helical-rotor pumps).

The principal requirement for pumping equipment used in commercial sprinkler irrigation is high efficiency against comparatively high pressures. This requirement usually limits pumps used for spray systems to rotodynamic pumps.

Rotodynamic pumps are also suited to the main requirement of surface irrigation systems: high efficiency against comparatively low heads.

Centrifugal pumps are widely used in agriculture and are a good example of the rotodynamic pump group.

However, for small systems requiring pump discharges of less than 2 L/s (2 litres per second), positive displacement pumps can be used under certain conditions. In irrigation terms, a pumping rate of 2 L/s is a very low flow and would be applicable to nurseries with misting jets, vegetable growers using drip irrigation, and domestic irrigation situations.

The two pump categories should be looked at separately since the basic principle of operation of each is different.

Rotodynamic pumps

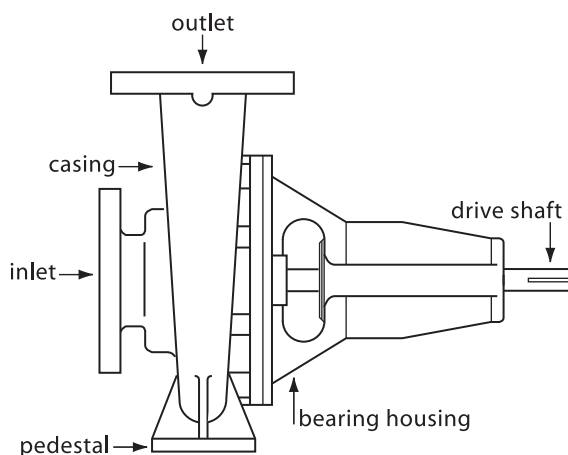
Rotodynamic pumps have a rotating impeller which gives energy to the water. The speed and size of the impeller determines the pressure and the rate of water flow out of the pump.

The two main types of rotodynamic pumps are the volute pump and the turbine pump.

Volute pumps are widely used in irrigation. They are of simple construction, the only moving parts being the impeller and shaft. The impeller is housed in a casing (volute).

The volute pump most often used for irrigation purposes is the (radial-flow) centrifugal pump.

A typical centrifugal pump



It can be installed with the pump shaft in the vertical or horizontal position. Its size is specified by the internal diameter at the discharge outlet.

The advantages of the centrifugal pump include the following:

- It can be installed above the water surface.
- It can be mounted on skids for rapid removal from danger of floods.
- Not being submerged, it is less liable to corrosion, although most can operate submerged for short periods without damage.
- It can be installed as a portable unit and used at more than one pumping site.
- Where its use is applicable, it is easy and cheap to install.
- It is cheap to maintain.

Where large quantities of water have to be pumped against low heads, mixed-flow volute (MFV) pumps are used. At low heads it is possible to get higher efficiencies with MFV pumps than with radial-

flow centrifugal pumps. Another advantage is that the power requirements (for a given speed) are approximately constant through the range of head and discharge.

Turbine pumps are mixed-flow and radial-flow (centrifugal) pumps which direct water to the discharge outlet with diffusion vanes. Axial-flow pumps, in which the impeller resembles a ship's screw, are generally classed with the turbines.

Since turbine pumps are most often used for pumping from bores, there is a limit on impeller diameter and the pressure which can be developed at a given speed. Volute pumps do not have this physical limitation. When high pressures are required from turbine pumps, extra impellers (stages) are added to the pump. Turbine pumps are driven by either a line-shaft or a submersible electric motor mounted below and close coupled to the pump.

The advantages of the turbine pump include:

For bores and wells:

- It can be driven by an engine.
- It is less prone to damage by silt and sand in the water than the electro-submersible pump.
- It is easier to maintain than an electro-submersible unit.

For dams, creeks and rivers:

- The prime mover can be mounted above flood level by extending the drive shaft.
- It can be used for supplies inaccessible to centrifugal pumps which would require too long a suction pipe.
- It can be used for high pressure conditions beyond the capacity of conventional centrifugal pumps.
- It can be used to pump silt- or sand-laden water unsuitable for an electro-submersible pump.

Electro-submersible pumps are turbine pumps that are close-coupled to an electric motor. The motor and pump are in the one unit with the motor underneath keeping the unit submerged. The motor depends on the water pumped for cooling, and a failure of the water supply can result in serious damage to the unit. The pump is dimensioned for use in bores and is very long in comparison to its diameter.

The advantages of the electro-submersible pump are:

- It does not have a long drive shaft.
- It may be installed in a misaligned bore.

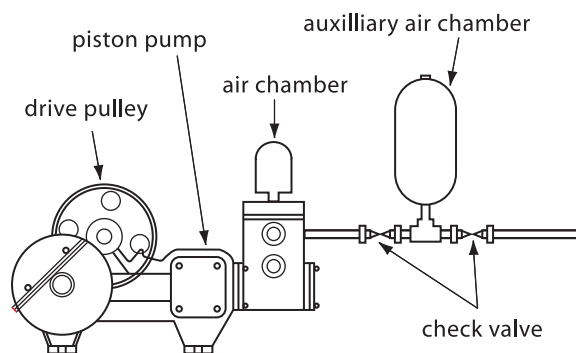
- It may be installed in rivers subject to flooding. As the pump has no above-ground working parts, the starting equipment, meter and transformer can be placed above flood level on a pole.

Jet pumps are single-stage centrifugal pumps fitted with a special assembly called an **ejector**. The ejector allows the pump to draw water from depths not possible with a conventional centrifugal pump. The disadvantage of jet pumps is their very poor efficiency and discharge when used in high pressure applications.

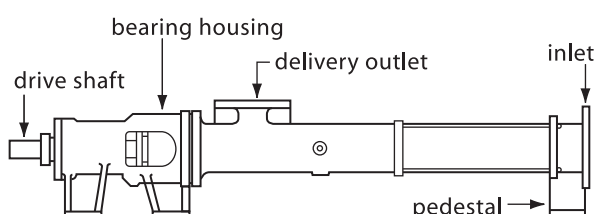
POSITIVE DISPLACEMENT PUMPS

The positive displacement (or reciprocating pump) consists of a piston (or displacer) moving in a cylinder from which liquid enters or leaves through a valve arrangement. The positive displacement pump is a low volume, high head pump, and so is not used extensively in irrigation systems. Where these pumps are used, they are most commonly in constant flow systems like drip, spray or mist irrigation.

Piston pumps have a horizontal cylinder sealed at both ends with a piston inside. As the piston moves backwards and forwards, water is drawn in during the suction stroke and discharged during the compression stroke. The discharge pulsates because of this and needs to be smoothed out using an air chamber in the delivery line.



Helical rotor pumps are single screw pumps consisting of a rigid screw-like rotor rolling with a slight eccentric motion in a resilient internal rubber lining (stator). The rotor and stator engage so that a constant seal between the two is maintained. The diameter, pitch and eccentricity of the rotor control the pump's performance.



The characteristic curve for helical rotor pumps is very steep: small changes in flow result in large changes in pressure.

All positive displacement pumps require a pressure relief valve downstream of the pump to protect the mainline.

VARIABLE SPEED PUMPS

Traditionally, electric motors have operated at a fixed speed. Variable speed technology allows pumps to operate at exactly the speed required for the pump duty, without the need for throttling the system. In long pipelines, using variable speed control can substantially reduce water-hammer effects.

Variable speed motors are more costly than fixed speed motors but they offer significant savings in power costs. Apart from these savings, many farmers are finding that variable speed drives provide the flexibility required for their range of irrigation demands.

These pumps are being installed as a single unit or as part of a multi-pump package (**packaged pressure systems**) combining variable and fixed speed pumps.

Packaged pressure systems (also called **pressure-boosting systems**) consist of two or more pumps operating in parallel. These systems combine variable speed and fixed speed pumps, and are used where a wide range of operating conditions is required. They give irrigators the flexibility to irrigate anything from a small poly house to several hectares of production.

The units are modular, and, provided there is an allowance for expansion, extra pumps can be added to cater for any planned farm development.

CHARACTERISTIC CURVES

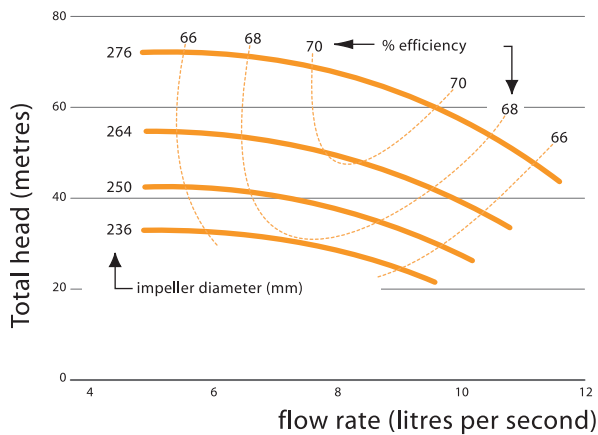
Pump manufacturers provide performance characteristics called pump characteristic curves. They are a graphical representation of the relationship between the variables involved in pumping:

- head
- discharge
- speed
- power
- susceptibility to cavitation (which limits suction lift).

For centrifugal pumps, the curves simplify the selection process. They can be presented in either one of two ways:

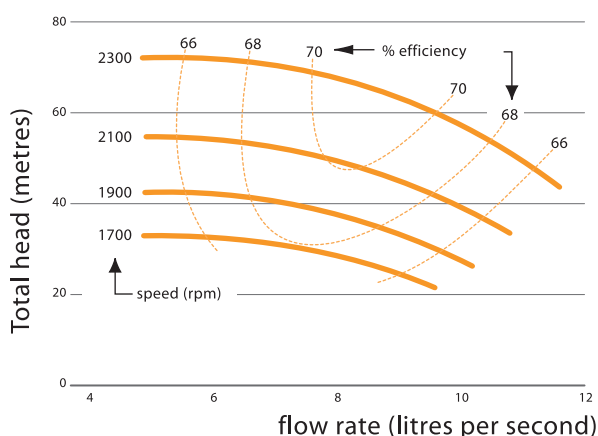
- at a constant speed with a set of head/discharge curves with various impeller diameters
- a set of head/discharge curves at varying speeds but with a constant impeller diameter

Performance curve, centrifugal pump — constant speed, different impeller diameters



To obtain an operating point on the characteristic curve we must know the pump duty. Pump duty is the basis of pump selection, and is the performance required of the pump. It is expressed in terms of flow rate (or discharge) and the total head (pressure) required. For example, in the second performance curve, a flow rate of 4 L/s and a total head of 25 m requires the pump to be operated at 2100 rpm for an efficiency of about 70%.

Performance curve, centrifugal pump — constant impeller diameter, different speeds



SUCTION PERFORMANCE

Most problems with volute pumps can be traced to the suction system.

Water is non-cohesive and cannot be pulled. It is not lifted by a pump, but pushed by atmospheric pressure to the low pressure area created at the suction inlet of the pump. The suction 'lift' a pump can handle is a function of pump design and atmospheric pressure.

Theoretically, the atmosphere at sea level will push water about 10 m up an evacuated column. This height is reduced by elevation, about 1.1 metres per 1000-metre increase in altitude. The actual suction lift must be less than this to allow for friction, pump design and pump wear.

Suction lifts are shown on some characteristic curves produced by pump manufacturers.

CAVITATION

Cavitation is the formation and subsequent collapse of bubbles (cavities) of vapour in the water. The bubbles form when the liquid boils. Boiling can happen without heating, when the absolute pressure of the water is reduced to the point where vapour bubbles form.

The water carries these bubbles to regions of higher pressure in the pump where they suddenly collapse. If the bubbles collapse near a metal surface, then pitting of the surface will occur. Cavitation is accompanied by noise and vibration, and the vapour bubbles decrease the performance (the **efficiency**) of the pump.

To avoid the undesirable and costly effects of cavitation, do not site the pump so that it has to raise water more than the limit of suction lift set by the manufacturer.

PROTECTION OR CONTROL EQUIPMENT

Controls for irrigation pumping equipment fall into two groups:

1. prime mover (engine or motor) protection
2. protection of the irrigation system.

A variety of pressure, temperature and water level sensing devices are available. They are usually fully automatic and are designed to override the manual control if anything happens which could damage the pumping unit or irrigation system.

1. Prime mover protection

Diesel engines running unattended should be protected against any failure of the pressure lubrication system, water cooling system or belt drive components, as applicable.

Electric motors are usually protected by sensing current rises or temperature rises, thus detecting electrical overloads.

Both types of prime mover should also be protected against overloads resulting from a change in delivery conditions. For example, a pipe failure with

rotodynamic pump system will result in a large increase in power demand, beyond that which can safely be met by the prime mover.

2. Distribution system protection

Pipelines usually break because of too much pressure. If a pipe breaks, then there is a risk of pump damage: crop losses around the break are also likely. A pressure-sensing device to stop the pump avoids both of these possible outcomes.

Pipeline protection can also be achieved by monitoring the pump output and taking care in the manual operation of valves, that is, closing and opening them slowly.

EFFICIENCY AND COST

With the ever-rising cost of power and the need to use water effectively, the overall efficiency of a pumping system will continue to be of major importance to farmers.

The selection of a pump, prime mover and piping to provide the best operating efficiency for your system will result in lower power costs. Good design also results in a longer component life, further reducing operating costs through lower maintenance costs.

Good design and correct pump selection will also assist you to use your water effectively.

The first place to begin looking at improving efficiency is at the pump. As the pump is a major energy consumer, any improvement in its efficiency reduces the cost of operating the system. However, other factors should also be considered. Further savings may be found in improved pump operation and maintenance and by the selection of system components (such as pipe diameters, valves and fittings) which do not add excessive head losses.

Effect of wear and corrosion

A major factor in the loss of performance of pumps is due to the everyday wear and corrosion on internal parts of the pump. Wearing down the impeller vanes, for example, reduces the effective impeller diameter and results in a general loss of performance over the full range of the pump characteristic curve. The three main types of physical deterioration are:

1. abrasion
2. corrosion
3. cavitation.

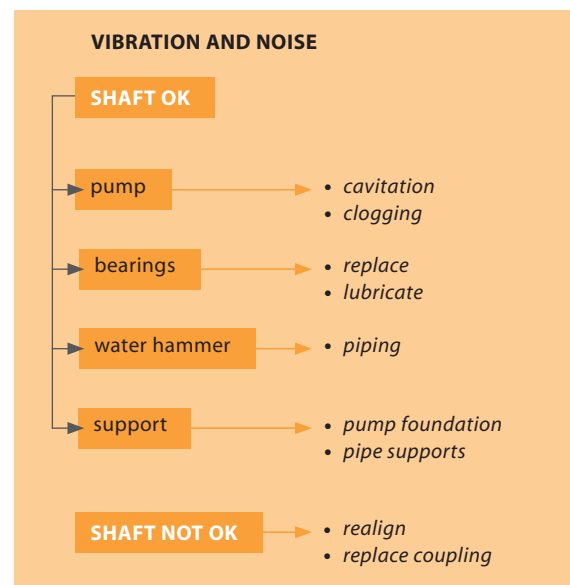
The rate of deterioration depends on:

- material type
- water quality

- temperature
- mechanical design
- maintenance schedule
- suitability of pump for the duty
- cavitation susceptibility.

TROUBLESHOOTING

These diagrams can be used to help identify and remedy common operating problems in centrifugal pumps, the most commonly used irrigation pumps. If the pump is noisy and vibrating:



If the pump does not start:

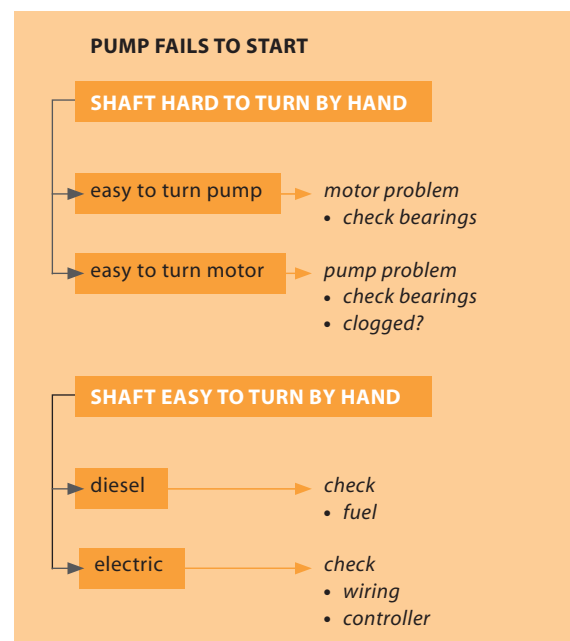


Table 1. Troubleshooting guide for centrifugal pumps

Problem	Possible solution
No water	prime pump head too high suction lift too high air leak in suction pipe suction pipe clogged
Not enough water	prime pump speed too low head too high suction lift too high air leak in suction pipe wrong foot valve size wrong foot valve submergence
Low pressure	speed too low air in water wrong impeller diameter pump wear impeller damage
Too much power used	speed too high mechanical defect
Pump works, then stops	air pocket in suction pipe suction lift too high wear in stuffing box

PUMPING DO'S AND DON'T'S

Do:

- site the pump as close as possible to the water
- make sure suction and delivery pipes do not put a strain on the pump casing
- check that all pipe connections are tight
- use a strainer recommended by the pump manufacturer
- anchor the pump securely so that it doesn't move during operation
- work the pump within its limits
- provide ventilation for the motor or engine
- keep the pump and motor connection aligned
- make sure the pump is primed before starting
- keep the strainer clean
- service the pump regularly.

Don't:

- pump corrosive liquids
- operate the pump without water
- operate the pump if the discharge valve is closed
- operate the pump if the strainer is blocked
- operate the pump if it is vibrating excessively
- install the suction pipes so that air can build up in them
- forget to do regular maintenance.

Related Agfacts on electric pumps

Agfact E5.10 *How much does it cost to pump?*

Agfact E5.11 *How efficient is your pump?*

Disclaimer

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Soil water monitoring: choosing the right device

Agfact AC.27, March 2002

David Williams

Irrigation Officer

Griffith

This Agfact is for irrigators who need to choose a soil water monitoring device.

Best management practice in irrigation includes regularly monitoring soil water levels throughout the irrigation season. NSW Agriculture encourages farmers to adopt and use long-term soil water monitoring to help achieve efficient water use, protect the environment, and maximise crop yields and quality. We also strongly recommend that, before you purchase any soil water monitoring device, you identify your individual requirements.

Sadly, too many decisions to purchase soil water monitoring equipment are made on price alone. After a short period of use, the equipment is abandoned, a wasted investment and a poor advertisement for soil water monitoring.

