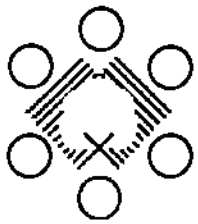

COOPERATIVE RESEARCH CENTRE FOR SUSTAINABLE COTTON PRODUCTION

CRDC

Proceedings of the Cropping Systems Forum

A meeting to discuss results and coordinate research relating to cotton cropping systems

2 &3 December, 1998

Richard Williams Conference Room
Australian Cotton Research Institute
Narrabri NSW

Proceedings edited and compiled by
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Cropping Systems Forum 2nd & 3rd December 1998

Conclusions presented by Dave Anthony on the last day.

The objectives of this Forum, namely to encourage communication, generate dialogue and exchange information between growers, researchers, advisors and regulatory people have been met, but the questions we need to ask ourselves are :

"What would we like to know?"
"Do we know this already?"
"Why do we need to know this?"
"When we know it, how do we manage and maintain this knowledge?"

Soil management issues in the cotton industry have brought a lot of good news and positive results in the past. We can look forward to an exciting future in farming systems work particularly with Precision Agriculture arriving on the scene.

The key issues considered at this Forum were:

BEST MANAGEMENT PRACTICE

This is a rising force in the industry. It is addressing pesticide issues now but will include other issues in future. BMP should be based on the best information and this means using appropriate research information or commissioning appropriate research to assist in the development of robust best management practices: for example, vegetative buffers, dust management, droplet size manipulation when spraying, use of transgenics in sensitive areas.

Researchers should be aware of what is influencing and shaping the cotton industry; looking for where there are questions without answers. (Often a research gap or an area a growing industry has forgotten)

FARMING SYSTEMS EXPERIMENTS and STUBBLE RELATED ISSUES

The question now is should we pick up on several key treatments and run these up to large enough production units to assess them under broad commercial and biological environments? What is the next level of issues facing such treatments beyond the small field strips?

Should we support:

a) more monitoring/assessments of our treatments rather than individual input testing?

b) allowing the machinery options in Machinepak to be tested on various treatments at a commercial scale?

c) introducing "dryland" technologies,(very innovative & efficient processes from which irrigated agriculture may pick up some important leads)?

The issue of carbon retention is reasonably well understood; retention of stubble is accepted widely but some fine-tuning on the quality of stubble is still to be determined. It is recognised that longer term benefits come from wheat or pulverised cotton stubble as opposed to high nitrogen legume stubble which dissipates rapidly in the soil.

Controlled traffic is a well accepted practice whose benefits are clearly established and when combined with stubble retention provides the basis of an improved farming system.

Stubble retention provides benefits for surface soil conditions, pesticide capture and retention.

Deep sub-soil accessions of water was still questioned? How important is it for our cotton area and do certain farming systems encourage such movement?

DISEASE COMPLICATIONS

This is a major issue especially, Black Root Rot and Fusarium. What can we do to establish a seed bed which minimises the susceptibility of young cotton to these diseases? Does disease control conflict with Farming Systems initiatives involving stubble retention etc?

RUN OFF WATER

The issues of storm run off water and pesticide loads are important. They need to be included in Farming Systems assessments. The key issue seems to be the need to minimise storm water run off reaching sensitive areas like rivers.

WATER USE EFFICIENCY

This is a big issue in the public arena. If you look at a lot of what has been discussed at this Forum, WUE has been at the base of much of what we are dealing with. Good soils, good crop management, good rotation programs, all help improve WUE.

We have come a long way, but very few growers can demonstrate their actual WUE. The only measures we have are the gross/global calculations of Brian Hearn's, or the research data of Constable/Hodgson et al. If you can't measure something you can't manage it properly.

Again, inputs from dryland farming systems should not be ignored.

SALINITY

This is an important area. We need to question where does the industry go with the current salinity program? We now have a fast and efficient monitoring technique. Do we now apply that to farms on a commercial basis? Who should do the monitoring? Do we monitor some of the preferred Farming Systems options to assess them under commercial conditions?

INFORMATION PACKAGES (such as the "pak and logic series").

These are important information collation vehicles. They are performance measures of the 'Rules of thumb' or 'Decision options' that the industry uses. They are also user friendly ways of transcribing complex amounts of information. There are several questions about these packages:

What is their role in the BMP process?
How are they reviewed?
How are they updated and managed?
How are they promoted and adopted?

PRECISION FARMING

This has the ability to convert crop yield information into useful decision support information for producers by combining a range of technologies. The key area to be worked on is ground-truthing (cause / effect / potential solutions) of the information being collected.

GPS controlled tractors, Harvest monitors, Video guidance are with us already. Weed control using PA will lead to pesticide load reductions. Combining technologies on a GPS platform provides exciting possibilities provided an open data architecture for these new remote or precision farming systems is employed to allow seamless manipulation.

NUTRITION

High yields are leading to high demand for nutrient inputs. Potassium (K) under premature senescence is not a deficiency but rather a demand re-allocation of internal plant resources under high boll load.

Phosphorous: a gap in our research is being addressed with questions being raised about the testing of labile P in assessing available P levels.

Nitrogen: Continued work is helping fine tune the predictive N rates and the value of various rotations.

Notes from discussions following each forum session

Session 1 Stubble management

- Early season growth was improved with mulching, but may not be practical because of the cost and volume of organic material needed. Soil structure was improved and weeds controlled by the mulch.
- Yield benefits of mulches seen on healthy plants as well as unthrifty plants.
- Soil temperature effects under mulch not measured.
- A thick mulch is required to affect soil temperature and retain soil moisture.
- Protective effect of mulch from wind.
- Retention of stubble (cf burning) increases labile C in soil.
- OM quality - Resilience of stubble to decomposition can be manipulated with tannin (etc) content.
- Microbial biomass is a relatively small component of the soil C pool and may not be representative of soil quality.
- Although substantial changes in C management index occur in cotton systems, the changes in lint yields are not as dramatic as in other cropping systems.
- Need to grow rotation crops which improve soil quality (ie add C and/or N).
- Soil structure may be best improved by low-input wheat.
- Future cropping systems may have shorter fallows.

Session 2 Farming systems

- Flow charts being prepared by the Cotton Extension Team to aid growers selection of rotation crops, with regard to economic, productivity, weeds and disease aspects.
- Some legume treatments in CRC farming systems experiments have not done as well as in other experiments because eof late sowing and saline soil and irrigation water.
- Compaction may be a problem at the Warra site and requires measurement.
- As legumes have the potential to host some cotton diseases, (eg Black root rot) cereals have been the rotation crop of choice – wheat, vetch, sorghum may all reduce BBR.
- Black root rot (BRR) more closely related to soil texture (worse on medium textured clay soils) than to waterlogging or drainage of fields.
- Possibility of bio-control for BRR, also new fungicide treatments (eg Baytan).
- Wheat crops don't encourage BBR, cotton crops do.
- BRR fungus probably does not fix N, although some fungi do, but the N input is Very small.
- Bacterial stunt – some cultivars more resistant than others.
- Disease surveys are conducted on same farms each year, so increases in reported disease incidences are real.
- Northern Australia – water is cheap but trickle irrigation is better on lighter soils. Failures due to importation of southern technology rather than applying more appropriate technology.
- Results from small-plot research needs to be tried in real farming situation to validate the benefits of improved systems.
- Need to regularly revue treatments imposed in these experiments (eg direct drill into stubble) and methodologies used (eg water individual treatments when required, not all at same time).

- Need to initiate new experiments occasionally to research specific cropping systems issues.
- Need to make the practical results available to growers.
- The prime requisite for cropping systems is sustainability (economic, productivity).
- Social aspects of cropping systems must be recognised – aging population of farmers, declining rural communities etc.
- Fallow weed management is critical to control in-crop weeds.