This Agfact can help you choose a device that matches your management style, crop and situation, the amount of information you need, and your budget.

1 WHAT INFORMATION CAN I GET FROM A SOIL WATER MONITORING DEVICE?

Soil water monitoring devices can provide a range of information. Some tools give simple 'wet/dry' measurements, which gives a basic guide to reducing plant stresses due to waterlogging or under-watering and to minimising irrigation water losses in the field.

What is the key information?

As a minimum, you need the device to provide soil water readings for the plant rootzone of a block before

and after an irrigation event. A reading following a rainfall event is also of benefit.

The reading before an irrigation shows how dry the soil is before irrigation. The reading after the irrigation or rainfall event shows how deep the water has gone: it can be used to indicate how much was applied.

A reading taken below the active rootzone of a crop will generally indicate if over-irrigation has occurred.

Don't buy any device until you answer each of these questions for your enterprise:

- 1 What information can I get from a soil water monitoring device?
- 2 How labour-intensive is the device?
- 3 How usable is the information from the device?
- 4 What level of accuracy do I need?
- 5 Does soil type affect my choice?
- 6 Does the irrigation system I use limit my choice?
- 7 Does crop type limit my choice of device?
- 8 What other site factors affect my choice?
- 9 How durable is the product?
- 10 How much maintenance will it need?
- 11 Can I afford it?
- 12 What should I do now?

If you take additional readings between irrigation events you can determine a pattern of water use.

Other tools can gather more complex information:

- depth and amount of irrigation
- root activity and development
- extent of any watertables within or just below a crop's rootzone
- irrigation timing and forecasting based on water use (known as **irrigation scheduling**)

There are many products (currently around forty) on the market that, in some way, determine the water content of soil, and they range in price, complexity, use and methods of data collection. (Only a small number, however, are in commercial use.)

2 HOW LABOUR-INTENSIVE IS THE DEVICE?

Devices where the irrigator has to collect information manually are more labour-intensive than devices that collect or log data automatically.

Labour availability is usually the least considered factor in the purchasing decision but lack of time/labour may be an important reason why irrigators abandon manual monitoring.

Manually read devices need to be read regularly throughout an irrigation season. Any missed readings result in incomplete data, which makes the data far less useful. The irrigator may then assume there is no benefit in collecting data, and abandons the monitoring operations midseason. The purchase cost is written off and the equipment, although sound, is left to gather dust. The soil water monitoring process has ceased because regular readings were not given priority.

If you choose to purchase a manually read device, you have to commit the labour required to undertake the readings. If you cannot guarantee this labour commitment, then you should consider other options such as **automatic logging devices** or a contract service.

3 HOW USABLE IS THE INFORMATION FROM THE DEVICE?

The information from soil water monitoring devices is often most useful when presented as **graphs** or **charts**: this makes it easier to compare and interpret data.

Some devices come with software to view and interpret data on date/time, soil water value and depth of

reading, or else this software may be available as an optional purchase. Most devices that are continuously logged come with comprehensive software which converts the data and presents this information in a convenient format. For other products you may need to use spreadsheet software to work with the data.

You may need extra training in operating the device and interpreting and analysing data from the device. Check with the supplier whether training is provided, and to what degree. Try and choose a device where you can get ongoing support and software updates. Are there grower support groups where results and other issues can be discussed?

Is any equipment needed to access and interpret the data (specially the data from electronic devices)? This equipment may be as simple as a pen and paper or as complex as a mobile phone or radio telemetry and computers. Is it included in the purchase? And can the data be printed or emailed?

4 WHAT LEVEL OF ACCURACY DO I NEED?

You need the device you select to have a level of accuracy that matches your irrigation system and the degree of control it allows. For example, if your system is capable of delivering varying amounts of water precisely, the device you choose should be accurate enough to provide detailed and frequent soil water use information. You would need less detail when system management is more basic or where water can only be supplied on roster.

The level of accuracy of a device is not always related to cost, and some low-cost devices are quite accurate. Note that hand-feel readings will not be as accurate as a device which directly and repeatedly measures soil water content.

Calibration

The device's ability to obtain consistent readings every time (**repeatability**) can be improved by **calibration**. In calibration, the readings from the device are compared to independent measures of soil water content: the method of calibration depends on the type of device.

Calibration can also be used to determine a volumetric reading for the soil water (often given in mm).

5 DOES SOIL TYPE AFFECT MY CHOICE?

Soil type can affect which device you can choose in that some of the sensors used by soil water monitoring

devices may be inaccurate in some **soil types**. For example, gypsum blocks in sand and capacitance probes in cracking clays may give inaccurate readings. Salinity may also affect the accuracy of some sensors.

Variations in soil type may occur over your farm or even over a block. You need to check that you have enough soil water monitoring sites to get representative data for the area being irrigated at that time.

6 DOES THE IRRIGATION SYSTEM I USE LIMIT MY CHOICE?

The characteristics of the irrigation system can affect what device is chosen or how it is installed.

Surface irrigation may impede access for manual readings, and may also cause problems by inundating sensors or access tubes, so waterproofing is important.

The distribution uniformity of a system affects how sensors may be placed. Drip and micro irrigation in particular require correct selection of representative monitoring sites.

7 DOES CROP TYPE LIMIT MY CHOICE OF DEVICE?

Yes, the profile and placement of the device must match the requirements of the crop at the monitored site.

- Deep-rooted plants may need more sensors, or single sensors that give readings at multiple depths.
- In annual crops, sensors have to be installed after emergence and removed at the end of the season.
- The machinery and human traffic in the crop affects how sensors can be placed. Lucerne is a particularly difficult crop to monitor because of the traffic during haymaking.

8 WHAT OTHER SITE FACTORS AFFECT MY CHOICE?

- Livestock grazing on crops also affects how data can be collected.
- Reading sensors manually could damage some crops and compact the soil around the sensor site: automatically logged devices may be a better choice for these situations.
- How is the device powered? Is this power available, and can the power source be protected in the field or in transit?

9 HOW DURABLE IS THE PRODUCT?

Both portable and permanent products need to be assessed for durability.

- Will the device stand up to damage from ultraviolet rays, moisture and extreme temperature?
- Livestock, pests and machinery traffic can damage fixed devices. Will water get into electronic parts, for example, or will the seals weather? What about lightning strikes?
- Portable products need to withstand possible damage in transport.

10 HOW MUCH MAINTENANCE WILL IT NEED?

Some devices may have particular maintenance needs or particular difficulties in servicing, and these have to be considered during your selection process.

- Look at mid-season and end of season **maintenance requirements**. Can you maintain it, or is dealer servicing required? Does it need to be sent away, and if so, how long for?
- Does the product come with adequate **dealer support**? Back-up service is crucial. If the product needs to be sent away, is a replacement product available? What is the likely turnaround for product repairs?

11 CAN I AFFORD IT?

In answering this question, assess both the initial and the annual costs of a product.

Initial cost is usually the most important factor considered by irrigators when a product is purchased. Cheaper products tend to be manually read and so can be more labour-intensive. If labour can be provided easily and cost-effectively, then this will not be an issue.

Where it does become an issue is when the true **cost of labour** is considered over the length of many full seasons. Here the cost of labour, mainly in the area of data collection, can be quite high, as readings are taken every two to three days at each site throughout the season.

It is important to look at methods such as the **automatic collection of data** as a means of reducing the labour cost of manual data collection. The trade-off is usually an increased initial purchase cost of a product, but in some cases, and on some crops, savings can be achieved between 5 and 10 years after purchase.

The issue of **annual costs** relates to maintenance both during and after the season, and re-installation costs in annual crops. Here the variation in cost between products lies with differing labour requirements and the need for dealer or outside support.

12 WHAT SHOULD I DO NOW?

- Talk to an Irrigation Officer from NSW Agriculture before any purchase.
- Consider doing an irrigation management course, such as the free WaterWise on the Farm *Introduction to Irrigation Management* course offered by NSW Agriculture, which shows how to determine soil variability, soil water characteristics and crop water use, evaluate irrigation system performance, and use soil- or climate-based methods for scheduling irrigation.
- Consider what level of scheduling you want to undertake.
- Match the device to your enterprise and your management style.
- Ensure adequate labour is available for manually read devices to be read regularly if it isn't, consider automatic read devices, or contractors.
- Talk to another irrigator who has successfully used the product or products that you are considering, and cover the questions we have listed in this Agfact. The supplier may have other purchasers who are happy to be contacted.

A list of soil water monitoring devices, categorised by method, and contact details for manufacturers and distributors are available from NSW Agriculture at www.agric.nsw.gov.au/reader/soilwater.

References

<http://www.sowacs.com/sensors/index.html>

Charlesworth, P 2000, *Information Package on Soil Water Monitoring*, CSIRO Land and Water Consultancy Report 03/00, prepared for LWRRDC's National Program for Irrigation Research and Development, February.

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Disclaimer

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DPI&F notes

Irrigation: water balance scheduling

*Graham Harris, DPI&F's Delivery Business Group, South region
and Staff of Australian Cotton Cooperative Research Centre*

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise net returns. The maximisation of net returns requires a high level of irrigation efficiency. This requires the accurate measurement of the volume of water applied or the depth of application.

It is also important to achieve a uniform water distribution across the paddock to maximise the benefits of irrigation scheduling. Accurate water application prevents over- or under-irrigation. Over-irrigation wastes water, energy and labour, leaches nutrients below the root zone and leads to waterlogging which reduces crop yields. Under-irrigation stresses the plant, resulting in yield reductions and decreased returns. To benefit from irrigation scheduling you must have an efficient irrigation system.

Advantages of irrigation scheduling

The advantages of irrigation scheduling include:

- The rotation of water amongst paddocks to minimise crop water stress and maximise yields.
- A reduction in energy, water and labour costs through fewer irrigations.
- A lowering of fertiliser costs through reduced surface runoff and deep drainage.
- Increased net returns through increased yields and improved crop quality.
- A minimisation of water-logging problems.
- Assisting control of root zone salinity problems through controlled leaching.
- Additional crops through savings in irrigation water.

Water-balance irrigation scheduling

Water-balance irrigation scheduling is the day-to-day accounting of the amounts of water coming into and going out of the effective root zone of a crop. It is based on estimating the soil water content in the crop root zone viewed as a system (see Fig. 1).

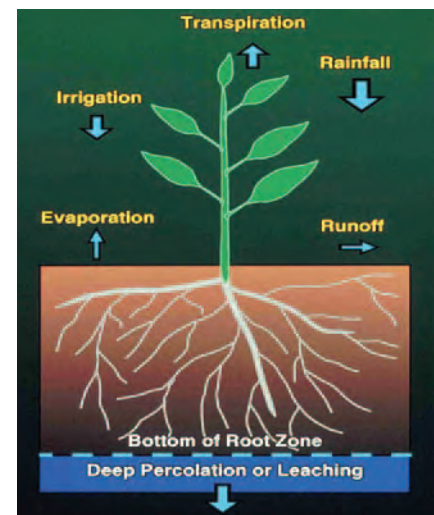


Figure 1: Soil water balance in irrigated cropping systems (courtesy of Colorado State University, USA).

Irrigation and rainfall add water to the root zone. Some water may be lost before entering the root zone as runoff. Some may drain below the root zone (and in some situations water can also enter the root zone from a high water table or water moving laterally through the ground). Water is also lost from the root zone through direct evaporation of water from the soil surface, and transpiration through the plants.

Information contained in this publication is provided as general advice only. For application to specific circumstances, professional advice should be sought. The Department of Primary Industries and Fisheries, Queensland, has taken all reasonable steps to ensure the information in this publication is accurate at the time of publication. Readers should ensure that they make appropriate inquiries to determine whether new information is available on the particular subject matter.

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The total water in the root zone on a particular day can be represented by the water balance formula:

	TW_T	=	$TW_{T-1} + Irr + Rain - ET_c - DEEP - Runoff + FLUX_{net}$
where:	TW_T	=	total water in the root zone on day T
	TW_{T-1}	=	total water in the root zone on the previous day (T-1)
	Irr	=	irrigation water applied
	Rain	=	rainfall
	ET_c	=	evapotranspiration (soil evaporation plus plant use)
	DEEP	=	drainage or percolation below the root zone
	Runoff	=	runoff
	$FLUX_{net}$	=	any change in total water in the root zone from underground water movement (e.g. high water table or water moving laterally in the ground).

The water balance approach to irrigation scheduling chooses a starting point total soil water in the root zone. Then the water balance equation is solved on a daily basis, considering the amounts of water that move into and out of the root zone for that day.

The basic steps for water balance irrigation scheduling of a paddock are:

1. Determine the depth of the effective root zone

The effective root zone (ERZ) of the crop is the depth of soil where you as the irrigator want to control soil moisture. It may or may not be the full depth of the plant roots. Table 1 shows the root depth at effective cover (when the crop has reached maximum ET_c and maximum rooting depth). The effective root zone where fully irrigated crops draw most of their water is usually between 60 cm and one metre. Although roots may be found below this depth, the bulk of the water extracted from the soil by an irrigated crop will come from the top one metre of soil.

Table 1: Ranges of maximum effective root depth (in metres) and soil water depletion fraction for no stress

Crop	Maximum root depth ¹ (m)	Depletion Fraction ²
Barley	1.0 to 1.5	0.55
Chickpea	0.6 to 1.0	0.50
Cotton	1.0 to 1.7	0.65
Maize	1.0 to 1.7	0.55
Millet	1.0 to 2.0	0.55
Mungbeans	0.6 to 1.0	0.45
Navy beans	0.6 to 0.9	0.45
Peanuts	0.5 to 1.0	0.50
Sorghum	1.0 to 2.0	0.55
Soybeans	0.6 to 1.3	0.50
Sunflower	0.8 to 1.5	0.45
Wheat	1.0 to 1.8	0.55

Source: Allen, R.G. et al (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56

1. The larger values for maximum root depth are for soils having no significant layering or other characteristics that can restrict root growth. The smaller values should be used for irrigation scheduling and the larger values for soil water stress or rain-grown conditions.

2. The Depletion Fraction values apply for $ET_c \approx 5$ mm/day. The value for the Depletion Fraction can be adjusted for different ET_c conditions using the formula $DF = DF_{Table 1} + 0.04 (5 - ET_c)$

2. Determine the Total Available Water

Available water is the amount of soil water in the effective root zone that is available to plants. Following heavy rainfall or irrigation, water will drain out of the root zone until the Drained Upper Limit (DUL) is reached (also known as Field Capacity) – this is the amount of water that the soil can hold against gravitational forces. Crops will use this water and lower the water content in the absence of further rain or irrigation. As the water content falls, the remaining water is held by the soil with greater force and it becomes more difficult for the plant to extract it. Eventually a soil water level is reached where the crop can no longer extract water – the Crop Lower Limit (CLL).

The difference between the water level at DLU and CLL is referred to as the Plant Available Water Content (PAWC) – it is measured in mm water per metre of soil depth. Different soils hold different amounts of PAWC. Table 2 shows the typical PAWCs for a range of soil types.

Table 2: PAWCs for a range of soil types

Soil type	PAWC (mm/m)
Coarse sand	35 to 60
Sand	60 to 75
Loamy sand	75 to 110
Sandy loam	100 to 160
Fine sandy loam	145 to 185
Loam	150 to 220
Silt loam	170 to 250
Clay loam and silty clay loam	170 to 220
Silty clay and clay	150 to 200

The Total Available Water (TAW) in the root zone is found by multiplying the PAWC by the depth of the

effective root zone. For example, a maize crop with an effective root zone of 0.8 m growing on a clay soil with a PAWC of 200 mm has a TAW of 160 mm (200 mm/m x 0.8 m).

3. Determine your Readily Available Water level

As the soil water level falls it becomes more tightly held by the soil and it is more difficult for plants to extract. Once the level falls below a threshold value, soil water cannot be transported quickly enough to crop roots to meet the demand of transpiration and the crop begins to stress. The fraction of TAW that a crop can extract from the root zone without suffering water stress is referred to as readily available water (RAW). It is found by multiplying TAW by the depletion fraction (DF) - the fraction of PAWC that can be depleted from the effective root zone before irrigation is necessary to minimise yield loss. The depletion fraction changes with crop and at different stages in crop growth. Depletion fractions for a range of full-grown irrigated crops are given in Table 1.

4. Determine your Refill Point

The Refill Point (RP) is the total soil water balance in the effective root zone at which irrigation is required. It is found by subtracting the readily available water (RAW) from the total soil water at the Drained Upper Limit in the effective root zone (TW_{DUL}).

5. Determine the starting point for total soil water in the Effective Root Zone

A starting point for soil water in the effective root zone (ERZ) is

needed before beginning to schedule irrigations. It can be established before or after crop emergence by direct measurement (gravimetric soil water sampling as described in *Soil Matters: monitoring soil water and nutrients in dryland farming*) or a calibrated soil-monitoring device such as a neutron moisture probe or a capacitance probe (for example an EnviroSCAN, Gopher or Diviner). Alternatively you can estimate it using software such as HOWWET. In furrow irrigated cropping systems it is often assumed that a pre-irrigation will fill the effective root zone to TW_{DUL} , but direct measurement will be more accurate. Once the starting soil water content is known it is possible to estimate it on successive days using the water balance formula.

6. Quantify water movement into and from the Effective Root Zone

Measure rain using rain gauges. Irrigation depth is calculated from the duration and rate of application of the irrigation system, or by dividing the total net amount of water applied by the irrigated area (this allows for the efficiency of the irrigation system, as none is 100% efficient). For an accurate estimate of irrigation depth you must measure its operational efficiency.

If the depth of rain or irrigation exceeds the depth of soil water depleted from the effective root zone the difference is considered to be deep drainage and/or runoff (the DEEP and RUNOFF terms in the water balance formula). The $FLUX_{net}$ is usually considered negligible although it can be significant where a perched water table exists.

The crop evapotranspiration (ET_c) term is the daily withdrawal figure from the soil water balance in the effective root zone. It is estimated from weather and crop information. The formula for estimating ET_c is:

$ET_c = K_c \times ET_0$ where: K_c = the crop coefficient which expresses the difference in evapotranspiration between the cropped and a reference grass surface. ET_0 = a grass reference crop evapotranspiration (mm per day).

ET_0 is calculated using the Penman-Monteith method and requires radiation, air temperature, air humidity and wind speed data. A number of automatic weather stations with sensors for these measurements calculate ET_0 using this method. Class A Pans are no longer considered adequate for estimating ET_0 owing to poor siting and maintenance.

The crop coefficient (K_c) integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. Thus different crops have different K_c coefficients. It also changes over the growing season with changes in crop development and with changes affecting soil evaporation. Estimates of K_c values for the major irrigated crops are presented in Table 3.

Table 3: Crop coefficients (K_c) for major irrigated field crops.

Crop	$K_{c \text{ initial}}$	$K_{c \text{ mid-season}}$	$K_{c \text{ end of season}}$
Barley	0.30	1.15	0.25
Chickpea	0.40	1.00	0.35
Cotton	0.35	1.15-1.20	0.70-0.50
Maize	0.30	1.20	0.35
Mungbean	0.40	1.05	0.35
Navy bean	0.40	1.15	0.35
Peanut	0.40	1.15	0.60
Sorghum	0.30	1.00-1.10	0.55
Soybeans	0.40	1.15	0.50
Sunflower	0.35	1.15	0.35
Wheat	0.30	1.15	0.25

Source: Allen, R.G. et al (1998) *Crop evapotranspiration: guidelines for computing crop water requirements*, FAO Irrigation and Drainage Paper 56.

The crop stages used to select a K_c value are:

1. Initial stage – planting until 10% ground cover.
2. Crop development stage – 10% to effective groundcover (around 70-80%).
3. Mid-season stage – 70-80% groundcover to the start of maturity.
4. Late season stage – the start of maturity until harvest.

The steps in constructing a crop coefficient curve similar to that in Figure 2 are:

1. Divide the growing period into the four crop stages above, determine their length and identify the corresponding K_c values from Table 3.
2. Adjust K_c values for frequent irrigation or rainfall events, humidity and wind speed.
3. Construct the curve by connecting straight lines through each of the growth stages as shown in Figure 2.

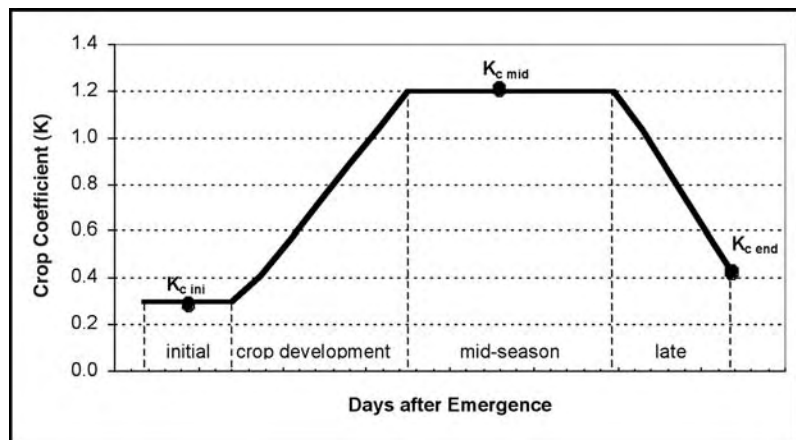


Figure 2: Crop coefficient curve.

7. The irrigation decision

Where the total water in the effective root zone falls below the Refill Point then the crop must be irrigated. The amount of irrigation required is equal to the TW_{DUL} less TW_r plus efficiency losses and any required leaching amount.

It is possible to predict future dates and amount of irrigation using long-term average reference evapotranspiration data, crop coefficient curves and knowledge of the effective root zone.

8. Use soil moisture checks to adjust water balance

The water balance approach to irrigation scheduling is based on estimates and is not always accurate. Actual readings of soil water using gravimetric soil water sampling or a calibrated soil-monitoring device such as a neutron moisture probe or a capacitance probe should be taken to update the estimated balance. This is most important following rainfall and irrigation events where estimation of their effectiveness can lead to errors in calculations of the water balance.

Although the calculations for the Water Balance Irrigation Scheduling approach are relatively simple, it is tedious. For this reason the use of irrigation scheduling software is recommended (for example, WaterSCHED) – this significantly increases the ease with which the soil water balance is calculated for each paddock on your farm.

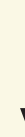
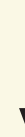
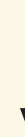
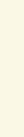
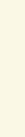
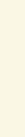
Example

A maize crop is planted on the 14 October into a clay soil with a drained upper limit water holding capacity (TW_{DUL}) of 450 mm/m and a plant available water content (PAWC) of 180 mm/m.

The maize crop has an effective root zone (ERZ) of 1 metre and a depletion fraction (DF) of 0.55 (see Table 1) – therefore the readily available water level (RAW) is 99 mm ($200 \times 1 \times 0.55$). The refill point (RP) is thus 351 mm ($450 \text{ mm} - 99 \text{ mm}$).

On the 17 December the soil water balance is 380 mm (measured using a neutron moisture meter). Table 4 is an extract from the WaterSCHED soil water balance sheet for this crop from this date.

Table 4: Extract from WaterSCHED soil water balance sheet for example maize crop.

Date	Days after planting	Ref ET (mm) ⁽¹⁾	Crop factor ⁽²⁾	Crop water use (mm) ⁽³⁾	Rainfall (mm) ⁽⁴⁾	Irrigation (mm) ⁽⁵⁾	Soil water balance (mm) ⁽⁶⁾	Average daily crop water use (mm) ⁽⁷⁾	Days to next irrigation ⁽⁸⁾
17-Dec	64	3.1	1.04	3.2			380	4.5	6
18-Dec	65	6.1	1.04	6.3			374	4.6	5
19-Dec	66	6.2	1.04	6.4			367	5.3	3
20-Dec	67	6.2	1.04	6.4			361	6.4	2
21-Dec	68	8.2	1.04	8.5		98	450	7.1	14
22-Dec	69	10.2	1.04	10.6			440	8.5	10
23-Dec	70	8.6	1.20	10.3			429	9.8	8
24-Dec	71	9.1	1.20	10.9			418	10.6	6
25-Dec	72	10.4	1.20	12.5			406	11.2	5
26-Dec	73	8.5	1.20	10.2			396	11.2	4
27-Dec	74	8.9	1.20	10.7			385	11.1	3
28-Dec	75	7.3	1.20	8.8			376	9.9	3
29-Dec	76	8.2	1.20	9.8			366	9.8	2
30-Dec	77	7.4	1.20	8.9	35		393	9.2	5
31-Dec	78	9.2	1.20	11.0			382	9.9	3
									

- Reference evapotranspiration (ET_0)
- Crop factor (K_c)
- $ET_c = K_c \times ET_0$
- Rainfall – all amounts should be included in table.
- Irrigation – effective irrigation amounts should be entered here.
- $TW_T = TW_{T-1} + Irr + Rain - ET_c - DEEP - \text{Runoff}$. Rainfall and irrigation amounts above that needed to increase the soil water balance to TW_{DUL} are considered lost as drainage below the root zone (DEEP) and runoff (Runoff).
- Daily crop water use averaged over the past three days.
- Estimated from the difference between the daily water balance and the refill point, divided by the average daily water use $\{[(6) - 351]/(7)\}$.

Further information

Allen, R.G. et al (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56.

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Irrigation water quality Salinity & soil structure stability

One of the major concerns with water used for irrigation is decreased crop yields and land degradation as a result of excess salts being present in water and in soils. Salinity is the term used when referring to the presence of soluble salts in or on soils, or in waters.

To assess the suitability of irrigation water in regards to salinity management, other factors must be considered besides water quality. These include salt tolerance of the crop being cultivated and the characteristics of the soil under irrigation. Climate, soil management and water management practices can also impact on the extent of salinity.

Do I have an irrigation salinity problem ?

To assess whether or not you have an irrigation salinity problem, the irrigation water must be analysed for a number of parameters. These are:

- Electrical conductivity (EC_i). This is measured in deciSiemens per metre (dS/m). The EC_i provided in a water analysis report may be shown in microSiemens per centimetre ($\mu S/cm$). This value can be converted to dS/m by dividing by 1000 i.e. 1 dS/m = 1000 $\mu S/cm$.
- Level of sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions present.

These values can then be used to determine the suitability of irrigation water to a particular irrigation situation as outlined below. For information on water sampling procedure, see fact sheet 'Sampling your water supply'.

Crop salt tolerance

The electrical conductivity (EC_i) is a measure of the salt content of the irrigation water. Another electrical conductivity measurement (EC_{se}), referred to as the average root zone salinity, determines the salt content of the soil-water in the crop's root zone.

EC_i can be used to calculate the average root zone salinity which will indicate which crops are suitable for cultivation on particular soils. This requires estimation of the average root zone leaching fraction (LF) of the soil under irrigation, i.e. the proportion of applied water moving below the root zone. This is shown in Figure 1.

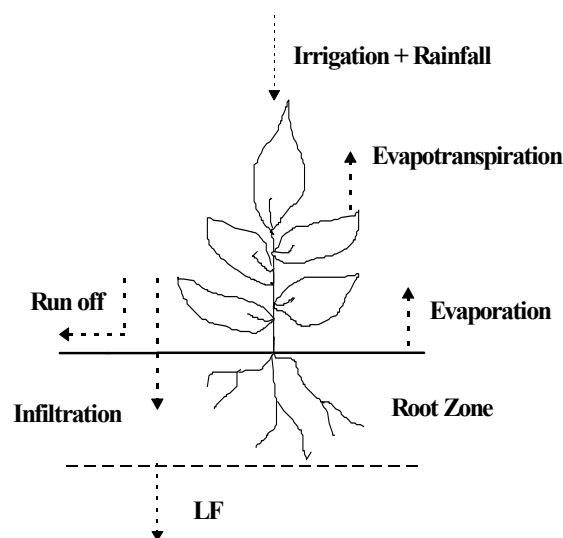


Figure 1 Diagram of the Leaching Fraction (LF) concept

Approximate average root zone leaching fractions for various soil types are listed in Table 1.

Table 1 Soil type and average root zone leaching fraction

Soil type	Average root zone LF
Sand	0.6
Loam	0.33
Light clay	0.33
Heavy clay	0.2

Average root zone salinity (EC_{se}) can then be calculated from the following equation:

$$EC_{se} = \frac{EC_i}{2.2 \times LF} \quad \text{where:}$$

EC_{se} = Average root zone salinity in dS/m

EC_i = Electrical conductivity of irrigation water in dS/m

LF = Average leaching fraction

The EC_{se} value can then be evaluated against the criteria in Table 2 to assess the general level of crop tolerance in the particular irrigation situation.

Table 2 Soil and water salinity criteria based on plant salt tolerance groupings

Plant Salt Tolerance Grouping	Water or soil salinity rating	Average root zone salinity EC_{se} (dS/m)
sensitive crops	very low	< 0.95
moderately sensitive crops	low	0.95 - 1.9
moderately tolerant crops	medium	1.9 - 4.5
tolerant crops	high	4.5 - 7.7
very tolerant crops	very high	7.7 - 12.2
generally too saline	extreme	> 12.2

A list of the relative salt tolerances of various common crop and pasture species is provided in **Table 3** on pages 3 and 4. The table gives approximate values of average root zone salinities at the threshold level (the level causing yield reduction). It also shows electrical conductivity of irrigation water at the threshold level for a range of soil types. It is meant as a general guide only.

Where there is uncertainty regarding crop salt tolerance in a particular irrigation situation, it is strongly recommended that a soil sample (representative of the profile under irrigation) be submitted for analysis and expert management advice be sought.

Soil structure stability

The EC_i value can also be used to predict soil structure stability in relation to irrigation water quality. The Sodium Adsorption Ratio (SAR) of irrigation water is also required for this. SAR can be calculated from the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where Na, Ca and Mg are expressed in milliequivalents per litre (meq/L). These values are provided in the water analysis report.

The SAR value measures the relative concentration of sodium to calcium and magnesium.

High concentrations of sodium in irrigation water can result in the degradation of well-structured soils. This will limit aeration and soil permeability to water, leading to reduced crop growth.

Figure 2 shows how to evaluate irrigation water quality in relation to its potential impact on soil structure using EC_i and SAR values.

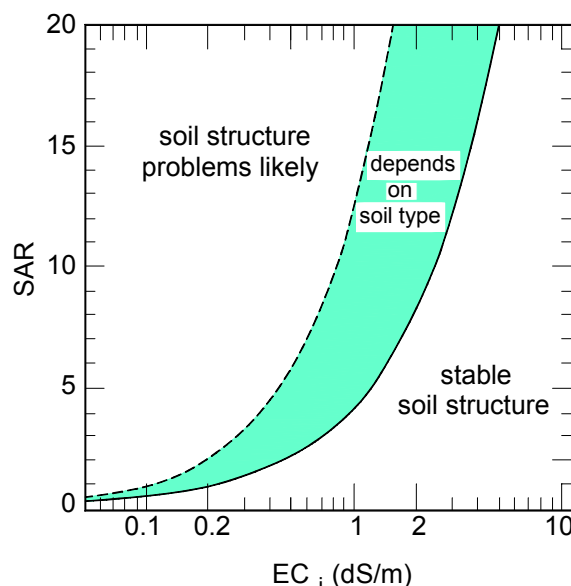


Figure 2 Relationship between SAR and EC_i of irrigation water for prediction of soil structure stability

Water quality that falls to the right of the solid line is considered satisfactory for use, while values to the left are considered unsatisfactory and will require management. Values that fall in between the lines (indicating marginal water quality) should be treated with caution.

Where there is uncertainty regarding the effect of irrigation water quality on soil structure stability, it is strongly recommended that a soil sample (representative of the profile under irrigation) be submitted for analysis. Expert management advice should also be sought.

Both crop salt tolerance and the effect on soil structure stability needs to be taken into account when determining the suitability of irrigation water.

Reference

Chapter 4 of the “**Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)**” provides further information on water quality for irrigation and stock watering. You can purchase this publication from the Commonwealth Department of Environment and Heritage via their web site at www.deh.gov.au/water/publications/index.html

Further information

Fact sheets on water and other topics are available from Natural Resources, Mines and Energy (NRM&E) offices and service centres or can be downloaded at www.nrme.qld.gov.au/factsheets

You can also contact NRM&E on (07) 3896 3111; or Toll free (outside Brisbane metro) 1800 803 788 or send an email to Enquiries@nrme.qld.gov.au

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Table 3 Tolerance of plants to salinity in irrigation

Common name	Scientific name	Average root zone salinity threshold (EC _{se})	EC _c threshold for crops growing in		
			sand	loam	clay
Field Crops					
Sorghum, crooble	<i>Sorghum alnum</i>	8.3	11.6	6.6	3.9
Barley, grain	<i>Hordeum vulgare</i>	8	12.6	7.2	4.2
Cotton	<i>Gossypium hirsutum</i>	7.7	12.1	6.9	4.0
Beet, sugar	<i>Beta vulgaris</i>	7	11.0	6.3	3.7
Sorghum	<i>Sorghum bicolor</i>	6.8	9.4	5.3	3.1
Safflower	<i>Carthamus tinctorius</i>	6.5	8.2	4.7	2.7
Wheat	<i>Triticum aestivum</i>	6	9.4	5.3	3.1
Wheat, durum	<i>Triticum turgidum</i>	5.7	9.6	5.5	3.2
Sunflower	<i>Helianthus annual app.</i>	5.5	7.5	4.3	2.5
Oats	<i>Avena sativa</i>	5	7.0	4.0	2.3
Soybean	<i>Glycine max</i>	5	7.0	4.0	2.3
Peanut	<i>Arachis hypogala</i>	3.2	4.4	2.5	1.5
Rice, paddy	<i>Oryza sativa</i>	3	4.8	2.7	1.6
Cowpea, Caloona	<i>Vigna unguiculata</i> var. <i>Caloona</i>	2	3.7	2.1	1.2
Corn, grain, sweet	<i>Zea mays</i>	1.7	3.2	1.8	1.1
Flax/Linseed	<i>Vinum usitatissimum</i>	1.7	3.2	1.8	1.1
Sugarcane	<i>Saccharum officinarum</i>	1.7	4.3	2.5	1.4
Cowpea (seed)	<i>Vigna unguiculata</i>	1.6	3.4	2.0	1.1
Phasey bean, Murray	<i>Macroptilium lathyroides</i>	0.8	2.7	1.5	0.9
Fruits					
Natal plum	<i>Carissa grandiflora</i>	6	7.6	4.3	2.5
Fig	<i>Ficus carica</i>	4.2	5.3	3.0	1.8
Date	<i>Phoenix dactylifera</i>	4	8.7	5.0	2.9
Olive	<i>Olea europaea</i>	4	5.1	2.9	1.7
Pomegranate	<i>Punica granatum</i>	4	5.1	2.9	1.7
Macadamia seedling		3.6	4.6	2.6	1.5
Peach	<i>Prunus persica</i>	3.2	4.7	2.7	1.6
Rockmelon	<i>Cucumis melo</i>	2.2	4.6	2.6	1.5
Grapefruit	<i>Citrus paradisi</i>	1.8	3.0	1.7	1.0
Orange	<i>Citrus sinensis</i>	1.7	2.9	1.7	1.0
Walnut		1.7	2.2	1.2	0.7
Apricot	<i>Prunus armeniaca</i>	1.6	2.5	1.4	0.8
Almond	<i>Prunus dulcis</i>	1.5	2.7	1.5	0.9
Blackberry	<i>Rubus</i> spp.	1.5	2.5	1.4	0.8
Boysenberry	<i>Rubus ursinus</i>	1.5	2.5	1.4	0.8
Grape	<i>Vitis</i> spp.	1.5	3.3	1.9	1.1
Plum(Prune)	<i>Prunus domestica</i>	1.5	2.5	1.4	0.8
Avocado	<i>Persea americana</i>	1.3	2.3	1.3	0.8
Guava, pineapple	<i>Feijoa sellowiana</i>	1.2	1.5	0.9	0.5
Apple	<i>Malus sylvestris</i>	1	2.0	1.2	0.7
Lemon	<i>Citrus limon</i>	1	1.3	0.7	0.4
Pear	<i>Pyrus</i> spp.	1	1.3	0.7	0.4
Raspberry	<i>Rubus idaeus</i>	1	1.3	0.7	0.4
Strawberry	<i>Fragaria</i>	1	1.6	0.9	0.5
Lychee		0.8	1.0	0.6	0.3
Pastures					
Urochloa	<i>Urochloa mosambicensis</i>	8.5	11.8	6.7	3.9
Wheatgrass, fairway	<i>Agropyron cristatum</i>	7.5	11.3	6.4	3.7
Wheatgrass, tall	<i>Agropyron elongatum</i>	7.5	12.5	7.2	4.2
Rhodes grass, Pioneer	<i>Chloris gayana</i>	7	12.8	7.3	4.2
Couch grass	<i>Cynodon dactylon</i>	6.9	10.8	6.1	3.6
Barley, forage	<i>Hordeum vulgare</i>	6	9.4	5.3	3.1
Barley, hay	<i>Hordeum vulgare</i>	6	9.4	5.3	3.1
Buffel grass, Nunbank	<i>Cenchrus ciliaris</i> var <i>Nunbank</i>	6	9.5	5.4	3.2
Buffel grass, Gayndah	<i>Cenchrus ciliaris</i> var <i>Gayndah</i>	5.5	8.2	4.7	2.7
Trefoil, birdsfoot	<i>Lotus corniculatus tenuifolium</i>	5	7.6	4.3	2.5
Phalaris	<i>Phalaris tuberosa</i> (aquatica)	4.2	5.3	3.0	1.8
Fescue	<i>Festuca clatior</i>	3.9	7.3	4.2	2.4
Wheatgrass, crested	<i>Agropyron desertorum</i>	3.5	7.6	4.3	2.5
Barrel medic, Cyprus	<i>Medicago truncatula</i>	3	4.7	2.7	1.6
Green panic, Petri	<i>Panicum maximum</i>	3	5.6	3.2	1.8
Kikuya grass, Whittet	<i>Pennisetum clandestinum</i>	3	8.0	4.6	2.6
Leichhardt	<i>Macrotyloma uniflorum</i>	3	4.6	2.6	1.5
Trefoil, big	<i>Lotus uliginosus</i>	3	4.9	2.8	1.6
Sudan grass	<i>Sorghum sudanense</i>	2.8	6.5	3.7	2.1
Setaria, Nandi	<i>Setaria speculata</i> var. <i>sericea</i>	2.4	4.0	2.3	1.3
Townsville stylo	<i>Stylosanthes humilis</i>	2.4	3.7	2.1	1.2
Sesbania	<i>Sesbania exaltata</i>	2.3	4.7	2.7	1.6
Desmodium, green leaf	<i>Desmodium intortum</i>	2.1	3.5	2.0	1.2
Clover, berseem Clover	<i>Trifolium alexandrinum</i>	2	3.8	2.2	1.3