Session 3 Chemicals in the environment

- Whole river system not monitored, just few sites throughout catchment.
- Research required on fate of pesticides lodged in silt (sediment) on river floor.
- Relatively small amounts of chemical in river system, probably resulting from storm runoff.
- Most pesticide is retained in surface 5 cm soil.
- Need to research through drainage and movement of pesticides into groundwater.
- Contain pesticide run-off with retained wheat/cereal straw – little data – soil loss reduced by 70% with retained wheat stubble.
- Labile C moving through the soil may be accompanied by pesticides adhering to it.
- No research into pesticides moving down soil cracks.
- Heliothis moths may be deterred from laying eggs on cotton as standing wheat/cereal stubble may provide a barrier to them.
- Weeds can be controlled with shielded sprayers and fertilizers applied without disturbing the stubble unnecessarily.
- Pesticides are still found in tail-water coming of stubble-retained systems, possibly at reduced concentration.
- Erosion and endosulfan movement are essentially early season problems which can be managed, possibly by adopting practices like sowing into cereal stubble.
- Are pesticides adhering to OM leached into subsoil? Does stubble retention increase this? Selection of stubble type may be important.
- As most pesticides decompose relatively quickly (unlike DDT) there is little likelihood of serious contamination of farm storages due to recirculation of tail-water.
- Inconsistencies between acceptable levels of pesticides in tail-water and drinking water were noted.
- Dust important mechanism for nutrient and pesticide movement off-farm. May account for 40% of endosulfan in non-flowing river. Dust is rich in nutrients and OM.

Session 4 Soil water / structure / quality

- Biolog system developed for "clinical" tests - need to modify/select substrates used.
- Is this system a legitimate measure of soil degradation or quality?
- Biodiversity reduced but more variable in cultivated soils.
- Soil having very low populations of specific organisms may require longer incubation times to show their presence, which allows for contamination of the detection system.
- Need to measure WUE on whole farm, including efficiency of channels for conducting water.
- The cotton industry is efficient, but still requires measurement to indicate where improvements need to be made.
- Some soils may be more "leaky" than others and we have little appreciation of groundwater systems. Should these suspect areas be avoided for irrigated agriculture? These areas could be identified with current surveying technology and irrigation

developments planned accordingly. Many prior streams noted in Namoi valley which are characterised by higher sand content conducive to water movement.

- Cost of measuring soil salinity? – EM sensors @ $200 ha/day.

Session 5 Extension/BMP

- Need for quantifying the amount of pesticide in soil.
- Management of storm water runoff difficult but needs some planning.
- EPA involvement in auditing for BMP.
- Risk management – some risk associated with all agricultural practices.
- Legal ramifications with MACHINEpak – cannot openly criticise inadequate machinery.
- NutriLOGIC only interprets soil and petiole nitrate data currently – look-up tables for other nutrients available.
- Are growers becoming over-loaded with information? Information must be easy to find – CD's and Internet will probably increase accessibility in the future.
- CottonLOGIC is being well received and more user-friendly.

Session 6 Precision Agriculture

- Can compaction be better managed with Precision Ag techniques? Use guidance systems to better manage controlled traffic areas.
- Need more resources into shared technology – eg merge weed management, GPS technology with CottonLOGIC and commercial software packages.

Session 7 Crop nutrition

- Fate of applied P – what forms of low-solubility P are formed (Ca-P, Fe-P etc)? How accessible is this P to the crop?
- Role of P and physiological stresses (eg waterlogging) in premature senescence?
- Considerable loss of N in wet winters (as in 1998) from early applied N fertilizer. Loss of N dependent on severity of waterlogging and length of flooding period.

Soil Survey of the Edgeroi District, 1985-1987

W.T. Ward
formerly CSIRO Division of Soils, Brisbane

Our soil examination was concerned with the area covered by the Edgeroi 1:50 000 topographic map but we also looked at the adjoining Narrabri, Wee Waa, Bunna Bunna, and Pilliga areas. Our purpose was to identify the main soils and their natural place in the landscape.

Comment on Soil Classification

There are different ways to look at soils. We commonly assess their value to users. From this point of view what is important is soil depth, texture, structure and fertility. And whether the soils have features that limit land use.

Soils are also natural objects that come in different varieties. Our task is to recognize them. Some might be useful, and others of little value.

The pioneers of soil science found, in Russia, that soils were the product of several environmental factors. Similar soils elsewhere had presumably the same origins. Russian names (such as podzol, solod and solonetz) became common around the world.

The Russian classification didn't give us great results. Their theories didn't fit our Australian soils well. We agreed that the soil-forming factors had left their imprint on the soil profile but it seemed to follow that studies of the factors were unnecessary. Factual descriptions of profiles should be enough. Soils were accepted to be not greater than 2 m deep; the subsoil B horizon was the one with the greatest colour and/or structure; the profile was uniform, gradational, duplex or organic. You could simply follow a straightforward key to classify a soil. But did this give you an adequate description of the natural soil world? Do the classes have more than the key properties in common?

Soil classification might need experts, but they are here today and gone tomorrow. How can we know if their views are well founded? What are their prejudices? Would it not be better to use an explicit approach, a clear classification that uses local facts and research?

That is what we wanted to do. We wanted to explain the Edgeroi area as it is. Our thinking should be transparent. If we made the data freely available others, whose experiences were different, could use our observations and provide their interpretations.

We wanted the best from the past. We wanted to reconcile the classical approach to soil science with modern methods of data analysis.

Geological background to the soils of the Edgeroi District

The parent rocks of the soils include Pilliga Sandstone, Nandewar and Garrawilla basalts, and clayey sands of Purlawaugh Formation. The calcareous Rolling Downs Group also occurs (at the University of Sydney's Wheat Research Farm), and there is a soft Tertiary sandstone. Thin veneers of sediment eroded from these rocks are common. For instance, the lower slopes of the sandstone ridges east of the Newell Highway are covered with sediment washed down from the weathered sandstone higher up. These surface washes are much more important as soil parent materials than the actual parent rocks in place.

In past ages, sediments have accumulated intermittently. The materials eroded from the hills were deposited on the plains and spread back from there onto the lower slopes of the hills. Soils were formed on the sediments as they accumulated, and were later buried. We found one buried soil on Murrumbilla that was formed on limey clays blown into the hills. Similar windblown clays today cover vast areas of the plains. They form the Grey Clays and Brown Clay soils. It is these windblown sediments that form the soils mainly used to grow cotton.

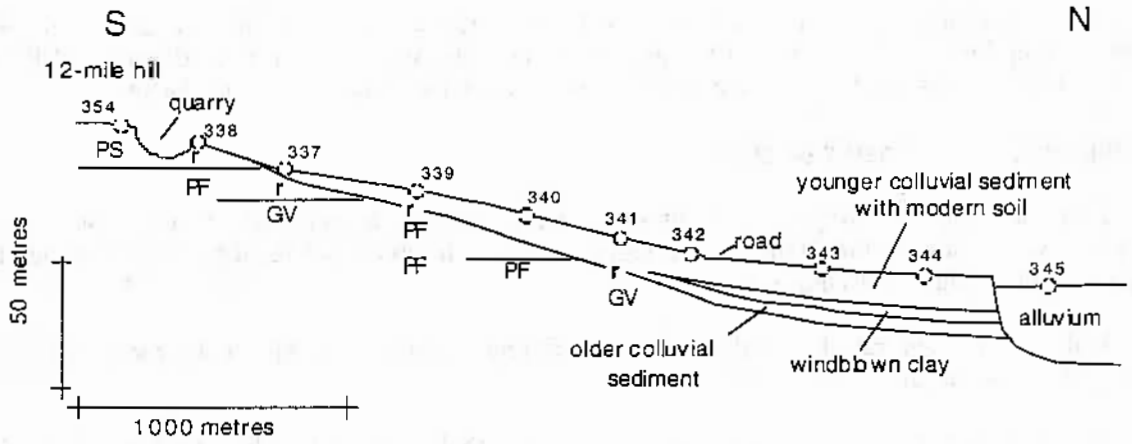


Fig. 1. Hill slope at 'Murrumbilla', showing veneer of colluvial surface wash over country rocks. Calcareous windblown clays form a bed within the colluvium. '**r**' indicates red weathering.
PS = Pilliga Sandstone, PF = Purlawaugh Formation, G = Garrawilla Volcanics. The numbers show drilled locations.