Common name	Scientific name	Average root zone salinity threshold (EC _{se})	EC _e threshold for crops growing in		
			sand	loam	clay
Lovegrass	<i>Eragrostis</i> spp.	2	4.0	2.3	1.3
Lucerne, Hunter River	<i>Medicago sativa</i>	2	4.7	2.7	1.6
Lucerne (USA)	<i>Medicago sativa</i>	2	4.3	2.5	1.4
Pangola grass	<i>Digitaria decumbens</i> (pentzii)	2	5.7	3.3	1.9
Siratro	<i>Macroptilium atropurpureum</i>	2	4.2	2.4	1.4
Corn, forage	<i>Zea mays</i>	1.8	4.0	2.3	1.3
Glycine tinaroo	<i>Glycine ughtii</i>	1.8	3.5	2.0	1.2
Paspalum	<i>Paspalum dilatatum</i>	1.8	3.7	2.1	1.2
Clover, strawberry (Palestine)	<i>Trifolium fragiferum</i>	1.6	3.3	1.9	1.1
Clover, alsike, ladino, red	<i>Trifolium</i> spp.	1.5	2.9	1.7	1.0
Clover, white (Safari)	<i>Trifolium semipilosum</i>	1.5	2.9	1.7	1.0
Meadow foxtail	<i>Alopecurus pratensis</i>	1.5	3.2	1.8	1.1
Orchard grass	<i>Dactylis glomerata</i>	1.5	3.9	2.2	1.3
Snail medic	<i>Medicago scutellata</i>	1.5	2.9	1.7	1.0
Strand medic	<i>Medicago littoralis</i>	1.5	3.0	1.7	1.0
Cowpea (vegetative)	<i>Vigna unguiculata</i>	1.3	2.5	1.4	0.8
Barrel medic, Jemalong	<i>Medicago truncatula</i>	1	2.9	1.7	1.0
Clover, rose (Kondinin)	<i>Trifolium hirtum</i>	1	2.7	1.5	0.9
Clover, white (New Zealand)	<i>Trifolium repens</i>	1	2.5	1.4	0.8
Desmodium, silverleaf	<i>Desmodium uncinatum</i>	1	1.8	1.0	0.6
Dodonea	<i>Dodonea viscosa</i>	1	2.9	1.7	1.0
Dolichos Rongai	<i>Lablab purpureus</i>	1	2.0	1.2	0.7
Lotononis, Miles	<i>Lotononis bainesii</i>	1	2.3	1.3	0.8
Vegetables					
Kale	<i>Brassica campestris</i>	6.5	8.2	4.7	2.7
Zucchini	<i>Cucurbita pepo melopepo</i>	4.7	7.3	4.2	2.4
Rosemary	<i>Rosmarinus lockwoodii</i>	4.5	5.7	3.3	1.9
Asparagus		4.1	5.2	3.0	1.7
Beet, garden	<i>Beta vulgaris</i>	4	6.5	3.7	2.1
Squash, scallop	<i>Cucurbita pepo melopepo</i>	3.2	4.8	2.7	1.6
Broccoli	<i>Brassica oleracea</i>	2.8	4.9	2.8	1.6
Cauliflower	<i>Brassica oleracea</i>	2.5	3.2	1.8	1.1
Cucumber	<i>Cucumis sativus</i>	2.5	4.2	2.4	1.4
Pea	<i>Pisum sativum</i> L.	2.5	3.2	1.8	1.1
Squash	<i>Cucurbita maxima</i>	2.5	3.2	1.8	1.1
Tomato	<i>Lycopersicon esculentum</i>	2.3	3.5	2.0	1.2
Spinach	<i>Spinacia oleracea</i>	2	4.2	2.4	1.4
Cabbage	<i>Brassica oleracea</i> (var. <i>Capitata</i>)	1.8	3.5	2.0	1.2
Potato	<i>Solanum tuberosum</i>	1.7	3.2	1.8	1.1
Celery	<i>Apium graveolens</i>	1.8	4.3	2.5	1.4
Sweet corn		1.7	2.2	1.2	0.7
Broadbean	<i>Vicia faba</i>	1.6	3.3	1.9	1.1
Sweet potato	<i>Ipomoea batatas</i>	1.5	3.0	1.7	1.0
Pepper	<i>Capsicum annum</i>	1.5	2.8	1.6	0.9
Lettuce	<i>Latuca sativa</i>	1.3	2.7	1.5	0.9
Onion	<i>Allium cepa</i>	1.2	2.3	1.3	0.8
Radish		1.2	1.5	0.9	0.5
Eggplant	<i>Solanum melongena</i>	1.1	3.2	1.8	1.1
Bean	<i>Phaseolus vulgaris</i>	1	1.9	1.1	0.6
Carrot	<i>Daucus carota</i>	1	2.2	1.2	0.7
Turnip	<i>Brassica rapu</i>	0.9	2.5	1.4	0.8
Ornamentals					
Bougainvillea	<i>Bougainvillea spectabilis</i>	8.5	10.8	6.1	3.6
Euonymus	<i>Euonymus japonica</i> var. <i>grandiflora</i>	7	8.9	5.1	2.9
Dracaena	<i>Dracaena endivisa</i>	4	6.5	3.7	2.1
Aborvitae	<i>Thuja orientalis</i>	2	2.5	1.4	0.8
Privet	<i>Ligustrum lucidum</i>	2	3.9	2.2	1.3
Pyracantha	<i>Pyracantha braperi</i>	2	3.9	2.2	1.3
Lantana	<i>Lantana camera</i>	1.8	2.3	1.3	0.8
Boxwood	<i>Buxus microphylla</i> var. <i>Japonica</i>	1.7	3.3	1.9	1.1
Star jasmine	<i>Trachelosperumum jasminoides</i>	1.6	2.0	1.2	0.7
Bambatsi	<i>Panicum coloratum</i>	1.5	5.8	3.3	1.9
Bottlebrush	<i>Callistemon viminalis</i>	1.5	1.9	1.1	0.6
Juniper	<i>Juniperus chinensis</i>	1.5	3.3	1.9	1.1
Xylosma	<i>Xylosma senticosa</i>	1.5	2.9	1.7	1.0
Viburnum	<i>Viburnum</i> spp.	1.4	2.8	1.6	0.9
Algerian ivy	<i>Hedera camariensis</i>	1	1.3	0.7	0.4
Chinese holly	<i>Ilex cornuta</i>	1	1.3	0.7	0.4

DPI&F notes

Interpreting water analysis for crop and pasture

Bill Mills, formerly of DPI&F's Delivery Business Group, South Region

Many natural waters contain impurities that make them directly harmful to crops. Plants vary in their ability to tolerate and use poor quality water; so do soils vary in their resistance to its effect. Therefore, knowledge of a water supplies quality, assessed by chemical analysis, is essential in determining its usefulness in an irrigation system. However, unless you have some understanding of the analysis, the reasons why a water is suitable or unsuitable may not be clear.

In general, water for irrigation of agricultural crops can be assessed in terms of five criteria, which, together, indicate its potential to harm crop, soil or equipment. They are grouped into categories:

Salinity

Total salinity

Specific ions

Iron for irrigation equipment that uses small water outlets.

Sodicity

Sodium

Residual alkalinity.

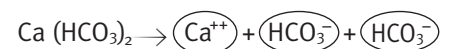
Precise standards for irrigation water quality are virtually impossible to set, since the conditions of use must also be taken into account and will modify the effects of the water. Factors that must be considered include:

- type of crops to be irrigated
- soils to be irrigated
- climate
- method of irrigation
- management of irrigation and drainage.

A water sample analysis serves the purpose of making you aware of what the main problems with your water supply are likely to be. The comments made about a water analysis are based on predictions of the likely effects the water will have when used for irrigation, and should be considered as guidelines only.

Chemical analysis

When salts dissolve in water, they dissociate into particles carrying either positive (cations) or negative (anions) electrical charges. For example Calcium Bicarbonate becomes:



Much of a water sample's chemical analysis depends on the determination of the **ion** concentration of elements in the sample. Ionic concentrations of salts dissolved in a water sample are listed on the analysis report in metric units as **milligrams/litre (mg/L)**, which are similar to the imperial unit parts per million (ppm).

pH

The term pH is a measure of the acidity or alkalinity of a water sample.

Information contained in this publication is provided as general advice only. For application to specific circumstances, professional advice should be sought. The Department of Primary Industries and Fisheries, Queensland, has taken all reasonable steps to ensure the information in this publication is accurate at the time of publication. Readers should ensure that they make appropriate inquiries to determine whether new information is available on the particular subject matter.

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Department of Primary Industries and Fisheries

NEUTRAL

← ACID ← → ALKALINE →									
	Very strong	Strong	Moderate	Slight	Slight	Moderate	Strong	Very strong	
3	4	5	6	7	8	9	10	11	

The pH of natural waters normally falls between the range of pH 4.0 to pH 9.0. Soils generally are highly buffered systems and the pH of the soil would not be significantly affected by the application of irrigation water within this range.

Waters having pH values greater than 8.0 would be expected to contain sodium carbonate and bicarbonate and the waters usefulness would depend on the amount of these salts present.

Corrosion is more rapid in acid than in neutral or alkaline waters. Irrigation with strongly acid water may dissolve iron, aluminium and magnesium from the soil in amounts that could be toxic to plant growth.

Salinity

All natural water contains water-soluble chemicals known as **salts**. They may be plant foods or other organic or inorganic salts gathered as it travels over or through sub soil rock or through the soil. The total salt content of water is its **salinity**, but it is the types of salts that make up this salinity that will determine the suitability of a water for its intended use.

Large quantities of salt may be added to the soil each year in saline irrigation water, eg. 1 milligram per litre (mg/L) of salt as Total Dissolved

Ions (TDI) is equal to 1 kilogram of salt per megalitre (ML) or 1,000,000 litres of irrigation water. Even though it may not be immediately harmful to the plant or soil structure, this salt has to go somewhere. Depending on the soil texture, its depth and the amount of leaching that occurs, this salt will accumulate at some point in the soil profile.

Salinity can have the following effects on plant and soil

- Plants may grow well in moderately saline soil when soil water is in good supply. When soil water is removed, by plant transpiration, evaporation and drainage, the salt concentration in the remaining soil water increases. Salts also attract and absorb water so as the available soil water declines plants have to exert more energy to satisfy their water needs. In this way salts compete directly with plants for available moisture and reduce the amount available to the plant.
- Reduce the availability of certain plant foods, for example, high levels of magnesium or sodium may induce calcium or potassium deficiencies in plants growing on soils low in these elements.
- As a plant root absorbs water from the soil it also

absorbs the salts, plant foods etcetera, dissolved in it. High concentrations of undesirable salts introduced into the soil irrigation water may become toxic to salt sensitive plants.

- Salt accumulation on plant foliage after spray irrigation may burn the leaves.
- Sodium reacts with the soil to change the soil structure in a detrimental manner.

Conductivity

A simple test for quick assessment of a water's salinity or total dissolved ion content. The conductivity test does not identify the dissolved salts, or the affects they may have on crop or soil, but it does indicate fairly reliably the degree with which a salinity problem is likely to occur.

The Water Laboratory, Resource Sciences Centre, Department of Natural Resources and Mines, measures conductivity in microsiemens per centimetre ($\mu\text{S}/\text{cm}^{-1}$). Water of high purity strongly resists the passage of electric current, a poor conductor of electricity. When salts are dissolved in water they improve its conductivity, so the greater the quantity of dissolved salts a water contains the higher will be its conductivity reading.

Table 1. Salinity classes for irrigation water

Conductivity	Salinity class
< 650	1 - Low salinity water, suitable for use on all crops except tobacco, with all methods of water application, with little probability of a salinity problem developing.
650 – 1300	2 - Medium salinity, suitable for use on all but very low salt tolerance crops. Water can be used if a moderate amount of leaching occurs. Plants with medium salt tolerance can be grown, usually without special practices for salinity control. Sprinkler irrigation with the more saline waters in this group may cause leaf burn on salt-sensitive crops, especially at higher temperatures in the daytime when evaporation may be high.
1300 – 3000	3 - High salinity - suitable for use on medium and high salt tolerant crops only. Water should not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required.
3000 – 5000	4 - Very high salinity - suitable for use only on high salt tolerant crops. For use soils must be permeable, free draining, and water must be applied in excess to provide considerable leaching.
5000 – 8000	5 - Extremely high salinity generally unsuitable for irrigation unless soils are permeable, well drained and crops are of very high salt tolerance.
> 8000	6 - Too saline for irrigation

< less than > greater than.

Some laboratories measure conductivity in decisiemens/metre (dS/m⁻¹). Microsiemens/centimetre (uS/m⁻¹) can be converted to decisiemens/metre by dividing by 1000. ie. 1 dS/m⁻¹ = 1000 uS/m⁻¹.

Effective conductivity

As salts of low solubility are likely to precipitate out of solution in the soil and not contribute to the salinity of the soil water, some allowance must be made for this. The main salt of concern is calcium carbonate and an estimate is made of the amount of CaCO₃ that would precipitate from the water.

The conductivity measurement is then corrected accordingly. Waters high in calcium carbonates and bicarbonates are fairly common in Queensland. Correcting the conductivity for loss of these salts allows a wider range of waters to be considered suitable for irrigation use. The conductivity corrected for CaCO₃ loss is then referred to as the **effective conductivity**.

Total dissolved ions (TDI)

Is the sum of all the ions present in a sample of water and represents the total salt content of the water.

Sodicity

This is the effect the irrigation water will have on the physical properties of the soil due to an accumulation of sodium.

Sodium can affect plants in three ways:

- By destroying soil structure causing clay particles to disperse rather than cling together as small peds (coarse blocky texture, crust formation after rain or irrigation) and reducing water movement (permeability) and aeration in the soil.
- By poisoning sodium sensitive plants when absorbed by either their roots or leaves.
- Calcium and/or potassium deficiencies may occur if the soil or irrigation water is high in sodium.

Sodium absorption ratio (SAR)

The sodium absorption ratio measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium. The SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali.

The sodium absorption ratio is used to predict the potential for sodium to accumulate in the soil, which would result from continued use of a sodic water, referred to as the **Exchangeable Sodium Percentage (ESP)**.

Water sample with a high SAR and a low RA usually has high sodium content due to the predominance of sodium chloride.

Effective SAR

Similarly to conductivity the SAR can be corrected to allow for calcium carbonate precipitation. It usually raises the reading for SAR because the presence of calcium can cause the calculation for SAR to understate the importance of sodium in a water.

Residual alkalinity (RA) or Residual sodium carbonate (RSC)

Residual alkalinity represents the amount of sodium carbonate and sodium bicarbonate in the water and is said to be present in a water sample if the concentration of carbonate and bicarbonate ions exceed the concentrations of calcium and magnesium ions. Residual alkalinity is usually expressed as milliequivalents per litre (meq/L) of sodium carbonate, or on some analysis reports as calcium carbonate.

When irrigation water containing residual alkalinity is used on clay soils containing exchangeable calcium and magnesium, sodium from the residual alkalinity in the water will replace calcium and magnesium in the soil. An increase in a clay soils sodium content may cause structure damage.

Table 2. Sodicity classes for irrigation water

Sodium absorption ratio	Residual alkali	Sodicity class
Less than 3	Less than 1.25	No sodium problem
3 to 6	Less than 1.25	1. Low sodium, few problems except with sodium sensitive crops.
6 to 8	Less than 2.5	2. Medium sodium, increasing problems; use gypsum and not sodium sensitive crops.
8 to 14	Less than 2.5	3. High sodium - not generally recommended.
Greater than 14	Disregard	4. Very high sodium - unsuitable.
Less than 6	1.25 - 2.5	5. Medium R.A. - as for class 2.
Less than 14	2.5 - 5	6. High R.A. - as for class 3.
Less than 14	Greater than 5	7. Very high R.A. - unsuitable.

Toxicity

Toxicity is the detrimental effect that certain specific ions have on plants. The toxicity problem differs from the salinity and sodicity problems in that it occurs within the crop itself and can occur in sensitive crops even if the total salinity of the water is low.

Chloride (Cl⁻)

Chloride toxicity is taken into account with salinity evaluation as chloride sensitive plants are all in the low salt tolerance range.

Irrigation water high in chloride may cause foliage burn, especially on salt sensitive plants, starting at the leaf tip and progressing back along the leaf margins or edges. Foliage burn may be aggravated by hot dry weather.

The chloride ion can be toxic to plants with a low salt tolerance when taken up by their roots and absorbed through their leaves. Crops mentioned under sodium are also most sensitive to chloride.

Table 3. Chloride classes for irrigation water

Chloride ion concentration	Suitability for irrigation
Less than 350 mg/L	1. Suitable all crops.
350 - 700 mg/L	2. Suitable for high, medium and low salt tolerant crops.
700 - 900 mg/L	3. Suitable for high and medium salt tolerance crops.
900 - 1300 mg/L	4. Suitable for high salt tolerant crops only.
Greater than 1300 mg/L	5. Too saline for irrigation of any crops.

Iron (Fe^{+++})

Dissolved iron in water is present in the ferrous state. Except at low pH values, ferrous iron is readily oxidised to ferric iron, an insoluble reddish brown precipitate on exposure to air and sunlight. For information on how to take water samples for iron analysis, check with the laboratory that will be conducting the analysis.

For localised irrigation schemes that use very small outlets, the presence of iron in the irrigation water has proved to be a problem. It has been found that iron bacteria flourish in water that contains as little as 1.0 mg/L of iron. The bacteria extract the iron out of solution and convert it into a rust coloured sludge, which quickly blocks filters and outlets.

Nitrate (NO_3^-)

For many crops nitrate in the irrigation water will provide them with some extra nitrogen, but nitrate sensitive crops could be affected by concentrations greater than 22 mg/L nitrate and problems may occur with increasing concentrations up to 133 mg/L nitrate, above which severe problems could arise. Ammonium nitrogen is seldom found in significant amounts in natural waters.

Nitrogen could be found in dams containing decaying organic matter; or in underground water contaminated with seepage from soils, that have had large quantities of nitrogen fertiliser applied, or by effluent from cattle feed lots or piggeries.

Sodium (Na^+)

Symptoms of sodium toxicity appear as burning or drying on the outer edges of older leaves. Progressing inwards towards the centre. Sodium can be absorbed through roots or leaves if sprinkler irrigation is used. Tree crops and woody perennials are most affected. With the exception of beans annual crops are not so sensitive.

Beans, avocado, citrus, deciduous fruits and nut trees are very sensitive to sodium and may show its toxic affect when:

- Flood irrigation water has a sodium absorption ratio (SAR) as low as 4.5
- Spray irrigation water, that wets the foliage, has a sodium content greater than 70 mg/L or SAR greater than 3.0.

To access DPI's services and products

- DPI&F Call Centre:
Phone 13 25 23 (Queensland residents) between 8 a.m. and 6 p.m. weekdays; non-Queensland residents phone 07 3404 6999;
email: callweb@dpi.qld.gov.au
- DPI&F's web site:
www.dpi.qld.gov.au/

Sampling your water supply

A water analysis is often essential before water is used for stock, domestic, or irrigation purposes. Chemical or biological composition can adversely affect crops, soils, humans, animals, or equipment.

Having an analysis carried out is not as simple as filling a bottle and giving it to an analyst. The accuracy of a water analysis is very much dependent on the sampling method used and the time elapsed between sampling and analysis.

This fact sheet outlines the basic requirements for water sampling, where to send samples for analysis and the types of analyses that can be made.

Collecting the sample

The most suitable bottles to use are made from polyethylene or glass and should hold one litre. Polyethylene bottles are available from water testing analysts, chemists and certain retail outlets. Soft drink, milk or chemical containers are not acceptable because residues are likely to remain in them, even if they have been washed out.

The bottle should be cleaned prior to sampling by rinsing the bottle three times in the water to be sampled (except in the case of sterile bottles used for bacteriological sampling). The bottle should be filled to the top with as little air as possible remaining, and sealed tightly.

All samples should be properly labelled with details of the source, date of sampling, your name and address and the intended use of the water.

Surface water samples

For flowing water the sample should be collected from mid-stream and mid-depth. This should ensure that the sample is representative of the entire flow in a stream or channel. A note should be made of the condition of flow in the stream (volume and/or velocity of flow etc.) as this often influences the quality of water at different times of the year.

For still waters such as lakes, reservoirs and dams, samples should be taken away from the water's edge and at a depth that represents normal pumping depth. Stratification (i.e. thermal and chemical layering of the

body of water due to seasonal changes and chemical content) can significantly affect results.

Groundwater samples

When sampling water from bores and wells, the first step is to remove the 'stale' water that lies inside the casing. It may not be representative of the water from the aquifer. It is usual to remove about three times the volume of the well storage. Take note of the pumping rate, the water level and the time of sampling after pumping has started.

Some bores may draw water from several aquifers. Should samples from different depths be required, specific techniques must be used. You should refer to your water analyst for these techniques.

Sampling for specific analyses

Standard chemical analysis

- ⇒ Use a one litre polyethylene bottle and follow the general procedure outlined above or by your water analyst
- ⇒ If possible take conductivity and pH measurements at the time of sampling
- ⇒ Send in the sample for analysis promptly (refer page 2 for more details).

Specific ions

Samples for specific ions often require a 'preservative' to be added to prevent precipitation or other chemical activity, which might give a false reading of relative concentrations. Treatments required are too numerous to list in this fact sheet, however some common ions and their collection procedures are listed below. Before sampling for a specific ion, you should contact an accredited testing laboratory to check if any special procedures are necessary.

- Iron, Manganese (and other metals) - add 5 ml concentrated nitric acid per litre of sample
- Nitrogen (Nitrate, Nitrite or Organic) - freeze or place in cold storage
- Sulphates - as for nitrogen

- Cyanide - add Sodium Hydroxide until pH is 11 or higher, then place in cold storage.

You must nominate the particular ion or metal to be determined when you submit the sample.

Bacteriological content

A sample for bacteriological analysis should be collected in a sterile container supplied by the analytical laboratory. A minimum volume of 200 ml is required. The sample should be placed in cold storage immediately. These samples should ideally be analysed within 6 hours, but certainly no longer than 24 hours after collection.

Algae

A sample taken for algae identification and cell count should be of one litre capacity, preferably in an opaque bottle. The bottle should be sealed with about 25mm air space at the top. The sample should not contain thick 'scum' algae as this makes the count inaccurate.

If the sample can be delivered to a laboratory within 24 hours, it need only be kept in the dark and in cool storage (e.g. in an esky). Otherwise it must be kept under refrigeration, preferably on ice, but not frozen.

For bacteriological or algae analyses it is usually necessary to make arrangements with the testing laboratory before sampling is carried out.

Where to send samples

Queensland Health

Landholders concerned with the quality of their water supply can arrange a bacteriological or chemical analysis through Queensland Health Scientific Services at Coopers Plains in Brisbane. Arrangements must be made prior to the sampling being carried out. Further information is available on their web site at www.health.qld.gov.au/ghpss

Local Authorities

Sampling for chemical or bacteriological analyses can be arranged through your local Council. Some Councils maintain testing facilities, but this service is generally limited to water for domestic and drinking purposes.

Private Companies

Samples collected for any purpose can be forwarded directly to private companies for analysis. They may be located in the yellow pages of the telephone book.

You can also search for accredited testing laboratories at the National Association of Testing Authorities, Australia (NATA) web site at www.nata.asn.au.

Further information

Fact sheets on water and other topics are available from Natural Resources, Mines and Energy (NRM&E) offices and service centres or can be downloaded at www.nrm.qld.gov.au/factsheets

Instructions for sampling water and other resources can also be downloaded from the Natural Resource Sciences Chemistry Centre web pages at www.nrme.qld.gov.au/science/labs/sampling.html.

You can also contact NRM&E on (07) 3896 3111; or Toll free (outside Brisbane metro) 1800 803 788 or send them an email at Enquiries@nrme.qld.gov.au ■

DPI&F notes

Using conductivity meters in agriculture

Ian Walker, Bowen Horticultural Research Station, DPI&F

Electrical conductivity (usually referred to as EC) is an extremely useful and easy measure to use for monitoring agricultural waters, soils and potting mixes. It indicates the level of dissolved salts by measuring the ability of a solution to carry an electric current by ions. A high electrical conductivity will stress your plants and cause productivity losses. It may produce leaf tip and margin burns and in extreme cases wilting, collapse and death of the plant. The salts responsible for this may come from irrigation waters, soils, potting media, rising water tables or from fertilisers. They are mainly sodium, magnesium, calcium, chloride, sulphate and bicarbonate.

EC will not, however, tell you which salts are contributing to the reading. This is a matter for your intuition unless detailed laboratory analysis is undertaken. If your groundwaters are known to have a sodium chloride (sea salt) problem and you have a high conductivity reading, then most of it is probably due to sea salt. If you have a potting mix with a high conductivity and you know you have good quality water, then you would suspect that excess fertiliser or poor media components are the culprit.

This DPI&F Note is intended to guide you through the proper use of conductivity meters. For interpretation of results consult one of the references listed at the end of this document. Keep in mind that different irrigation methods allow the use of different quality waters. Trickle irrigation, for instance, tends to push salts away from the root zone which allows you to use irrigation waters with higher conductivities than if you used furrow irrigation which tends to push salts into the root zone. If the water you have is too saline, it is possible to mix it with less saline water to obtain suitable water for irrigation.

Units

The preferred unit of EC is deciSiemens per metre – dS/m or dS m^{-1} . Other units are microSiemens per centimetre (abbreviated $\mu\text{S/cm}$ or $\mu\text{S cm}^{-1}$) and milliSiemens per centimetre (mS/cm or mS cm^{-1}). Conversions between the units are listed below.

A Siemen is an inverse ohm (also called a mho), a measure of electrical resistance. The distance term (centimetre or metre) comes from the way conductivity is measured. Classically this is done between two platinum electrodes of known surface area and a known distance apart.

- $1 \text{ dS/m} = 1 \text{ mS/cm}$
- $1 \text{ dS/m} = 1\,000 \mu\text{S/cm}$
- $1\,000 \mu\text{S/cm} = 1 \text{ mS/cm}$

The EC of distilled or deionised water is approximately 0.002 dS/m because most of the salts have been removed. The EC of seawater is approximately 58 dS/m .

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Temperature effect

EC readings are affected by temperature and ion interactions which change with concentration of salts. Because conductivity changes by about 2% per degree Celsius (see table below), readings are adjusted to a standard temperature, 25 °C. Instruments will do this automatically but it is a good idea not to have your water samples either very hot or very cold. Don't leave your sample in a bottle on a car dashboard as they get extremely hot.

Conductivity for a dilute potassium chloride (KCl) solution at various temperatures in dS/m:

Temp (° C)	0.01 M KCl
5	0.896
10	1.020
15	1.147
16	1.173
17	1.199
18	1.225
19	1.251
20	1.278
21	1.305
22	1.332
23	1.359
24	1.386
25	1.413
26	1.437
27	1.462
28	1.488
29	1.513
30	1.54

Additionally, conductivity does not change linearly with concentration e.g. a 0.01M solution of KCl has a conductivity of 1.413 dS/m whereas a solution of 0.02 M (double the concentration) has a conductivity of 2.76 dS/m which is not double the EC. This is due to interaction between the salts in solution and is an important point to remember.

Other measures of salt concentration

A common unit of measurement of salt concentration called Total Dissolved Salts (TDS) is parts per million (ppm) or more correctly, milligrams per litre (mg/L or mg L⁻¹). This is a measure of how much salt is in the solution by weight obtained by evaporation. This is different from conductivity which gives a measure of how much electricity the solution will conduct as a result of all the salts present.

Conversions from EC to TDS can be made using an approximation. If you want to relate your new EC readings back to previous readings in ppm, then you can multiply your dS/cm reading by 550 to 900. All of these conversions are quoted in various sources.

Conversion factors

To convert from:	To:	Multiply by:
m S/cm	mS/cm	0.001 (or divide by 1000)
mS/cm	m S/cm	1000
m S/cm	dS/m	0.001 (or divide by 1000)
dS/m	m S/cm	1000
mS/cm	dS/m	1 (i.e. they are the same)
m S/cm	ppm or mg/L	0.6 (approximately)
mS/cm	ppm or mg/L	600 (approximately)
dS/m	ppm or mg/L	600 (approximately)

Conductivity meters

There are basically two types of meter commonly available – small “stick” types and larger, more complex and more accurate bench top and portable models. A stick type will cost about \$100, a portable around \$700 including electrode and laboratory bench top models are about \$1500 including electrode.

Stick types, e.g. the TDScan4, are quite inexpensive and fit in your pocket and as such are quite useful. It should be remembered that these are not as accurate as the larger models and tend to irretrievably break down after a season or two depending on use. There are also more expensive waterproof versions that can last much longer. The digital reading on these is usually in dS/m thus a reading of 1.4 is 1.4 dS/m or 1400 m S/cm. Because they only have one decimal place it means that each step is 0.1 dS/m (100 m S/cm) which makes for reasonably coarse readings and less than perfect calibrations. There is usually a small screw on the meter that is used to calibrate it (see below).

Larger models often have a number of functions (often combined with a pH meter).

They usually give readings to 0.001 dS/m (1 m S/cm) and have a more convenient knob to calibrate them and are more accurate. The electrode is separate and plugs into the instrument.

Electrodes can be the classic two separated platinum plates (these are black as the plates are given a layer of platinum black) with a separate reference electrode or other arrangements that are often round and encased in a protective PVC sheath. These latter models are meant for environmental monitoring and are built to withstand field conditions. Both models cost about \$270.

Electrodes come with various cell constants (written as “K”). Different cell constants are suitable for measuring different strength solutions. For agricultural measurements K=1 is suitable. This will be written on the electrode or the cable.

Calibrating the instrument

It is very important that you calibrate your instrument every time you use it otherwise you will get inaccurate readings. Calibration means reading a solution of known conductivity and adjusting your meter to read the same. The adjustment is done with a screw or knob. The commonly used standard solution is potassium chloride (KCl). A solution of 0.01 M gives a conductivity of 1.413 dS/m and a 0.02M solution gives 2.76 dS/m. It is good practice to calibrate using a solution that approximates the readings you expect. Agricultural applications are usually in the 0.5 to 4.0 dS/m range and both 1.413 and

2.76 dS/m would be suitable. After calibration, never return the standard to the bottle as it will contaminate the standard. Discard it.

These solutions can be bought from scientific supply companies but tend to be quite expensive. A cheaper method, if you have access to an accurate balance and volumetric glassware, is to make up a stock solution of 1M KCl and then use that to make up your calibration standard a litre at a time using a 1:100 dilution (e.g. use a 10 mL pipette and a 1 L volumetric flask). It is important to ensure that the solutions are kept airtight to avoid evaporation as this will concentrate your salts and so change the conductivity. Provided the solutions are tightly sealed, kept from extremes of temperature and out of the light (e.g. in cupboard) then they will last for years.

To make up a stock solution of 1M KCl use 74.555 g of dry reagent grade KCl and make up to 1 litre with distilled water. Keep this as your stock and do 1:100 (0.01 M KCl) for 1.413 dS/m or 1:50 (0.02 M KCl) dilutions for 2.76 dS/m standard solutions.

Measuring the conductivity

Taking a conductivity reading is easy, simply immerse the electrode in the solution, jiggle the electrode up and down a few times to remove any bubbles. Wait thirty seconds or so for the sample and electrode to come to the same temperature and then read the measurement. The instrument will do the temperature correction for you. The electrode should be immersed over the plates and reference electrode or up to the hole in the protective PVC

sheath. With the stick types, immerse the pins to the level indicated in the instructions. It is most important that the level of the liquid is not above the waterproofed section of the electrode or meter.

If you are making a series of measurements, you should rinse the electrode with distilled water and dab dry with a tissue between samples (without rubbing the electrode itself).

Ensure that the battery is in good condition for portable types. Most modern instruments will give a battery warning if it is low. If you suspect it is low, then replace it.

Remember:

- Calibrate your meter (see above)
- Ensure that the sample you have is truly representative of what you want to measure (see below).

Storing the electrode

After making your last measurement, rinse with distilled water and dab dry and then store it according to the manufacturers instructions. This may be storing in air or in a solution. Ensure that it is out of strong light and away from temperature extremes and dusts. Remember that fertilisers are very corrosive so keep all instrumentation protected from them. The stick types usually have a protective cover for the electrodes.

Maintenance of electrodes

Maintenance is only possible on the separated plate type electrodes. As electrodes age or if they are not rinsed thoroughly after each reading they will eventually get a build up of dirt and

scale on them and this will result in inaccurate readings, readings that drift or very low readings. Never attempt to touch, scrub or rub that electrodes as this will remove the platinum coatings. If you suspect that you may have contaminated your electrode with fats or oils, then these can be removed by soaking in methylated spirits for 10 to 15 minutes, rinse in distilled water and recalibrate. Scales (accumulated salts) can be removed by dipping briefly in a solution of one part concentrated hydrochloric acid and ten parts distilled water and then rinse thoroughly with distilled water and recalibrate. If neither of these procedures rectify your problem then your electrode may need replatinisation. This is done at the factory and costs about \$30, far cheaper than the \$270 replacement cost of the electrode.

Sample preparation

The essential thing to remember when preparing a sample is that it be representative of what you are trying to measure.

Water samples

If you are taking a sample from a bore ensure that you run it for at least half an hour beforehand to get a true indication of the water you will be using. This is particularly important for bores that have remained unused for a long time. Be careful not to contaminate your sample with the previous contents of the bottle you are using to take the sample. Wash it thoroughly before using and rinse the bottle three times with the water you are sampling before taking the final sample. Avoid temperature extremes before reading your sample. When sampling running waters sample from a place where the water is flowing, not a backwater. When sampling still surface waters, e.g. dams, lakes and swamps, it is important to remember that as saline water is denser than fresh, these waters often stratify with the denser saline water on the bottom and fresh at the top. Sample from the level where your intake is. This is also the case for tidal creeks and rivers.

Soil and potting media samples

Soil and potting media should be collected from a number of sites and depths throughout the sampling area and these should then be well mixed and sub-sampled to obtain a representative sample to test. The standard for soil samples is 1:5 w/v (weight for volume) soil to water. Take a weight of soil and add to it five times that volume of distilled or deionised water. A very handy size bottle is a 455 g Vegemite bottle using 60 g of dry soil and 300 mL of water in this. These bottles have nice broad mouths and good screw-top plastic lids. Cap your bottle and shake it 50 times, allow to stand for 15 minutes then shake 50 times again and allow to settle for another 15 minutes before reading. Place the electrode near the boundary of the water and settled soil.

Further information

Your first information source should be any manuals you have with your equipment. These will give the most relevant and specific information on your own particular instrument. Other good references are:

Handreck, K. & N.Black *Growing Media for Ornamental Plants and Turf* New South Wales University Press. This Australian classic has been through several editions and has excellent information on theoretical and practical aspects of conductivity and many other aspects of agriculture.

Bodman, K. & K.V.Sharman (Editors) *Container Media Management* DPI&F 1993. This book is sold by the Queensland Nursery Industry Association and gives a very practical approach the subject.