In this part of the North-western Plains of NSW five sets of old alluvial deposits occur by the modern flood plain. The three oldest are thickly mantled with windblown dust. Where the slope is great enough, the windblown materials are missing, owing to rain wash during and after deposition. The contribution of windblown dust is very great, for several soils are formed entirely on the dust or on dust that has been water-sorted. And most other soils have benefited from the addition of the windblown material.

Today's soil variation can be explained by landscape changes produced by climatic changes in the last half million years, and by the transport of nutrient elements in the soil (by rainfall, surface wash and subsurface drainage) from high points to stream lines and ultimately to floodwater soaks on the plains. The clay soils are in this way related to dust storms of past ages, to the accession of cyclic salts, and to the patterns of rain water dispersal. Water-shedding sites became leached of the more soluble elements that arrived with the dust or were subsequently released by weathering, and those elements have moved to the plains where, in places, the resulting changes in exchangeable sodium have resulted in topsoil texture and collapse of topsoil structure.

Before the wind-blown clays appeared the Namoi was a landscape of red soils. Red remnants can still be seen, and in several places the old red soils give rise to the modern soils.

The windblown sediments on the high plains at Bohena retain vast quantities of salt that is leaking slowly through the neighbouring soil to local watercourses. Land use here is restricted by the gilgaied surface and by the salt content, and on the sand-over-clay soils, by toxic levels of exchangeable aluminium.

The data we acquired by survey and soil analysis were examined by fuzzy analysis. Soil samples taken to 2.6 metres depth were described. Fourteen features were determined on every sample. There were 377 sample sites, that is over 5000 analyses. We found that clay contents and

cation chemistry agreed with field soil relationships. They allowed us to distinguish several clay soils. A simple soil-landscape approach was combined with the mathematical work to balance it with geological data.

Forty soils form 22 soil series. Their differences relate to differences in the type of parent sediment, soil drainage, and age of the alluvial ground surface. On the alluvial ground there is a trend from undifferentiated to differentiated sand-over-clay profiles. Sand-over-clay profiles also occur on the hilly lands but most soil differences there are due to the different rock types.

The soils can be related to three landscape units: the hills; the dust-mantled plains and lunettes; and the alluvial plains. Gilgai with brigalow *(Acacia harpophylla)* characterise the *in situ* dusts. Linear gilgai mark most areas of soil on weathered Garrawilla basalts.

The plains have taken a very long time to form, and were formed piecemeal, during past ice ages. The forest cover was mostly absent then, allowing rapid runoff and the catchments to be shaped by rainwash. The windblown dusts mark dry periods coinciding with ice ages.

We mostly think of ice ages as something remote, with ice caps in Europe and North America. Conditions were nothing like the present time. What connection could ice ages have to cotton growing, and to agriculture in the Namoi Valley?

We don't really know much about ice ages, except for the ice caps in what are now cool temperate areas, and the sea was lower by 120 metres. That was about 18 000 years ago. Surprisingly, mean annual temperatures were not much different. Maybe only 3 or 4° cooler than today. And it was windier, for windblown silts and clays were commonplace. The change of sea level would have affected the Southern Oscillation by cutting off water circulation through Indonesia. Northern Australia would have had less summer rain.

But we do know something else. The last big ice age was followed by several smaller events, the 'Little Ice Ages'. Some of them occurred in historic times. There was one about the year 1800. The Little Ice Ages were certainly not local European events, for they are evident on the Australian coast and in the western arid lands.

These Little Ice Ages, like the big ones, were dry and windy, and the last of them, I believe, occurred in the 1920s and '30s. The Namoi was subject to drought then, and was swept by dust storms.

There were plenty of weather observers then, among them Mr S.A.Thompson of Merah North. He wrote in his rainfall record:

> 'Thursday the 20th September 1923 will long be remembered in these parts as 'Black Thursday' - a hurricane started about mid-day and continued till 6 pm. In parts the surface was swept of all vegetation and bore drains were filled up level with rubbish, dust etc. In places fences collapsed and others had dirt etc piled up against them over 3 feet deep. This was the worst dust storm I have seen for over 20 years.'

He made other notes, for instance on 13 September 1928:

'Terrible wind and dust-storm, at times couldn't see more than 1/4 mile.'

The following figure summarises the 'Pendennis' rainfall record. It shows quite clearly how things were in the 1920s and '30s.

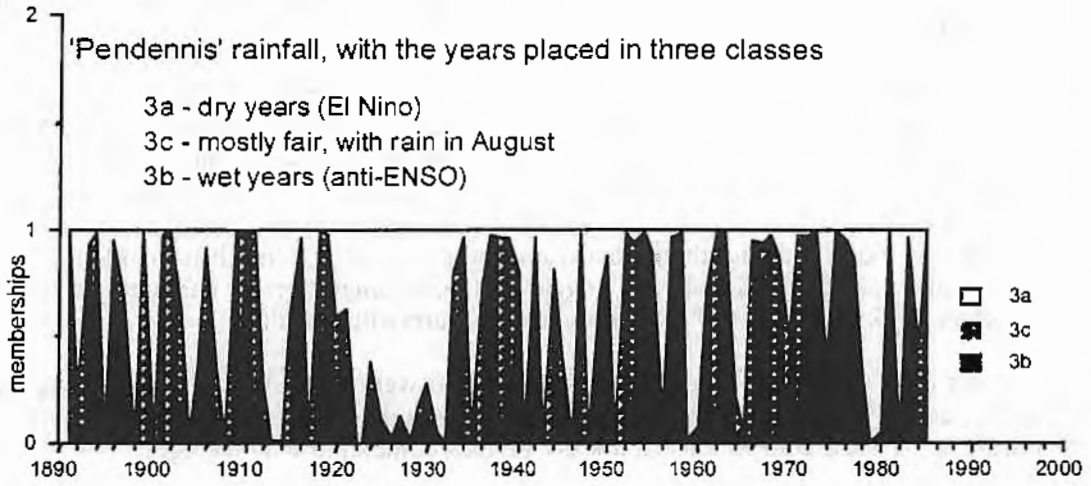


Fig. 2. Fuzzy analysis of 'Pendennis' rainfall, 1889 - 1985. The years are counted from April to March, e.g., 1930 = April, 1930 to March, 1931.

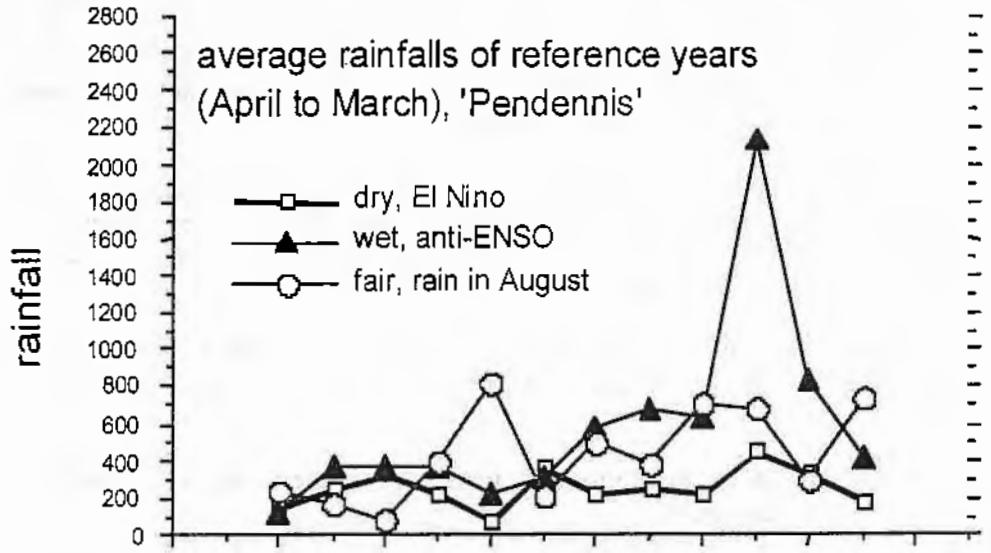
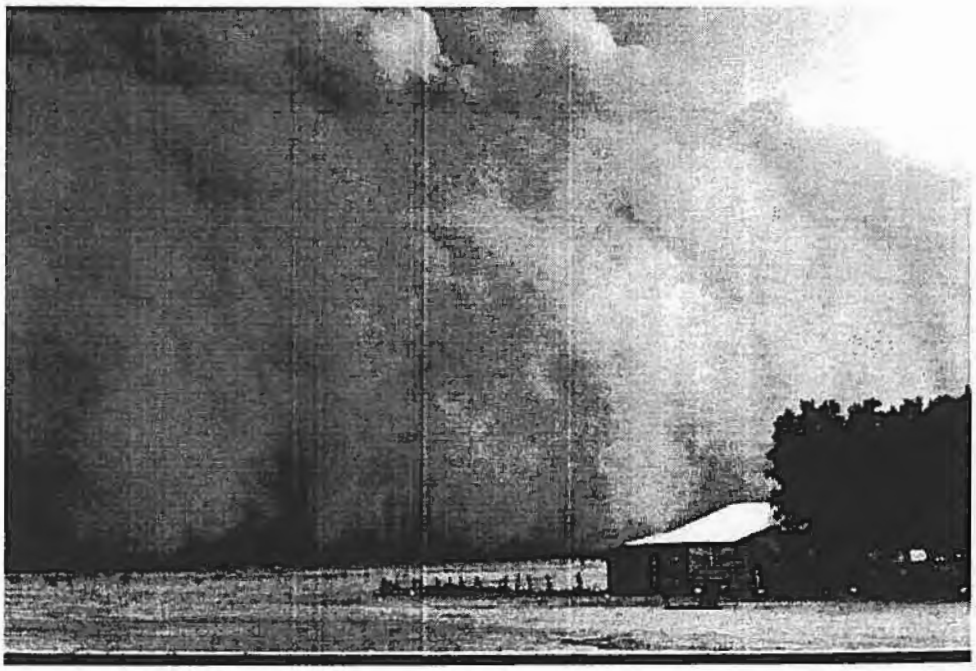


Fig. 3. Average monthly rainfalls of the three kinds of rainfall year, 'Pendennis'.

The droughts and duststorms of the 1920s and 1930s could represent, for us, a Little Ice Age. Meteorologists think these events are simply variations in common weather patterns. But it doesn't matter whether it is a Little Ice Age or a variation in weather pattern. The different viewpoints are not important. Farmers, stock and crops are hit just as hard.

Further meteorological and earth science investigations are needed to define the conditions that lead up to events of this kind.

Photographs of wind erosion within the Australian landscape.



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Mulches and cover crops to control *Bacterial Stunt* of cotton - an update

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Introduction

In 'bacterial stunt', (previously known as early season growth disorder or Galathera syndrome) bacteria infect the roots of cotton and inhibit plant growth and VAM development. The disease is most severe on heavy clay soils that are often high in nutrients. The fine roots of seedlings turn brown (not black) when infected. In a survey conducted in NSW and Queensland between 1995 and 1997, bacterial stunt was detected in 17 of the 43 fields examined. Maturity was often delayed and yield losses were occasionally as high as 50 %. A low level of bacterial stunt appears to be widespread. There are few options for control of bacterial stunt. Eradication of the pathogenic bacteria from soil is impractical. Permanent bed systems appear to have increased yields, although the pattems of stunting across fields remain visibly obvious. This paper provides an update on the potential to improve cotton growth at sites where stunting is severe by manipulating soil moisture using organic mulches, furrow irrigation and novel irrigation techniques was evaluated in several experiments.

Mulches

A lucerne hay mulch, applied at the end of October, resulted in large increases in early growth of cotton and this was reflected in greater boll mass in January (Table 1). However, shoot mass in the bare plots had caught up to that of cotton in the hay plots by January, suggesting that plants in the hay plots had 'cut out'. Later in the season there was no difference in cotton maturity and final yield between treatments (Table 1), as occurred when this experiment was conducted in the same plots in the previous season .

Table 1. Effect of hay mulch and extra N on cotton growth in 1997/98[z].

	Control	Hay	Hay N		Increase/decrease over control(%)
	15 December 1996				
Shoot fresh mass (g plant^{-1})	17.9b	23.3a	23.9a	p•0.007	32
Shoot dry mass (g plant^{-1})	4.6b	7.5a	7.3a	p•0.004	62
	15 January 1997				
Shoot fresh mass (kg m^{-1})	2.0	2.3	2.2	NS	14
Shoot dry mass (g m^{-1})	311	328	335	NS	7
Shoot N content (%)	6.7	6.9	6.9	NS	3
Boll number (m^{-1})	18b	28a	23ab	$p = 0.045$	43
Boll fresh mass (g m^{-1})	343b	569a	469ab	$p = 0.026$	51
Boll dry mass (g m^{-1})	50b	74a	65ab	$p = 0.058$[x]	40
Verticillium (% plants)	3.3	1.7	5.1	NS	
	9 March 1998				
Seed cotton (kg ha^{-1})	2620	3150	2820	NS	
	15 April 1998				
Total seed cotton (kg ha^{-1})	5239	4950	5099	NS	

[z] Values followed by the same letter are not significantly different at the stated probability by pairwise comparison of means with the Scheffe test.

[y] Mean for both hay treatments.

shoot growth were reflected in greater boll production in January, a greater proportion of extra photosynthate, produced in the drip and wick treatments, was allocated to vegetative rather than reproductive growth (Table 2). The drip and wick treatments increased seed cotton yield, in the middle two rows of the plots, by 17 % and 19 % respectively, but not significantly (Table 2). However, there was a significant increase (32 %) in seed cotton yield in the outside rows of the wick plots (Table 2). Hence the competitive effect of the outside rows over the adjacent buffer rows, and also over the centre rows of the plot, may have prevented the centre rows from reaching their yield potential. Larger plot sizes would resolve this issue. Assuming that the yield increase of approximately 19 % in the centre rows may have been significant on a commercial scale, then the potential benefit from mulching and providing supplementary water would be approximately 1.5 bales ha^{-1}.

Table 2. Effect of supplementary irrigation on growth, maturity and seed cotton yield at ACRI field 4[z]. Wick = periodic application of extra water with a wick buried in the centre of the 2 m bed. Drip = periodic application of extra water with drip lines on top of the bed. Hay = hay mulch. Bare = untreated.

	Hay Drip	Hay Wick	Hay	Control		Increase over control (%) Drip	Wick
18 December 1997							
Shoot fresh mass (g $plant^{-1}$)	105a	97a	73ab	60b	p • 0.043	76	62
Shoot dry mass (g $plant^{-1}$)	16a	16a	12ab	11b	p • 0.048	47	44
YFEL N content (%)	6.6	6.7	6.7	6.5	NS		
22 January 1998							
Shoot fresh mass (kg m^{-1})	3.87	4.85	3.54	3.03		28	60
Boll production (boll m^{-1})	41	67	47	43	NS		
Boll dry mass (g m^{-1})	111	177	134	125	NS		
Shoot dry mass (g m^{-1})	501ab	704a	525b	447b	p • 0.030	34	57
YFEL N content (%)	7.2	7.1	7.0	6.4		12	11
12 May 1998							
Seed cotton, middle rows (kg ha^{-1})	5993	6082	5804	5104	NS		
Seed cotton, outside rows (kg ha^{-1})	6161a b	6962a	5879b	5280b	p • 0.024[y]	17	32

[z] Values followed by the same letter are not significantly different at the stated probability by pairwise comparison of means with the Scheffe test.
[y] Mean comparison by Fisher's LSD test.