Lorenz, O.A & D.N.Maynard *Knott's Handbook for Vegetable Growers* 3rd Edition John Wiley & Sons, New York. This American book is an invaluable source of facts and figures on all aspects of vegetable production and gives a table of salinity tolerances of various vegetables.

NRM Water Facts *Irrigation Water Quality – Salinity & Soil Structure Stability*. This fact sheet is produced by the Department of Natural Resources, Mines and Energy, Queensland and is available on the **DPI&F Prime Notes CD**, on the Internet at www.nrme.qld.gov.au/ or as an NRM&E free faxback on 1800 240 691. It contains an extensive list of fruit, vegetable, field crop, pasture and ornamental species and their tolerance to salinity in irrigation water as measured by conductivity in dS/m.

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- DPI&F's web site:
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Appendix 9.11

Theoretical flow rates for siphons: head–discharge charts

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This appendix includes 3 charts of theoretical flow rate (in litres per second) for a given combination of operating head (in mm) and siphon internal diameter (ID, in mm). Each chart has been designed for a particular siphon length, representative of the most common lengths provided by manufacturers. The lengths specified are 3.6 m, 4.0 m and 4.3 m.

All charts have a range of operating heads specified in 20 mm increments up to a maximum of 1 m. The siphon sizes specified represent a selection of those widely used. Imperial siphon sizes are specified according to their internal diameter (ID). Different manufacturers should provide a siphon of similar ID, taking account of manufacturing tolerances.

Metric siphon sizes are specified according to outside diameter (OD) and hence the corresponding ID (which is the figure essential for determining flow) varies according to the variation in pipe wall thickness used for different pipe classes. For this reason, the charts may have more than one value of ID for a corresponding metric OD. It is imperative that siphon ID is measured to determine the appropriate corresponding chart ID. Measure the ID in more than one direction, and average the readings to account for any ovalness.

As can be seen on the charts, even a very small increase in ID (3 mm) can have a dramatic increase in the rate of discharge, particularly as head increases.

Because the level of water in the head ditch may vary and the discharge point of the siphon may not be consistent, it is suggested that head is measured for numerous siphons along the length of the head ditch and over a number of irrigations to see the possible variation.

Discharge is also affected by

- non-circular siphon pipes
- siphon inlet orientation (towards, perpendicular to, or away from the direction of flow in the head ditch)
- trash (blocking the siphons):

and even small factors such as water temperature and quality, and so the chart is only a guide to the actual flow rate.

For more detail on how the charts were constructed, see the discussion of **Theoretical flow** after the charts.

Flow rate in litres/seconds (L/s), siphon Length = 3.6 metres

Operating head (mm)	Nominal siphon size, internal diameter (mm)							
	1 ¼", 31.75	1 ½", 38.1	2", 50.85	50 mm, 44.0	50 mm, 47.0	63 mm, 55.5	63 mm, 59.0	75 mm, 65.1
100	0.55	0.83	1.58	1.15	1.33	1.91	2.19	2.71
120	0.60	0.91	1.73	1.26	1.45	2.10	2.40	2.97
140	0.65	0.98	1.87	1.36	1.57	2.27	2.59	3.21
160	0.70	1.05	2.00	1.45	1.68	2.42	2.77	3.43
180	0.74	1.11	2.12	1.54	1.78	2.57	2.94	3.64
200	0.78	1.17	2.23	1.62	1.88	2.71	3.10	3.84
220	0.82	1.23	2.34	1.70	1.97	2.84	3.25	4.03
240	0.85	1.29	2.45	1.78	2.06	2.97	3.39	4.20
260	0.89	1.34	2.55	1.85	2.14	3.09	3.53	4.38
280	0.92	1.39	2.64	1.92	2.22	3.20	3.66	4.54
300	0.95	1.44	2.74	1.98	2.30	3.32	3.79	4.70
320	0.99	1.49	2.82	2.05	2.37	3.42	3.92	4.86
340	1.02	1.53	2.91	2.11	2.45	3.53	4.04	5.00
360	1.05	1.58	3.00	2.17	2.52	3.63	4.15	5.15
380	1.07	1.62	3.08	2.23	2.59	3.73	4.27	5.29
400	1.10	1.66	3.16	2.29	2.65	3.83	4.38	5.43
420	1.13	1.70	3.24	2.35	2.72	3.92	4.49	5.56
440	1.16	1.74	3.31	2.40	2.78	4.02	4.59	5.69
460	1.18	1.78	3.39	2.46	2.85	4.11	4.70	5.82
480	1.21	1.82	3.46	2.51	2.91	4.19	4.80	5.95
500	1.23	1.86	3.53	2.56	2.97	4.28	4.90	6.07
520	1.26	1.89	3.60	2.61	3.03	4.37	4.99	6.19
540	1.28	1.93	3.67	2.66	3.08	4.45	5.09	6.31
560	1.30	1.97	3.74	2.71	3.14	4.53	5.18	6.42
580	1.33	2.00	3.80	2.76	3.20	4.61	5.27	6.54
600	1.35	2.03	3.87	2.81	3.25	4.69	5.36	6.65
620	1.37	2.07	3.93	2.85	3.30	4.77	5.45	6.76
640	1.39	2.10	3.99	2.90	3.36	4.84	5.54	6.87
660	1.41	2.13	4.06	2.94	3.41	4.92	5.62	6.97
680	1.44	2.17	4.12	2.99	3.46	4.99	5.71	7.08
700	1.46	2.20	4.18	3.03	3.51	5.07	5.79	7.18
720	1.48	2.23	4.24	3.07	3.56	5.14	5.87	7.28
740	1.50	2.26	4.30	3.12	3.61	5.21	5.96	7.38
760	1.52	2.29	4.35	3.16	3.66	5.28	6.04	7.48
780	1.54	2.32	4.41	3.20	3.71	5.35	6.11	7.58
800	1.56	2.35	4.47	3.24	3.75	5.42	6.19	7.68
820	1.58	2.38	4.52	3.28	3.80	5.48	6.27	7.77
840	1.60	2.41	4.58	3.32	3.85	5.55	6.35	7.87
860	1.62	2.44	4.63	3.36	3.89	5.61	6.42	7.96
880	1.63	2.46	4.68	3.40	3.94	5.68	6.49	8.05
900	1.65	2.49	4.74	3.44	3.98	5.74	6.57	8.14
920	1.67	2.52	4.79	3.48	4.02	5.81	6.64	8.23
940	1.69	2.55	4.84	3.51	4.07	5.87	6.71	8.32
960	1.71	2.57	4.89	3.55	4.11	5.93	6.78	8.41
980	1.72	2.60	4.94	3.59	4.15	5.99	6.85	8.50
1000	1.74	2.63	4.99	3.62	4.20	6.05	6.92	8.58



Flow rate in litres/seconds (L/s), siphon Length = 4.0 metres

Operating head (mm)	Nominal siphon size, internal diameter (mm)							
	1 ¼", 31.75	1 ½", 38.1	2", 50.85	50 mm, 44.0	50 mm, 47.0	63 mm, 55.5	63 mm, 59.0	75 mm, 65.1
100	0.54	0.81	1.54	1.12	1.30	1.87	2.14	2.66
120	0.59	0.89	1.69	1.23	1.42	2.05	2.35	2.92
140	0.63	0.96	1.83	1.32	1.53	2.22	2.54	3.15
160	0.68	1.02	1.95	1.41	1.64	2.37	2.71	3.37
180	0.72	1.09	2.07	1.50	1.74	2.51	2.88	3.57
200	0.76	1.14	2.18	1.58	1.83	2.65	3.03	3.76
220	0.79	1.20	2.29	1.66	1.92	2.78	3.18	3.95
240	0.83	1.25	2.39	1.73	2.01	2.90	3.32	4.12
260	0.86	1.30	2.49	1.80	2.09	3.02	3.46	4.29
280	0.90	1.35	2.58	1.87	2.17	3.14	3.59	4.45
300	0.93	1.40	2.67	1.94	2.24	3.25	3.71	4.61
320	0.96	1.45	2.76	2.00	2.32	3.35	3.84	4.76
340	0.99	1.49	2.85	2.06	2.39	3.46	3.95	4.91
360	1.02	1.54	2.93	2.12	2.46	3.56	4.07	5.05
380	1.04	1.58	3.01	2.18	2.53	3.65	4.18	5.19
400	1.07	1.62	3.09	2.24	2.59	3.75	4.29	5.32
420	1.10	1.66	3.16	2.29	2.66	3.84	4.40	5.46
440	1.12	1.70	3.24	2.35	2.72	3.93	4.50	5.58
460	1.15	1.74	3.31	2.40	2.78	4.02	4.60	5.71
480	1.17	1.77	3.38	2.45	2.84	4.11	4.70	5.83
500	1.20	1.81	3.45	2.50	2.90	4.19	4.80	5.95
520	1.22	1.85	3.52	2.55	2.95	4.27	4.89	6.07
540	1.24	1.88	3.59	2.60	3.01	4.36	4.98	6.19
560	1.27	1.91	3.65	2.65	3.07	4.43	5.08	6.30
580	1.29	1.95	3.72	2.69	3.12	4.51	5.17	6.41
600	1.31	1.98	3.78	2.74	3.17	4.59	5.25	6.52
620	1.33	2.01	3.84	2.78	3.23	4.67	5.34	6.63
640	1.35	2.05	3.91	2.83	3.28	4.74	5.43	6.73
660	1.37	2.08	3.97	2.87	3.33	4.81	5.51	6.84
680	1.40	2.11	4.03	2.92	3.38	4.89	5.59	6.94
700	1.42	2.14	4.08	2.96	3.43	4.96	5.67	7.04
720	1.44	2.17	4.14	3.00	3.48	5.03	5.75	7.14
740	1.46	2.20	4.20	3.04	3.53	5.10	5.83	7.24
760	1.48	2.23	4.26	3.08	3.57	5.17	5.91	7.34
780	1.49	2.26	4.31	3.12	3.62	5.23	5.99	7.43
800	1.51	2.29	4.37	3.16	3.67	5.30	6.07	7.53
820	1.53	2.32	4.42	3.20	3.71	5.37	6.14	7.62
840	1.55	2.35	4.47	3.24	3.76	5.43	6.22	7.72
860	1.57	2.37	4.53	3.28	3.80	5.50	6.29	7.81
880	1.59	2.40	4.58	3.32	3.84	5.56	6.36	7.90
900	1.61	2.43	4.63	3.35	3.89	5.62	6.43	7.99
920	1.62	2.45	4.68	3.39	3.93	5.68	6.51	8.07
940	1.64	2.48	4.73	3.43	3.97	5.75	6.58	8.16
960	1.66	2.51	4.78	3.46	4.01	5.81	6.65	8.25
980	1.68	2.53	4.83	3.50	4.06	5.87	6.71	8.33
1000	1.69	2.56	4.88	3.54	4.10	5.93	6.78	8.42

Flow rate in litres/seconds (L/s), siphon Length = 4.3 metres

Operating head (mm)	Nominal siphon size, internal diameter (mm)							
	1 ¼", 31.75	1 ½", 38.1	2", 50.85	50 mm, 44.0	50 mm, 47.0	63 mm, 55.5	63 mm, 59.0	75 mm, 65.1
100	0.52	0.79	1.52	1.10	1.27	1.85	2.11	2.62
120	0.57	0.87	1.66	1.20	1.40	2.02	2.31	2.88
140	0.62	0.94	1.80	1.30	1.51	2.18	2.50	3.11
160	0.66	1.00	1.92	1.39	1.61	2.33	2.67	3.32
180	0.70	1.07	2.04	1.47	1.71	2.48	2.83	3.52
200	0.74	1.12	2.15	1.55	1.80	2.61	2.99	3.71
220	0.78	1.18	2.25	1.63	1.89	2.74	3.13	3.89
240	0.81	1.23	2.35	1.70	1.97	2.86	3.27	4.07
260	0.85	1.28	2.45	1.77	2.05	2.98	3.41	4.23
280	0.88	1.33	2.54	1.84	2.13	3.09	3.54	4.39
300	0.91	1.38	2.63	1.90	2.21	3.20	3.66	4.55
320	0.94	1.42	2.72	1.97	2.28	3.30	3.78	4.70
340	0.97	1.46	2.80	2.03	2.35	3.40	3.90	4.84
360	0.99	1.51	2.88	2.08	2.42	3.50	4.01	4.98
380	1.02	1.55	2.96	2.14	2.48	3.60	4.12	5.12
400	1.05	1.59	3.04	2.20	2.55	3.69	4.23	5.25
420	1.07	1.63	3.11	2.25	2.61	3.78	4.33	5.38
440	1.10	1.67	3.19	2.30	2.67	3.87	4.43	5.51
460	1.12	1.70	3.26	2.36	2.73	3.96	4.53	5.63
480	1.15	1.74	3.33	2.41	2.79	4.04	4.63	5.75
500	1.17	1.78	3.40	2.46	2.85	4.13	4.72	5.87
520	1.20	1.81	3.46	2.51	2.91	4.21	4.82	5.99
540	1.22	1.85	3.53	2.55	2.96	4.29	4.91	6.10
560	1.24	1.88	3.59	2.60	3.01	4.37	5.00	6.21
580	1.26	1.91	3.66	2.65	3.07	4.44	5.09	6.32
600	1.28	1.95	3.72	2.69	3.12	4.52	5.18	6.43
620	1.31	1.98	3.78	2.74	3.17	4.59	5.26	6.54
640	1.33	2.01	3.84	2.78	3.22	4.67	5.35	6.64
660	1.35	2.04	3.90	2.82	3.27	4.74	5.43	6.74
680	1.37	2.07	3.96	2.87	3.32	4.81	5.51	6.84
700	1.39	2.10	4.02	2.91	3.37	4.88	5.59	6.94
720	1.41	2.13	4.08	2.95	3.42	4.95	5.67	7.04
740	1.43	2.16	4.13	2.99	3.47	5.02	5.75	7.14
760	1.45	2.19	4.19	3.03	3.51	5.09	5.83	7.24
780	1.46	2.22	4.24	3.07	3.56	5.15	5.90	7.33
800	1.48	2.25	4.30	3.11	3.60	5.22	5.98	7.42
820	1.50	2.27	4.35	3.15	3.65	5.28	6.05	7.52
840	1.52	2.30	4.40	3.18	3.69	5.35	6.12	7.61
860	1.54	2.33	4.45	3.22	3.74	5.41	6.20	7.70
880	1.56	2.36	4.51	3.26	3.78	5.47	6.27	7.79
900	1.57	2.38	4.56	3.30	3.82	5.54	6.34	7.87
920	1.59	2.41	4.61	3.33	3.86	5.60	6.41	7.96
940	1.61	2.43	4.66	3.37	3.91	5.66	6.48	8.05
960	1.62	2.46	4.71	3.40	3.95	5.72	6.55	8.13
980	1.64	2.49	4.76	3.44	3.99	5.78	6.61	8.22
1000	1.66	2.51	4.80	3.47	4.03	5.84	6.68	8.30



Theoretical flow

The equation used to calculate these charts is that proposed by Bos (1989) specifically for measuring theoretical flow through irrigation siphons. This differs from the more usually encountered equation based on Manning's outlet control, which is theoretically inappropriate (Queensland Water Resources Commission, 1984). Values used for entrance and exit loss coefficient (C) and friction factor (f) are 1.9 and 0.019 respectively. These values were decided upon following procedures outlined by Bos, and after careful analysis of available siphon discharge data.

This equation aims to provide the theoretical flow rate of siphons in the field and hence takes account of many in-field hydraulic issues. The charts do not provide a measure of theoretical flow of siphons operating under laboratory conditions.

Equations used

For those interested in calculating flows for siphon lengths or pipe internal diameters that are not specified in the following tables, the equation used is as follows.

$$Q = \frac{\pi D^2}{4} \left[\frac{2g\Delta h}{1.9 + \frac{fL}{D}} \right]^{0.5}$$

where:

Q – discharge (m³/s)

D – siphon internal diameter (m)

g – acceleration due to gravity (9.81 m/s²)

Δh – operating head (m)

f – friction loss coefficient (0.019 in the charts)

L – siphon length (m)

More information regarding the theory and application of this equation is available in Bos (1989).

For reference

The theoretically incorrect Manning's equation that has been used in the past is as follows:

$$Q = 10^{-5} \sqrt{\frac{124g\Delta h D^5}{0.00015D + \frac{124n^2 L}{D^{1/3}}}}$$

This equation, and charts based on this equation, should **not** be used, as they are likely to incorrectly estimate the siphon flow rate.

References

- Bos, MG 1989, Discharge measurement structures, 3rd edn, ILRI Publication 20, International Institute for Land Reclamation and Improvement, The Netherlands.
- Queensland Water Resources Commission 1984, Farm Water Supplies Design Manual vol. II: Irrigation Systems, 2nd edn, Queensland Water Resources Commission, Brisbane.

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Bill Yiasoumi

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Windsor

Failure to hold water is the most common problem with farm dams. Anxious farmers want the leak sealed and stopped—fast. However, like most business people, they are often short of funds and want the works to be as cheap as possible.

When a leak is suspected, all other sources of water loss should be thoroughly checked. Loss through evaporation can be the cause of some hard-to-find 'leaks'. Accidentally leaving a valve open on an outlet pipe can be another cause of apparent leaking. The farm dams that do leak were not planned or built properly; and sometimes it is hard to pinpoint the exact cause of the problem. Often you cannot keep a close eye on all the dam construction works; or the dam may have been constructed by a previous owner.

Common causes of dam leakage are:

- the work of a contractor unfamiliar with farm dam construction
- failure to remove topsoil and vegetation at the embankment site
- use of an unsuitable soil type in the dam wall
- failure to construct a cut-off trench
- poor soil compaction
- failure to backfill exposed rock, gravel or sand in the storage basin
- poor maintenance of the dam.

The right contractor

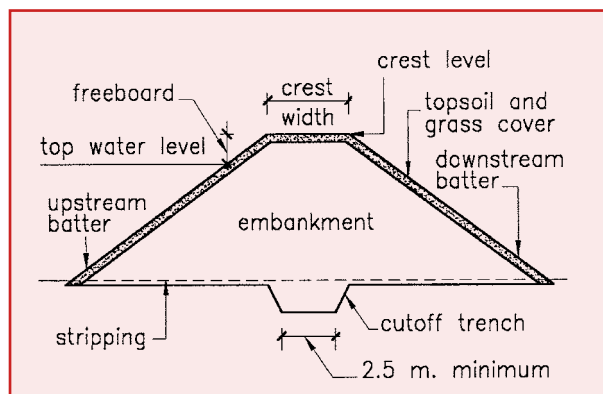
It is worthwhile to choose an earthmoving contractor who has experience and a good work record. Not every contractor has the experience or the ability to build a dam.