In a larger field experiment, furrow irrigations, over and above the normal irrigation schedule, were applied to plots at the north end of Auscott Field 8. Stunting is normally severe in this part of the field, while cotton growth is good at the southern end. The extra irrigations were applied in a 2 x 2 factorial design (four replicates) with plots either irrigated or not on 12 November, and half of these plots either irrigated or not on 11 January. In these four treatments, cotton was sown into uncultivated stubble remaining from a crop of oats that was grown as a cover crop, sprayed with glyphosate and slashed prior to planting. In the rest of the field the oats crop was incorporated by disk cultivation before planting. An extra 3 replicate plots were assessed at both the northern and southern ends of the field to account for the effects of incorporation of the oats.

The additional irrigation in November increased shoot fresh mass, dry mass and N uptake in December by 66 %, 44 % and 30 % respectively, suggesting that the extra water gave the plants greater access to nutrient reserves in the soil. However, this early growth increase did not result in

greater boll production. By January the N content of cotton given the November irrigation had fallen below that of cotton with the conventional irrigation schedule.

Although cotton given the extra irrigation was larger in December and had 15 % more lint in open bolls in March, it 'cut out' early, perhaps because the N supply was prematurely depleted, and there was ultimately an 8 % yield penalty (Table 3). The additional irrigation in January did not affect maturity or yield (Table 3), however, irrigation was very frequent at that time. Yield results are not yet available for all the plots where oats were incorporated. However, in one of the plots where oats were incorporated, at the northern end of the field, yield was 6.6 bales ha^{-1}, suggesting that a potential yield increase of 23 % was due solely to leaving the oat stubble standing. During the season, the beds in plots where the oats were left standing and slashed appeared to hold their shape, while beds elsewhere in the field, where the oat crop was incorporated were visibly slumped. Following rainfall events there was more water sitting in the furrows where the oat crop was incorporated, than in the standing oats plots. These qualitative observations suggest that the standing oats crop helped maintain good soil structure and increased infiltration.

Table 3. Effect of supplementary irrigation on lint maturity and total yield in the plots where oats were left standing and slashed.

First extra irrigation	November	November	-	-	
Second extra irrigation	-	January	-	January	
11 March 1998					
Seed cotton (kg ha^{-1})	3299a	3383a	2881b	2943b	$p = 0.039$
21 March 1998					
Total yield (bales ha^{-1})	7.6b	7.3b	8.1a	8.1a	$p = 0.001$

Conclusion

The growth increases caused by mulching and maintaining soil moisture were associated with proliferation of roots in the topsoil. Furthermore, the proportion of roots was greater near the surface, suggesting that greater access to the fertile layer of topsoil was responsible for the improvement. The effect of these treatments on the bacterial stunt pathogens is currently being determined. There is clearly potential to increase early season growth by optimising conditions for the plant in these nutrient rich soils, even in soils not badly affected by bacterial stunt (eg Field 4, ACRI).

The early gains in cotton growth with mulching and extra soil moisture resulted in advanced crop maturity. However, with a long hot season in 1997/98, cotton growth and yield in the control treatments ultimately caught up. The experiments were conducted in fields that were managed for conventional crops, not the experimental treatments. The challenge now is to convert the gains in early season growth into yield increases. Our treatments need to be adapted for full-scale crops: covercrops and drip systems are the subject of further research.

Acknowledgments

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Effects of cotton management on soil carbon and the effects of soil carbon on soil physical properties

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Blair et al. (1995) have developed a procedure using 333mM $KMnO_4$ as an oxidising agent to determine labile carbon concentration in soils. This allows the calculation of the Labile Carbon (C_L) and a Non-Labile (C_{NL}) components, the latter being calculated as the difference between total organic carbon (C_T), measured by combustion and the C_L. The relative amounts of these two fractions, and the total carbon in a cropped and reference soil, have been used by Blair et al. (1995) to calculate a Carbon Management Index (CMI). This index compares the changes that occur in total and labile carbon as a result of agricultural practice, with an emphasis on the changes in C_L, as opposed to C_{NL} in SOM.

Soils from a series of cotton experiments and from commercial cotton farms in Eastern Australia have been studied. In a survey of 65 soils from cropped and nearby uncropped (reference) soils Conteh (1998) found the following results

- pH: 5.8 - 8.8, > 60 % above pH 7.5
- C_{org}: 3.0 - 25.0 mg/g
- Colwell P: 5 - 78 mg/kg, 86 %above critical range
- KCl-40 S: 2 - 65 mg/kg, 86 % above critical range
- Exchangeable K: 0.2 - 2.2 cmol(+)/kg, 98 %above critical range
- Exchangeable Mg: 1.3 - 21.6 cmol(+)/kg, All above critical limit
- Exchangeable cations and P were unaffected by cropping
- NO_3-N, S, and pH were higher on cropped soils
- Fe lower on cropped soils
- Total carbon (C_T) loss with cropping ranged from 3 - 64 % relative to the reference
- Labile carbon (C_L) loss with cropping ranged from 5 - 82 % relative to thereference

In the CRC FS experiment being conducted at Warren, a series of seven rotations containing cotton are included. The experiment commenced in 1993 and the results of soil analyses on samples collected after 2 years are shown in table 1. A significant increase in C_L was recorded in the CFP rotation, a significant increase in C_T in the CWLLF rotation and significant increases in both C_T and C_L in the three rotations which included wheat (Table 3). These increases in C_L resulted in significant increases in CMI.

Table 1. Changes in C under 2 years of different cotton rotations at Warren NSW. Original C concentration 1993 C_T = 6.15 mg/g, C_L= 0.84mg/g

Rotation	$\cdot\Delta C_T$	$\cdot\Delta C_L$	CMI
Continuous Cotton (CC)	0.11	0.02	3
Cotton-long fallow (CLF)	-0.45	-0.07	-9
Cotton-field peas (CFP)	0.33	0.14*	18*
Cotton - low input wheat[1] (CWlo)	1.61**	0.20*	23**
Cotton - high input wheat[2] (CWhi)	0.84*	0.14*	17*
Cotton-wheat-lablab (CWLL)	1.12**	0.20*	24**
Cotton-wheat-lablab-fertiliser (CWLLF)	1.00*	0.07	8

[1] 40 kg seed /ha, 17 kg N /ha, [2] 106 kg seed /ha, 120 kg N/ha
* Change significant at p< 0.05%, ** Change significant at p< 0.01%

The effects of cotton trash management were examined in an experiment conducted by Ian Rochester over 3 years at the Australian Cotton Research Institute, Narrabri. Samples were collected in 1991 and again in 1994 these were analysed for C_T, C_L $^{13}\delta C$, N_T, light fraction carbon and polysaccharides. The experiment consisted of a split-plot with residue management as the main plot and nitrogen as the sub- plot. Results are shown in table 2.

Table 2. Trash Management Effects on N, C and Polysaccharides

	N_T	C_T	C_L	Polysaccharides	
				Total	Labile
			Trash retained		
1991	1.09 a[A]	10.05 b	1.13 b	1.28 b	0.11 b.
1994	1.11 a	11.11 a	1.67 a	1.66 a	0.14 a
Change	+0.02 m[B]	+1.06 m	+0.54 m	+0.38 m	+0.03 m
			Trash burnt		
1991	1.07 a	9.67 b	1.07 b	1.24 b	0.10 b
1994	1.09 a	10.08 b	1.01 b	1.20 b	0.10 b
Change	+0.02 m	+0.41 n	-0.06 n	-0.04 n	0.00 n

[A] Numbers within a column for each year followed by the same letter are not significantly different at $p<0.05$ according to DMRT.

[B] Numbers within a column for change data followed by the same letter are not significantly different at $p<0.05$ according to DMRT.

There was no significant change in N_T over the three year period in either the trash retained or trash burnt treatment. Both C_T and C_L increased significantly through time in the trash retained treatment but not in the trash burnt treatment. In addition to these changes in carbon a significant increase in total and labile polysaccharides was measured in the trash retained treatment and again no significant change occurred in the trash burnt treatment. The changes in both C_T and C_L resulted in significant changes in the CPI and LI resulting in marked differences in the CMI at the end of the experiment. In the trash retained treatment the CMI had increased to 141 and by contrast it had declined to 94 in the burnt treatment.

Conteh *et al* (1998) has examined the relationship between carbon measured by $KMn0_4$ oxidation and more traditional measures of soil carbon (Table 3). Neither C_L or C_{NL} were found to be related to humic acid. By contrast C_L related strongly to fulvic acid whereas, C_{NL} was more related to the humin fraction. Both C_L and C_{NL} were related to total polysaccharides but only C_L was related to the labile polysaccharides. C_L was also related to microbial carbon.

Table 3. Relationship (r^2) between C_L, C_{NL} and other measures of soil C (Conteh *et al.*1998)

Component	C_L	C_{NL}
Humic acid (HA)	0.19	0.02
Fulvic acid (FA)	0.91**	0.56
Humin	0.54	0.96**
Microbial Biomass C	0.59*	0.45
Total Polysaccharides	0.71*	0.63*
Labile Polysaccharides	0.84**.	0.40
Non-labile Polysaccharides	0.68*	0.64*

An indication of the size of various C pools in a grey clay soil from the Gwydir Valley is shown in Table 4. The concentration of C_L is some 10 times that of the microbial biomass in this soil. Whilst the concentration of C_L and total polysaccharides are similar in this soil this is not often so.

Table 4. Size of a range of C pools in the 0-20 cm horizon a grey clay soil from the Gwydir Valley.

Component	Uncropped	Cropped
C_T (mg/g)	22.4	9.4
C_L (mg/g)	3.6	1.3
Humic Acid(mg C/g)	2.7	1.9
Fulvic Acid(mg C/g)	8.4	4.0
Total Polysaccharides(mg C/g)	3.0	1.2
Labile Polysaccharides (mg C/g)	0.25	0.10
Light Fraction (mg/g)	15.1	6.9
Light Fraction -C (mgC/g)	6.9	1.1
Light Fraction -C_L (mgC)	2.5	0.2
Microbial Biomass (mg/g)	0.23	0.12

Nelly Blair (unpublished) has examined the relationship between various carbon pools and aggregate stability. In a survey of soils from the cotton growing areas of Eastern Australia she found that C_L was more closely related to mean weight diameter of aggregates following immersion wetting than was C_T (Table 5) in soils with <52% clay. No significant relationships were found between aggregate stability and C_{NL}, C_{LL} ($C_{Walkley\text{-}Black}$ - C_L) or C_I (C_T- C_{LL}). When soils with >52% clay were included in the relationship no correlations were found presumably because that in high clay soils, materials such as calcium are more important in binding aggregates than organic compounds.

Table 5. Linear relationships (Y=a+bX) between and aggregate stability(Y), expressed as mean weight diameter (MWD), and C fractions (X) in 20 soils collected throughout the cotton growing areas of eastern Australia

X	r^2
C_L	0.61 **
C_T	0.46 *
C_{NL}	0.41 ns
C_{LL}	0.43 ns
C_I	0.05 ns

These studies have demonstrated the effects of cotton cropping on soil C dynamics and shown the sensitivity of labile C (C_L) measurements in detecting changes in C pools in the soil. The use of fractionated C data to calculate a Carbon Management Index has been shown to be a useful guide as to whether the system is in decline or is rehabilitating. The impact of lower C_L concentrations in soils on soil physical fertility has also been demonstrated.

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CRC Farming Systems Experiments

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Introduction

Three long term experiments have been established, Warra (Queensland) is a dryland site, and the irrigated sites are Warren (NSW) and Merah North (NSW).

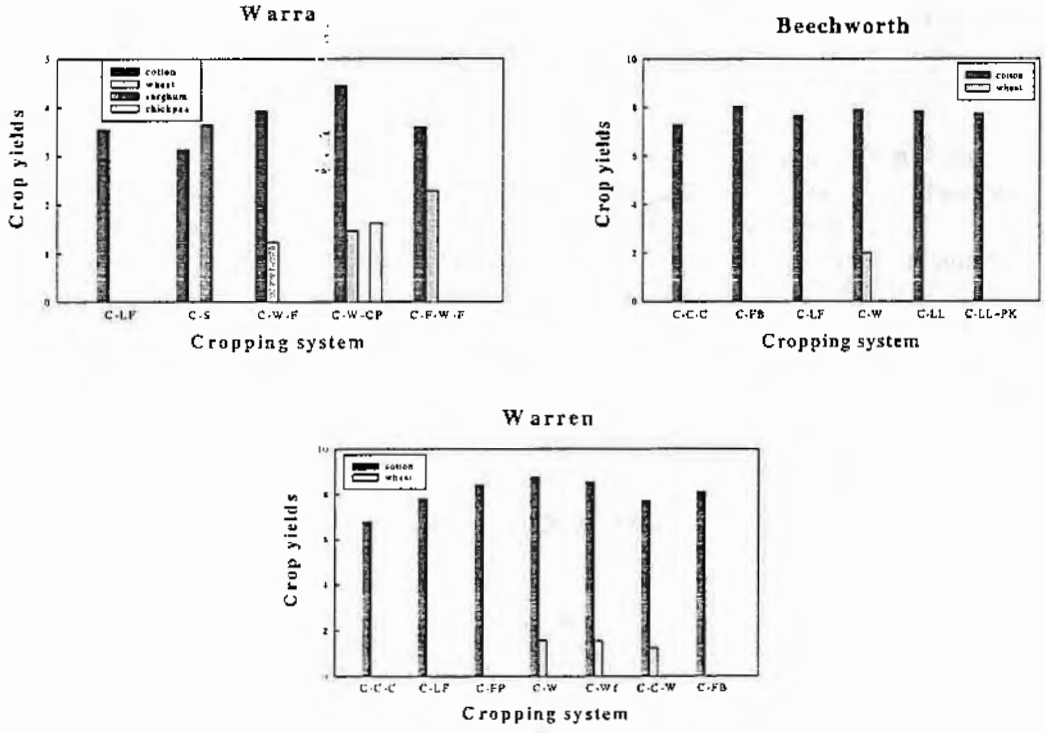
The Farming System Experiments are designed to look closely at several farming systems and compare their sustainability. The farming system integrates and coordinates many aspects of management. In the context of the three experiments, the farming system has important implications for tillage, rotation crop and fertiliser rates and types. The CRC aimed to establish three major experimental sites to enable many aspects of the farming system to be imposed and measured on the one site.

Results

Crop Yields

The three experiments have produced varying results. While the cotton and cereal crops have grown well at Beechworth and Warren, the legume crops have not been successful and only small inputs of fixed N have been possible. The data from Warra however, indicates better cotton (and wheat) yields following chickpea compared with fallow.

The following data is for years when all treatments are in cotton (i.e. 1994/94 and 1996/97), except for Warra which does not have a year when all treatments are in cotton, however the data is an average of all years were cotton was grown.



Warra Average Yield:

C/W-CP was higher than C/W/F was higher than C/F/W/F was higher than C/LF was higher than C/Sorg.

CC is not feasible in this dryland system so is not included.

Beechworth Average Yield:
C/FB was higher than C/W was higher than C/LL was higher than C/LL (P&K) was higher than C/LF is higher than CC

Warren Average Yield:
C/W(L) was higher than C/W (H) was higher than C/Field peas was higher than C/C/W was higher than C/FB was higher than C/LF was higher than CC

Wheat dried soil more than legumes and improved soil structure increasing yields. CC was consistently the lowest yielding rotation in the system. Legume rotation crops increased yield in some rotations.