Try to find someone who specialises in dam construction. For example, you could ask neighbours who have had dams built if they are happy with the results.

Once you have found a few dam builders, ask them to show you some of their recent work. If possible, talk to the owners of these dams and ask their opinions of the work.

If you choose an experienced dam builder with good references, you can reduce the chance of problems occurring during and after the building of your dam.

Figure 1. A typical cross-section of a dam



Topsoil and vegetation

Topsoil is porous: water runs freely through it. So, before building starts, the area to be covered by the embankment, spillway and excavation should be stripped of all topsoil, roots and vegetation (including trees and stumps). Store the topsoil for completion of the embankment.

Soil type

The soil used to build the embankment must be impermeable, so the embankment can hold water.

Clay soils are usually satisfactory. As a guide, a soil containing enough clay to be impermeable sticks to your fingers when it is damp. However, not all clays are suitable for dam embankments. For example, some clays disperse (break down easily) when wet,

causing tunnels to form in the embankment, so the soil must be tested to determine its behaviour.

For the tests, samples of the soil must be obtained from the excavation area. The samples can come from auger holes or backhoe trenches. The sampling depth should extend at least to the depth of anticipated excavation. The samples should be tested by someone experienced in assessing soil for dam construction.

A clay core may be required if there is not enough suitable material at the excavation area to build a homogeneous embankment. In these cases, the clay core is used to provide the impermeable barrier; and the balance of the material in the embankment provides the dam with structural stability.

The core can be located between more permeable material or it may be constructed at either the water- or non-water face. Typical arrangements are shown in Figures 2, 3 and 4.

Figure 2. A central clay core

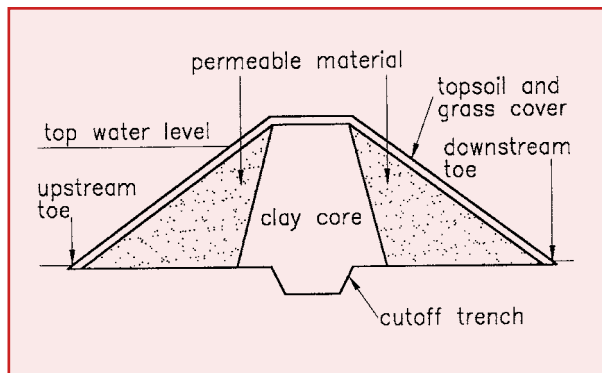


Figure 3. A typical upstream clay core

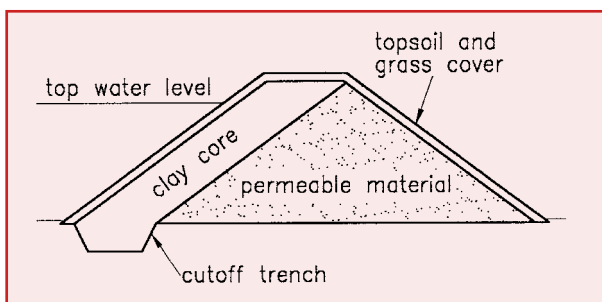
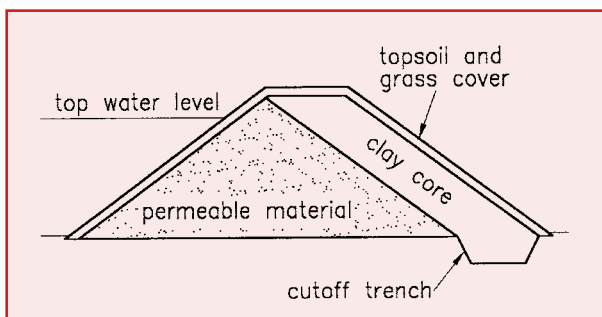


Figure 4. A typical downstream clay core



The cut-off trench

With good construction methods, seepage losses can be reduced. One way is to build a cut-off trench along the entire length of the embankment. The cut-off trench is used to prevent leaks caused by water escaping beneath the embankment. Usually the trench does not need to extend across the spillway. The trench is shown in Figures 1, 2, 3 and 4.

The trench should be at least 600 mm deep with a minimum 300 mm extending into impervious soil. The cut-off trench must be backfilled with good clay that is thoroughly compacted.

All farm dams must have a cut-off trench.

Soil compaction

Soil compaction is another way of reducing seepage losses. The soil used to backfill the cut-off trench and to form the embankment should be placed in layers, with each layer thoroughly compacted before the next layer is placed.

Preferably, compaction should be achieved with a sheep's foot roller; however, a scraper or bulldozer may be satisfactory depending on the soil behaviour and the layer thickness.

A layer 150 mm or less of loose thickness, for a sheepsfoot roller, or 100 mm or less of loose thickness, for a bulldozer or scraper, is recommended.

The number of passes that should be made by the compacting equipment depends on the soil type, but it should be at least four. Generally, embankments lower than about 2–3 m may be compacted satisfactorily with a bulldozer or scraper.

The soil used to build the embankment should not be too wet or too dry. If the soil is too dry when it is compacted there is a good chance that air voids will result and the soil will be permeable. Compaction will also be hampered and produce an unsatisfactory result if the soil is too wet.

A good guide to soil moisture content can be obtained from a simple field test. When soil moisture is at the best level for effective compaction, you should be able to roll the soil between your palms into a thread (about the thickness of a pencil) that just begins to crumble on further rolling. If the soil thread crumbles before it reaches pencil thickness, it is too dry. If the thread can be rolled to a thickness much less than a pencil, then it is too wet.

If the soil is too dry, a water cart can be used to wet it before it is used in the embankment. The best way to do this is to rip the excavation area, wet the soil, allow it to stand for about 24 hours, check its moisture content using the field test described previously, and, if that is right, place the soil in the embankment. Try to avoid wetting the embankment to increase the soil moisture during construction, as this usually causes very uneven soil moisture and uneven compaction.

If the soil in the excavation area is too wet, the drying process can be accelerated by ripping.

Exposed rock

Rock, sand or gravel exposed below top water level allows water to escape from the dam. To prevent seepage, the rock, sand or gravel should be covered with at least 300 mm of compacted clay.

How to look after the dam

To minimise problems with leaking from the dam, it is important to carry out regular maintenance and in particular to observe the following:

- Make sure you have about 100 mm of topsoil over the embankment. Topdress areas that become bare of topsoil as soon as possible. If the stripped areas do not provide enough topsoil, it should be

Figure 5. The recommended clay lining method if both excavation and embankment are pervious

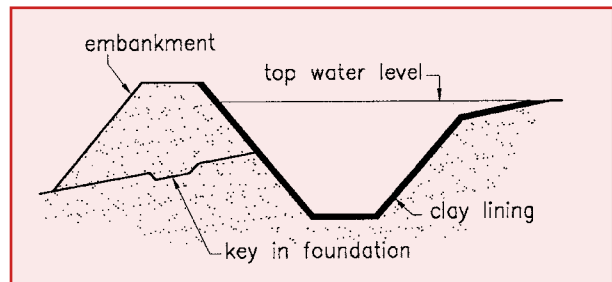


Figure 6. A clay lining is required if the topsoil has not been stripped from below the embankment, or if a cutoff trench has not been constructed

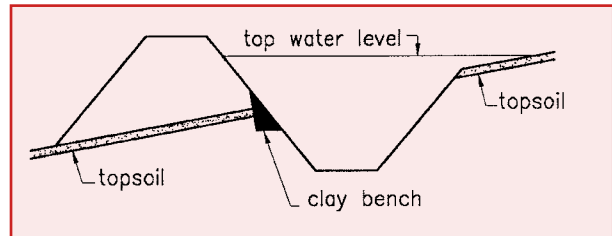


Figure 7. Clay lining treatment if the excavation exposes porous seams of sand or gravel

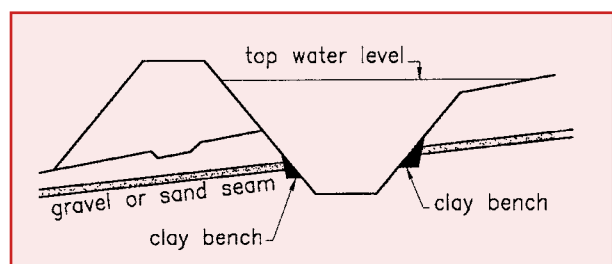
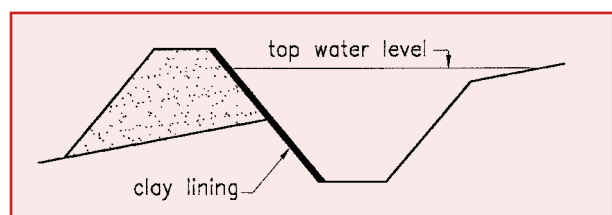


Figure 8. A blanket of clay used to seal a pervious embankment



imported. Avoid topsoil depths greater than about 200 mm, as slumping is likely, and an uneven surface tends to erode.

- Establish a grass cover on the embankment and spillway as soon as possible. A grass that mats, such as kikuyu, is preferable to a grass that tufts.
- Do not let trees or shrubs grow on the embankment, spillway or spillway outlet slope. Roots might disturb the compacted soil and provide a seepage path for water, while trees or shrubs in the spillway area will restrict the flow of flood water.

The importance of maintaining a good grass cover over topsoil cannot be stressed too much. Cracking or eroded soils are potential sources of dam seepage; and protection of the embankment clay is critical (particularly for dispersive clays). Topsoil protects clay soils from drying out and cracking during long dry periods. The grass cover protects the embankment from erosion.

Ways to seal your dam

The method used to repair the dam is often determined by the cost of the repairs in relation to the short- or long-term benefit.

The methods used to seal earth dams include:

- clay lining with available local material
- the use of bentonite
- installing commercial (plastic or synthetic rubber) liners
- chemical treatment of the soil
- the application of a sprayed membrane.

Clay lining

If a suitable clay can be found on or near your property then clay lining may be a cost-effective way of sealing your dam.

There are several ways to use clay lining to seal a dam depending on the nature of the seepage problem. These methods are illustrated in Figures 5, 6, 7, and 8. In all cases, a minimum 300 mm depth of compacted clay must be used. The clay must also be placed and compacted in layers at the optimum soil moisture content, as previously described.

If the dam still holds some water it should be pumped dry. All plants (e.g. reeds), loose sand

and silt must be removed to expose a firm foundation on which to place the clay lining. Sometimes a cutting or bench is required to hold the clay, as shown in Figures 6 and 7.

The cost of clay lining depends on many factors, including:

- the transport cost of the clay
- the amount of clay to be moved
- the cost of emptying the dam
- access to the site
- potential crop and income loss (because the dam will need to be emptied).

Bentonite

Bentonite is a naturally occurring clay which is commercially mined. In dam building it is useful because, when it is wet, it swells to many times its dry volume.

Bentonite may be used in several ways depending on the soil type on site and whether it is practical to empty the dam.

On light or loam soils a mixed blanket is worked into the soil. On heavy soils, a pure blanket would be required (similar to a clay lining). In both cases the dam would need to be emptied and allowed to dry. A third option, which is at best hit and miss, would be to broadcast the bentonite on the water surface.

The mixed blanket method mixes bentonite with the first 150–200 mm of soil. The area to be treated is first cleared of loose rocks and vegetation, then it is lightly harrowed. The bentonite is broadcast over the area at a rate of approximately 7 kg/m². After the bentonite is spread it is mixed with the existing soil by lightly harrowing and then compacting with a roller.

The pure blanket method also requires the removal of all vegetation and loose rocks in the area to be treated. The bentonite is spread evenly over the area at a rate of approximately 10 kg/m².

The bentonite must be covered with at least 100 mm of site soil otherwise you risk cracks developing in the bentonite blanket as it dries out. If stock have access to the dam then the cover to the bentonite must be at least 450 mm to avoid penetration of the bentonite by the stock.

The final step in this method is compaction of the treated area with a roller.

The broadcast technique involves spreading the bentonite over the water surface at a rate of 10 kg/m^2 . The bentonite settles to the bottom, hopefully where the problem is, and seals the storage. This method is not recommended, as success cannot be assured. However, if the storage cannot be emptied then it is the only option available to you.

Commercial liners

There are a number of commercial liners available to seal leaking dams. They are all flexible membranes but offer different levels of strength, durability and resistance to UV breakdown.

The liners have no structural strength; they rely on a continuous backing for support. This means that the soil such a liner rests on must be well compacted, offer an even grade, have no vegetation and be free from protrusions like stones and branches which would damage the liner.

A layer of fine soil or sand is required under thinner liners and the soil is sometimes sprayed with a herbicide to prevent any plants growing and penetrating the liner.

All liners must be anchored so that they do not move. The simplest way to provide anchorage is to bury the liner in a trench dug along the perimeter of the storage.

Commercial liners include woven polythene, black polythene, vinyl, HDPE (high density polyethylene), butyl rubber and composites of bentonite and polypropylene.

Woven polythene, in blue or green, resists tearing but is very susceptible to UV degradation. If it is not protected from sunlight with a layer of soil, it has a very short life. Woven polythene is very unlikely to last 5–7 years in the sun. A grade no steeper than 3:1 must be used to keep the soil from slipping off the liner.

Black polythene also has a short life due to UV degradation. It is also quite thin, generally less than 0.4 mm, and is susceptible to puncturing. It must be covered with a layer of soil to prolong its life.

There are two grades of black polythene. One uses reprocessed resin and the other uses prime resin. The prime resin liner lasts longer than the reprocessed resin liner. Also, the thicker the liner, the longer it will last, because it is better able to withstand the continual UV degradation of its surface.

Vinyl (or PVC) resists tearing and is more flexible than woven polythene. Again this material needs to be covered with a layer of soil to protect it from sunlight.

HDPE and butyl rubber. HDPE has a longer life and is tougher than vinyl or woven or black polythene. It resists tearing and does not need to be protected from UV exposure. Similarly, butyl rubber is resistant to sunlight, flexible and very tough. Both HDPE and butyl rubber are more expensive than vinyl and woven or black polythene.

Composite materials contain a thin layer of bentonite sandwiched between polypropylene material. They are not UV sensitive.

Because of the bentonite material, small ruptures in the liner are self-healed. However, these liners must be covered with soil to protect them from major punctures.

Chemical treatment of soil

Gypsum and sodium tripolyphosphate (STPP) are two chemicals used to seal storages.

Gypsum is used to stabilise dispersive soils so that both surface erosion and potential tunnelling failures are reduced. A fine-grained gypsum is preferable because it is more soluble.

The gypsum is mixed into the first 150–200 mm of surface soil at about 2 kg/m^2 , and then the treated area is compacted with a roller. Remember, dry soil will not compact well. Good compaction can only be achieved with a soil near its optimum moisture content, as described previously.

STPP is a chemical which has the opposite effect to gypsum. It is used to disperse the clay particles in stable, but porous, clay soils. These soils are very hard to compact and STPP is used to help the compaction process.

Not all clay soils are suitable for STPP treatment and a laboratory test is needed to determine if the soil will react favourably.

If the soil is suitable for STPP use, the treatment is similar to the bentonite mixed blanket method. The dam must be drained, and the soil allowed to dry. All vegetation, loose gravel and sediment must be removed and the surface cultivated to a depth of about 150 mm.

STPP, in powder form, is then broadcast over the area to be treated at a rate determined from the laboratory tests, usually about 0.5 kg/m^2 . The soil must be near its optimum moisture content before the STPP is mixed with the surface soil using a rotary hoe. The treated area must then be compacted with a roller.

Finally, the area must be covered with untreated soil to prevent the STPP/soil mix from drying out and cracking. A compacted thickness of about 300 mm is recommended. Remember that STPP is ineffective in sandy soils or soils high in calcium carbonate.

Sprayed membranes

Concrete and asphalt are examples of sprayed membranes. They are applied to the area to be treated under pressure to form a continuous skin of material that acts to seal the storage. They are rarely used to seal farm dams because of the high cost of the work involved.

Sprayed concrete or **asphalt**. Sprayed concrete (known as gunite or shotcrete) requires specialised equipment and experienced applicators. Its application involves spraying a mix of water, cement and aggregate onto a graded surface. Steel reinforcement is usually required.

Asphalt (bitumen) also requires a prepared, graded surface, experienced applicators and specialised equipment. The process can be messy but no steel reinforcement is required.

Both methods require a depth of at least 75 mm to be effective and are prone to movement cracks and weathering.

Further information

Each dam site is different, and this Agfact is not intended to replace the advice of qualified consultants. For further information, you can also contact your local office of NSW Department of Primary Industries.

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Surface Irrigation Evaluation

Anthony Fairfull, Aquatech Consulting, Narrabri and Warren, NSW

KEY POINTS

This paper outlines the water savings attained with the use of the first commercially available in-field surface irrigation evaluation service. The measurements required and the evaluation process is demonstrated through a case study with actual in-field evaluation results.

1.0 THE NEED FOR IN FIELD IRRIGATION EVALUATION

The pressure on all water users to justify their usage is increasing. The demand for the limited water available has meant that all water users are obligated to use their allocation efficiently and minimise losses. Irrigators are no exception.

Surface (furrow) irrigation relies entirely on the infiltration characteristics of the soil. A heavy clay, for instance, has a high initial infiltration rate that quickly reduces to a low long term rate. Surface irrigation on heavy soils with tailwater recycling can be very efficient. Other than a small number of research projects, however, the measurement of irrigation application depths, uniformity or efficiency in the field has not been done.

Most irrigators measure how much water they pump onto their farms but very few measure how much water is applied to each field. Some irrigators have volume gauges in their reservoirs that will give an indication of how much water is used per irrigation cycle on a whole farm basis. Moisture probes are also used in fields to measure the rate soil moisture is extracted and the approximate amount applied.

Whilst soil moisture meters are all very useful tools for irrigators to monitor their water usage they do not give an accurate indication of which fields take the most water to irrigate or if a change in irrigation practices will result in significant water savings. A commercially viable method has now been developed to reliably measure irrigation application efficiencies on an individual field level.

Aquatech Consulting started the first commercially available in-field irrigation service in 1999 at Narrabri in north-western New South Wales. The system that has been adopted utilises the IRRIMATETM Surface Irrigation Evaluation Service developed with the National Centre for Engineering in Agriculture (NCEA) in Toowoomba. The IRRIMATETM system utilises new:

- hardware,
- software, and
- field data collection procedures.

Both the equipment and software are proven research tools and have been evaluated over many years. This is the first commercial package used to improve surface (furrow) irrigation performance in Australia.