Nutrient uptake and removal
Beechworth, Warra and Warren's nutrient uptake and removal data is average. Warra's nutrient uptake and removal data is different to that of Beechworth, however it is characteristic of that valley. Warren's nutrient uptake and removal is also different to that of Beechworth as is has lower uptake of P and K, as shown in the table below:

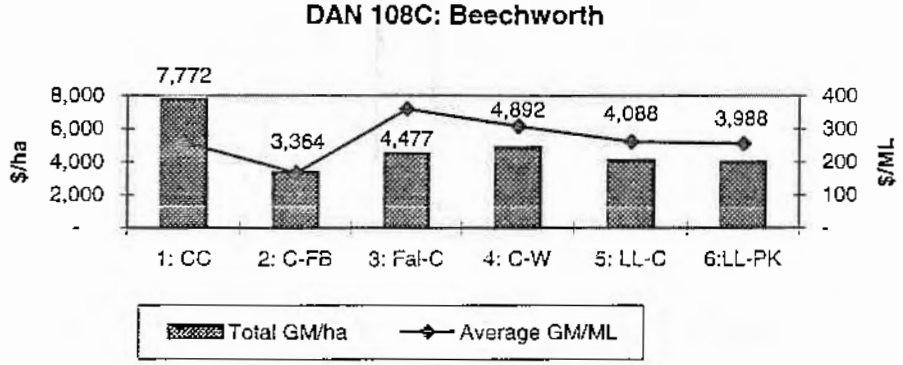
Site	Beechworth		Warren		Warra	
Nutrient	Uptake	Removal	Uptake	Removal	Uptake	Removal
N	169	107	170	106	112	144
P	34	26	15	11	23	18
K	170	41	198	26	86	38

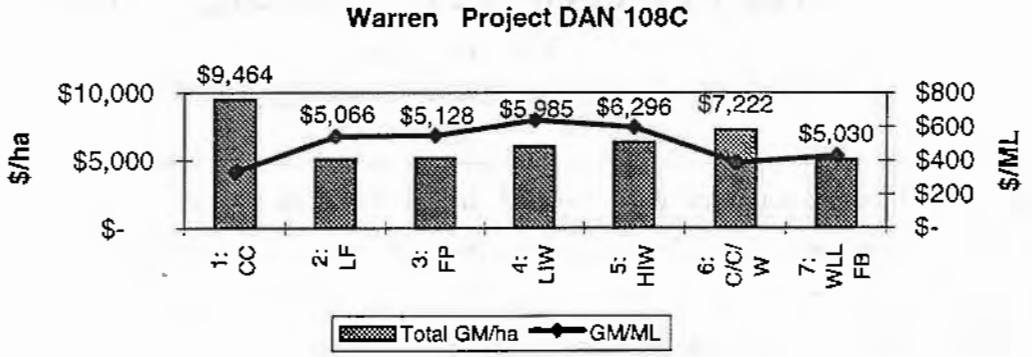
Data is from the last season when cotton was in every treatment: 1997/98.

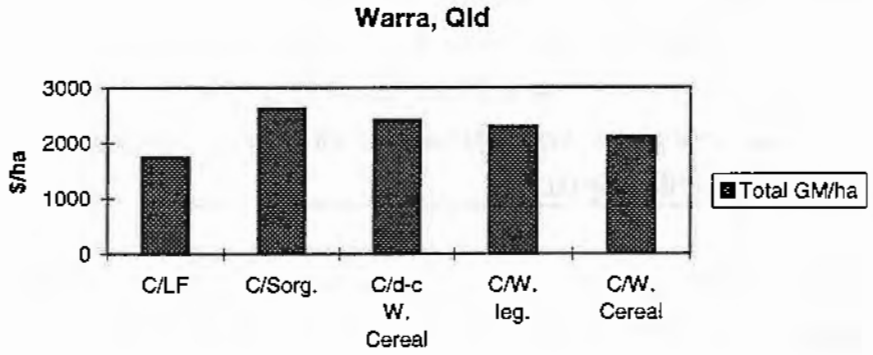
Soil Quality
Soil information in these experiments have been collected by Nilantha Hulugalle who has written the following paper.

Gross Margin Analyses
Depending on which resource (land or water) is the limiting factor on a farm, the gross margin analysis should be calculated by GM/ha or GM/ML, respectively. For example at Beechworth the CC treatment seems the best option for total GM however when that is calculated in ML per ha cotton/long fallow or cotton/Faba bean are the best options.

This also applies at the Warren site. Both the CC and C/C/W treatments are shown to have a higher Total GM than an average GM/ML. This shows that the cotton requires larger amounts of water than the other rotation crops and that the rotation crops are better value in terms of profit per ML of water used.







Warra's data is a combination of 5 years data including 2 cotton crops in Treatments 1,2, 3 and 5 with 1 cotton crop in Treatment 4.

Implications for Cotton Farming Systems

- Cotton yield is increased if a rotation crop is included in the farming system plan.
- Soil and plant analyses aids in decision making for fertilizer rates.
- Soil compaction may be ameliorated, if a cereal rotation crop is included in the field management.
- There is a removal of larger quantities of N, P and K in seed cotton.
- Although GM for CC is highest, growers are limited by water and must grow water use efficient rotation crops

Weed Management in Farming Systems

Graham Charles

CRC for Sustainable Cotton Production

Summary. Weed pressure has been assessed since 1994 on each of the cropping systems on the 3 farming systems experiments. No major weed problems emerged during this period, with acceptable levels of weed control on all cropping systems. The exception to this was the peach vine problem at Beechworth, although this problem was apparent in all cropping systems.

Weed problems were anticipated on the cotton/legume rotation systems where broad-leaf weeds could not be adequately controlled during the legume phase. However, no major, long-term problems emerged in these systems, with no significant build-up in weed density over time.

Volunteer crop plants were a problem in all systems, although generally these were adequately controlled in the following fallows.

Weed density and diversity have been visually assessed on the 3 CRC cropping systems experiments since 1994. Assessment was by way of a transect with 6 sets of observations per plot, each observation covering 50 m^2.

A wide spectrum of weed species has been identified on each site, with 56 species at Prospect (Warra), 43 species at Beechworth (Merah North) and 41 species at Auscott (Warren). This count excludes individual grass and *Asteraceae* species. The 5 most commonly occurring species are shown below. The density for each weed has been averaged over rotation treatments and observations.

Weed		Average weed density (/m^2)		
		Prospect	Beechworth	Auscott
Peach vine[1]	*Ipomoea lonchophylla*		5.77	
Sow thistle	*Sonchus oleraceus*	0.09	0.84	0.84
Turnip weed[2]	*Rapistrum rugosum*		0.56	
Volunteer wheat		0.06	0.28	
Volunteer Faba beans				0.22
Volunteer cotton		0.04		0.15
Aust. bind weed	*Convolvulus erubescens*		0.10	
Caustic weed	*Euphorbia drummondii*	0.06		0.09
Pig weed	*Portulaca oleracea*	0.06		
Daisy family	*Asteraceae sp.*			0.03

Note[1]. Peach vine or cow vine.

Note[2]. Mixed population, predominantly of *R. rugosum*., but including other species.

While peach vine was the major problem weed at Beechworth, sow thistle was a major weed on all 3 sites, followed by volunteer crops.

A weed index was developed to allow the different cropping systems to be compared. The index is expressed in terms of small weed equivalents/m^2. Larger weeds are weighted in the index, with, for example, a large broad-leaf weed such as noogoora burr receiving a weighting factor of 8 compared to a grass. This makes some allowance for the relative competitiveness of the different species, although weed size is also a major factor, but was not recorded.

Overall, weed pressure was relatively low at Prospect as might be expected on a non-irrigated site (Figure 1). Volunteer crop plants and small and medium sized broad-leaf weeds make up the bulk of the weeds present at Prospect, with relatively little difference in weed pressure between the different cropping systems. What differences were present are becoming less pronounced with time. Sesbania was a major problem weed at this site, but was successfully controlled on all systems and has not been present at high numbers in the survey area.

Weed pressure was very much higher at Beechworth, with peach vine by far the most common weed. Differences between the cropping systems were apparent, with the least weed pressure under the continuous cotton system (Figure 2). The proportion of weeds other than peach vine was highest on cropping systems including lab lab (Systems 5 & 6) and the wheat rotation (System 4). The control of broad-leaf weeds was a major problem during the summer legume phase of Systems 5 & 6, but the over-all weed pressure on these systems was not much higher than on System 3, the cotton/long fallow system. The weed index was also relatively low on System 2, which included a winter legume. High densities of winter weeds such as turnip weed were present on these plots during the legume phase, but the over-all weed index was still relatively low.