2.0 DETERMINING IRRIGATION APPLICATION EFFICIENCY

The measurements required to determine the application efficiency include:

- flow rate through the syphon,
- the length of time that water is applied,
- the water advance rate down the furrow,
- field geometry (length, slope and furrow shape),
- tailwater runoff,
- irrigation deficit or target application depth.

The inflow through the syphon and the total time of irrigation is measured with a flowmeter and data logger mounted in a syphon. To give representative measurements the syphon with the flowmeter is started and stopped at the same time as the rest of the field. The advance time is measured at five points down each of four furrows with sensors connected to data loggers. Tailwater flow from the same furrow can be measured using a specialised measuring flume mounted across the bottom end of the furrow. Field slope and length are measured by survey before the first irrigation. The cross sectional dimensions of the furrow and the depth of flow are measured after each irrigation in order to determine the width of flow and the volume of water stored on the soil surface at any time.

The total infiltrated volume can be calculated for each of the five advance points using the water balance equation:

$$\text{Water Infiltrated} = \text{Water Applied} - \text{Water Stored in the Furrow} \quad \text{Equation (1)}$$

A line of best fit is calculated for the five advance points measured down the furrow. This enables the infiltrated volume to be calculated for any point in time.

The computer model INFILT is used to analyse this data to determine the soil infiltration characteristics based on the Kostiakov equation;

$$I = k t^a + f_o t \quad \text{Equation (2)}$$

Where:

- I is the cumulative infiltration (m)
- t is the time the water has been applied to the soil (minutes)
- f_o is the steady state infiltration rate of the soil ($\text{m}^3/\text{min}/\text{m}$)
- k and a are fitted parameters

Another computer model, SIRMOD, uses the calculated soil parameters to simulate the irrigation event. The simulation results include advance times, water applied, tailwater runoff, infiltrated soil water and the application efficiency. The advance times and the tailwater runoff are used to calibrate the computer models to the measured irrigation.

As a bonus the irrigation field application efficiency can be calculated using the actual measured irrigation deficit. For this result to be representative it is important that the soil moisture probe is calibrated for the actual soil conditions. The accuracy of the calculated application efficiency is reliant on accurate soil moisture deficit measurements. The evaluation of the depth of applied irrigation and the uniformity of application down the field is not at all reliant on the irrigation deficit. These are independent calculations which can be linked as a bonus if available.

3.0 DETERMINING OPTIMUM IRRIGATION PRACTICES

Once the computer model has been calibrated for an irrigation event other alternatives can be examined to increase the efficiency. Management options include changing the inflow rate, the length of time the water is applied and the soil moisture deficit before irrigation. Other alternatives that include changes to the infrastructure such as reducing field lengths and changing field slopes can also be evaluated if required.

The optimum application efficiency can be predicted by changing one or a combination of the management variables. The SIRMOD results for the measured and optimised irrigations are shown in **Figure 1**. The application depths are shown down the field from the headditch 0m to taildrain 710m. The average depths of application and the deficit or target application depth are also shown.

4.0 CASE STUDY

The following case study is the results from one of the irrigation events measured on a farm in north-west New South Wales. The irrigation was fairly typical of cotton farms in the area with 63mm diameter polythene pipes syphoning from a headditch at the top end of the field. The furrows were spaced on 1 metre centers with every second furrow irrigated and the irrigation cycle time was based around a 12 hour working shift.

The irrigation reached the end of the field in around 9.5 hours. The furrow was running tailwater for about 3 hours before the irrigation was stopped. The advance times for the last sensor show that there was a 2 hour difference between the fastest and slowest advancing of the four rows measured.

After calibrating the SIRMOD model with the measured results, several different management techniques were looked at to see the effect on application depth and efficiency and possible water savings. The first three options are alternatives that are relatively easily implemented. These are:

- 1) Keeping the same inflow rate and stopping the syphons as soon as they reach the taildrain
- 2) Increasing the inflow rate by increasing the available head in the headditch by 10cm
- 3) Doubling the inflow rate by running two syphons per alternate furrows.

The last alternative maximises the potential water savings while increasing distribution uniformity by altering the inflow rate, time water is applied and the irrigation deficit as required. It is important to note in **Table 1** that in this particular case simply stopping the syphons when the furrow flows reach the taildrain saves 0.15 ML/ha/irrigation but the bottom end of the field is under-watered and the Distribution Uniformity is too low at 75%. Increasing the flow rate and stopping the syphons around 2 hours after the furrow flows reach the taildrain produces the best results provided tailwater is recycled.

As shown in **Table 1** there are significant water savings to be made with any of the management alternatives listed. In this case the application efficiency can be raised from around 70% to 90%

by simply increasing the flow slightly and managing the irrigation cut off times better. Based on these measurement there is the realistic potential to save 0.15 ML/ha/irrigation.

Over 400 ha and 7 irrigations, this means a saving of 420ML. That is almost enough water for one irrigation cycle on the 400 ha. The 420ML saved could be used to grow an extra 55 ha of cotton which with a gross margin of even \$1,500/ha equates to an extra \$82,500 of operating profit.

5.0 RESULTS SUMMARY

In **Season 1 (2000/1)**, 13 irrigation events on five fields were measured and evaluated. The measured application efficiencies ranged from 44% to 86% with an average of 71%. Some of our clients chose what they considered their worst field to be evaluated whilst others chose a field more representative of their whole farm. The range of efficiencies measured was consistent with these field types.

In **Season 2 (2001/2)**, 18 irrigation events were measured and evaluated. The measured application efficiencies ranged from 78% to 92% with an average of 84%, an increase in the average application efficiency of 13% over the first year of the service.

In **Season 3 (2002/3)**, some growers that had previously used the service decided to purchase their own equipment to conduct trials themselves, supplying the results for our analysis. Around 30 irrigation events were evaluated with new clients experiencing efficiency ranges similar to that in **Season 1** above and continuing clients experiencing efficiency ranges similar to **Season 2**. Pre-irrigation events were also evaluated for the first time in this season where applications as high as 2.5 ML/ha were measured. Water savings available on these events were in the range of 0.1 to 0.2 ML/ha. Growers that joined the service in the previous seasons had continued to fine-tune their irrigation management. Growers were also using the service to determine improved irrigation efficiency of fields that have been cut in half.

Season 4 (2003/4) showed similar results as Season 3.

A reliable tailwater flume that was capable of handling high stalk trash and leaf litter was developed and tested during the last two seasons. This flume measured the volume of tailwater coming out of the furrow and was able to confirm the accuracy of the computer models.

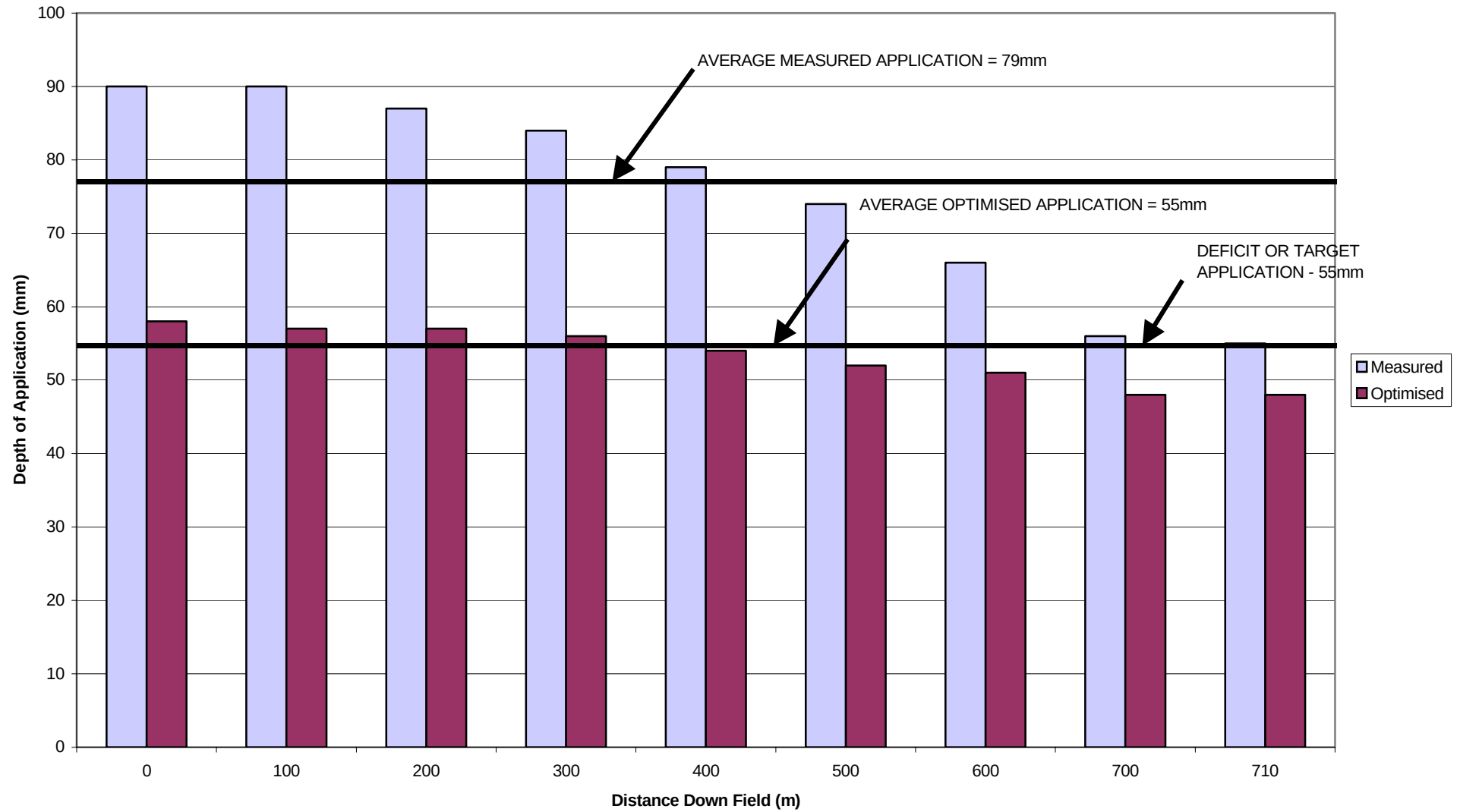
Soils with high cracking characteristics also provided the extra challenge of water breaking through beds into the non-watered furrow. This can now be accounted for with the tailwater meter measuring flows in both the water and non-water furrows by cutting both into the flume.

These results show that there is room for improvement in current surface irrigation practices. Irrigators are looking to maximise their returns from their water. These results show that optimum efficiencies can be obtained using surface irrigation by measuring application depth and uniformity and changing some accepted practices. As with all forms of irrigation, measurement, careful management and informed decisions are the key to getting the maximum results.

Reference: Walker, Dr WR, 1999, "Surface Irrigation Simulation, Evaluation and Design", Users' Guide and Technical Documentation, Utah State University, Logan, UT

FIGURE 1

APPLICATION DEPTH DOWN THE FIELD



AQUATECH CONSULTING IRRIGATION EVALUATION SERVICE

Client: Smart Irrigator
Property: Near Narrabri
Field: 1
Type: Alternate row - 1 m centres
Irrigation: Last Season

MEASURED DATA:

Field Length(m): 710
 Field Slope: 1 in 899 (0.11%)
 Irrigation Time (min): 745

Fastest advance to last sensor: 404 min (6 hr 44 min)
 Slowest advance to last sensor: 519 min (8 hr 39 min)
 Average Advance to last sensor: 456 min (7 hr 36 min)

	Measured Irrigation Event	POTENTIAL SAVINGS			
		Irrigation Stopped When Water Reaches Taildrain	Head on Syphon Increased by 10cm	Flow rate Doubled	Maximum Optimisation
Flow Rate - (l/s)	2.8	2.8	3.3	5.6	6.0
Time - Water Applied (min)	745 12hrs 25min	570 9hrs 30min	510 8hrs 30min	360 6 hrs	310 5 hrs 10min
Time - Advance to End of Field	573 min 9 hrs 33min	573 min 9 hrs 33min	445 min 7 hrs 25min	241 min 4 hrs 1min	226 min 3 hrs 46min
Deficit - (mm)	55	55	55	55	55
Inflow - (mm)	88	67	71	85	79
Tailwater - (mm)	9	3	7	27	24
Water Infiltrated - (mm)	79	64	64	58	55
Application Efficiency (85% of tailwater recycled)	68%	85%	84%	88%	95%
Distribution Uniformity	81%	75%	81%	92%	92%
Potential Water Saving - (ML/Ha)		0.15	0.15	0.21	0.25
Comments					

TABLE 1 – Measured Irrigation Event and Potential Water Savings

DPI&F note

Purchasing a centre pivot or lateral move

Emma Carrigan, Development Extension Officer

Step 1 – Planning

Calculate the required system capacity

System capacity (mm/day) is a measure of the ability of these systems to meet the crop water requirements for an extreme three day evapotranspiration event. It is found by dividing the January Point Potential evapotranspiration value for your location (see the Bureau of Meteorology maps at www.bom.gov.au) by the cotton industry calibration factor (21.5). This calibration factor has been determined after thorough investigation of existing cotton centre pivot and lateral move installations and their ability to meet cotton crop water requirements.

Determine water availability

Make sure you have sufficient water to grow your crop (typically centre pivot and lateral move irrigated crops require 30-40% less water than surface irrigated crops).

A variable supply rate results in variation in machine performance. For lateral moves consider the flow rates into supply channels and available head along the channel length. Groundwater supplies are often limited by the possible extraction rate – check this rate at the end of the season with a 48 hour bore pump test.

The supplied water flow rate is the lesser of the supply infrastructure capacity (channel and storage or aquifer extraction rate) or the maximum pump flow rate permissible by the machine manufacturer (around 300 L/s for large lateral moves).

Estimate your irrigated area

The possible irrigated area is estimated using the formula:

$$\text{Irrigated area (ha)} = \frac{\text{Pump flow rate (L/s)} \times 60\text{s/min} \times 60\text{min/hour} \times 24 \text{ hours/day}}{\text{System capacity (mm/day)} \times 10,000}$$

In the case of lateral move systems the irrigated area is that which is irrigated in any one season. The machine may actually have a larger area it can cover, but some of this may be fallow.

Physical considerations

Water quality should be analysed for its potential corrosiveness. Stainless steel or poly-lined systems are available for poor water quality situations.

Physical and biological contaminants may be an issue (especially where supply is by open channels). Consider filtration to minimise nozzle blockages.

Try not to have soil type variation under a machine. If this is unavoidable, avoid variation across the length of the machine; have the machine travel over changes in soil type so that application strategies can be modified.

Information contained in this publication is provided as general advice only. For application to specific circumstances, professional advice should be sought. The Department of Primary Industries and Fisheries has taken all reasonable steps to ensure the information in this publication is accurate at the time of publication. Readers should ensure that they make appropriate enquiries to determine whether new information is available on the particular subject matter.

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Full land levelling is not typically required, although fields should be cut to drain. Issues can occur under machines with LEPA systems when water runs and collects in lower areas – localised water holding strategies like dyking become important.

Step 2 – Design

Centre Pivot or Lateral Move?

Centre pivots have half the labour requirements of lateral moves and are easier to manage as dry ground is always directly in front of the machine. Lateral move channels allow evaporation and seepage losses, and require maintenance. Trash accumulation in channels accounts for the majority of machine shutdowns - trash screens are essential but do not stop this problem as trash is deposited back in the channel.

On larger centre pivots the average application rate on outer spans can be very high resulting in poor infiltration and surface runoff. Avoid end guns and racetrack machines.

Span pipe sizes & operating costs

Machines are often specified with all small diameter (6&5/8") pipe which has higher friction losses than larger pipe sizes at the same flow rate. Using larger pipe sizes (8" or 8&5/8") on larger machines will significantly decrease operating costs due to lower pressure requirements.

Ensure span lengths reflect your farming practice - if you want exactly 48.0 metre spans you will need to specify this to the supplier.

Sprinkler package

Sprinklers, nozzles and pressure regulators represent about 7% of capital cost but are responsible for 70% of irrigation performance. Try to use a package with as low pressure as possible to reduce operating costs - 6psi, 10psi and 15psi packages are common but 6 or 10 psi is usually adequate.

Sprinklers are necessary for germination, typically with a reduced nozzle size to limit flow rate. Sprinklers or LEPA may be used throughout the rest of the crop life. Be aware that you need to keep water where it is placed with either system, but more importantly with LEPA (dyking and stubble retention are possible solutions).

Step 3 – System performance

System checks

Have a system check performed by the supplier to ensure that the delivered machine is performing as it should (at least system capacity, distribution uniformity and energy consumption). Unfortunately there are typically few commercial providers of irrigation system auditing services.

System capacity

System capacity is the maximum rate at which water (mm/day) can be applied to the irrigated area. A low system capacity means peak crop water demand cannot be met. To check system capacity measure the daily pump flow rate (ML/day) and the irrigated area (ha) and insert these values into the formula

$$\text{System Capacity (mm/day)} = \frac{\text{Flow rate (L/day)}}{\text{Irrigated area (square metres)}}$$

Uniformity

Uniformity refers to how evenly water is applied across the field. The benchmark value for centre pivot and lateral move uniformity is 90% - below this yield variation and poor water use efficiency results.

Uniformity is measured by a catch can evaluation; this allows a comparison of the depth of water applied at various points within the field.

Average application rate (AAR) (mm/hr)

Average Application Rate is the ratio of an individual nozzle flow rate to its wetted area. Where the AAR exceeds the soil infiltration rate runoff results. This is usual at the end of long centre pivots and for all LEPA systems. This runoff can be managed by using dyking, surface roughness and stubble retention.

Increasing the number of sprinklers or decreasing the flow rate per sprinkler can decrease the AAR.

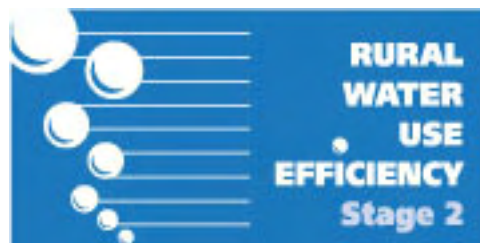
Field application efficiency

Field application efficiency is a measure of the amount of water available to the crop compared to that supplied to the field. Potential water losses result from runoff, deep drainage and evaporation (usually less than 5% for modern low pressure sprinkler systems). The benchmark application efficiency for LEPA is 98%, and for sprinklers, 95%. The formula for field application efficiency is:

$$\text{Application Efficiency} = \frac{\text{Irrigation water available to the crop}}{\text{Volume of water supplied to field}} \times 100$$

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