Large differences in weed pressure were apparent between the cropping systems at Auscott, with the continuous cotton giving by far the worst result (Figure 3). However, this bad result was largely due to a large population of sow thistle present on System 1 at the first observation in December 1994. Systems 2, 3, 4 & 5 were in bare fallow at this time, with some weeds present on Systems 6 & 7. When the December 1994 observations were removed, a much lower weed density was apparent for System 1, presented as System 1(b). The weed index was lowest on the cotton/wheat rotations (Systems 4 & 5), and highest on the cotton/faba bean rotation (System 7), where broad-leaf weeds were difficult to control during the faba bean phase, and volunteer faba beans were a major weed component. This same difficulty in controlling broad-leaf weeds during the legume phase was encountered in the cotton/field pea rotation (System 3), but the weed pressure was much lower on this system as the volunteer crop problem was much less. This result emphasises the importance of legume selection and planning rotations so that volunteer crop plants are either removed during the fallow phase or the crop is green manured before seed set.

Sustainability and cotton disease control

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Introduction

Cotton growers are supplied with considerable advice under the banner of 'sustainable cotton production'. Some recommendations conflict with others and the grower needs to make decisions. Attempts to make the 'right' decisions and develop more sustainable farming systems have generally contributed to increasing incidence of disease. Examples of some of these dilemmas which face cotton growers include the following:

Soil conservationists and crop agronomists have shown the benefits in retaining crop residues on or near the soil surface as a means of reducing erosion and conserving moisture. Plant Pathologists warn growers that most of the pathogens that cause cotton disease problems survive on, and/or are dispersed with, crop residues. Disease problems can generally be minimised by eliminating carryover of residues from one season to the next.

Agronomists are promoting the advantages of legumes in cotton production systems. Plant pathologists report that all legumes are hosts of *Thielaviopsis basicola* (Berk. & Br.) Ferraris which causes black root rot of cotton and legume residues are often associated with a high incidence of seedling disease in cotton.

Sustainable cotton production requires the development of disease control strategies which are compatible with all of the other aspects of the production system.

Permanent bed systems

The standard practice for irrigated cotton growers was to slash the crop after harvest, disc in crop residues and re-list the field into hills for the next cotton crop. Permanent bed systems with reduced tillage came into use in the mid 1980's and have become widely adopted by growers in all cotton growing areas of Australia.

A significant increase in the incidence of black root rot, Alternaria leaf spot and Verticillium wilt of cotton (until the release of resistant cultivars) has coincided with the increasing adoption of permanent bed / reduced tillage systems. One of the features of such tillage systems is the increased abundance of crop residues on the soil surface.

Black root rot

Black root rot was first observed in seedling cotton in NSW in 1989 and the distribution and incidence of the disease have increased significantly in recent seasons . Black root rot of cotton is now found in all of the major production areas of NSW and in the Darling Downs and St George areas of Queensland. Repeated cropping to cotton, the introduction of legumes into the rotation and the adoption of permanent bed systems in which cotton is sown in the same position each season have contributed to this increasing incidence. Assays of inoculum concentration show that there is approximately four times the amount of inoculum in the centre of the bed than there is 100mm away from the centre of the bed.

Discussion

It would appear that most of the significant changes in farming practice which have been introduced to improve the sustainability of the cotton production system have contributed to increased disease incidence and severity.

It is important to remember that a component of the microbial population that exists in the rhizosphere actually makes a positive contribution to plant health. The mycorrhizal fungi and plant

growth-promoting rhizobacteria are an essential part of the soil microflora which must be maintained despite the application of disease control strategies.

With these factors in mind several control strategies are being evaluated. These strategies include biocontrol with endophytic micro-organisms, biofumigation, systemic induced resistance, organic mulches and summer flooding.

Dr Subbu Putcha, based at the Australian Cotton Research Institute at Narrabri, has had considerable success in his program of field screening potential biocontrol agents for effective control of soilborne plant pathogens.

Plants belonging to the family Brassicaceae naturally contain significant quantities of glucosinolates which are hydrolysed to release isothiocyanates (ITCs) when crop residues are incorporated into the soil. These ITC compounds have been shown to suppress soilborne plant pathogens (biofumigation). Dr John Kirkegaard of CSIRO, Canberra has selected several brassica crops that display the capacity to produce high concentrations of the ITC compounds when incorporated and these are now being evaluated for the control of black root rot of cotton. One of the disadvantages of using Brassica crops in a rotation is that brassicas are not mycorrhizal. Slow early season growth of cotton resulting from poor colonisation by mycorrhizal fungi has been observed when cotton has been planted after canola (*Brassica napus* L.).

The concept of biofumigation for disease control also describes the suppressive effect of ammonia which is produced when hairy vetch green manure crops are incorporated into the soil.

Chemical activators may be used to 'turn on' or induce a plant's natural defence mechanisms. In many instances a disease occurs when a pathogen is not recognised by a host and the infection process is completed without the host's natural defence mechanisms being aroused. Systemic Induced Resistance (SIR) is generally non specific and results of work with cotton by Dr Emma Colson have demonstrated significant control of Verticillium wilt and Alternaria leaf spot under field conditions.

Organic mulches are used in other cropping systems to conserve moisture, reduce run-off and soil erosion, suppress weeds, control disease and/or improve soil health. The development of strategies to incorporate the use of organic mulches into cotton farming systems therefore has many advantages. A possible indirect benefit is the restriction to the movement of crop residues off the field thereby reducing the rate of spread of the pathogen inoculum. As indicated previously the use of an organic mulch can overcome the early season stunting that is characteristic of bacterial stunt of cotton.

The challenge to plant pathologists is to develop novel cotton disease control strategies which complement modern farm practice without impacting negatively on the activities of beneficial micro-organisms.

Cropping Systems Models in the Australian Cotton Industry

M.P. Bange[1], P.S. Carberry[2], and D. Richards[1]

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[2]Agricultural Production Systems Research Unit, CSIRO Tropical Agriculture

Introduction

Managing any cropping system involves making decisions and with that comes the risk of making a wrong decision especially when many of the factors involved are unknown or uncertain (eg. rainfall). Collaborative projects undertaken by the CSIRO Cotton Research Unit (CRU) and the Agricultural Production Systems Research Unit (APSRU) have been using crop simulation models to asses the impact of decisions on crop and system performance without suffering the consequent pain and real life experience when mistakes are made. Two crop simulation models are being used in this research. One model is the cotton simulation model OZCOT developed by Dr Brian Hearn at CRU which provides a useful and very powerful tool for obtaining a long term historical perspective for specific problems in cotton production. The second model developed by APSRU is called APSIM (Agricultural Production Systems Simulator) and it has the capability to simulate many aspects of the cropping system, including a range of crops grown in rotation or with fallows. The cotton module in APSIM is the OZCOT model developed by CSIRO Cotton Research Unit at Narrabri.

Research Methodology

Recent efforts in applying cropping simulation models to commercial farm management are utilising participatory research approaches. FARMSCAPE (*Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation*) (McCown et al., 1998) is an acronym employed to represent the participatory action research approach that explicitly addresses the question of the relevance of systems models to commercial farming. This approach has provided an excellent means for allowing farmers and advisers to become actively involved in the implementation of the research and interpretation of the outcomes. It has also provided the mechanism for all participants (including researchers) to learn more about their respective farming systems.

Crop Simulation in Commercial Farm Management

Benchmarking the performance of models and crops

Benchmarking the performance of models against measured crop yields and visa versa has been an important component of this research and was undertaken for two reasons. Firstly to establish model credibility and relevance to commercial farming systems, and secondly to assess the performance of crops at the end of the season with predicted potential yield. Generally the model has simulated crop yields well (Fig.1) and has proved credible enough to be relevant. The models are now used extensively in benchmarking performance of farmers' crops and exploring alternative management scenarios.

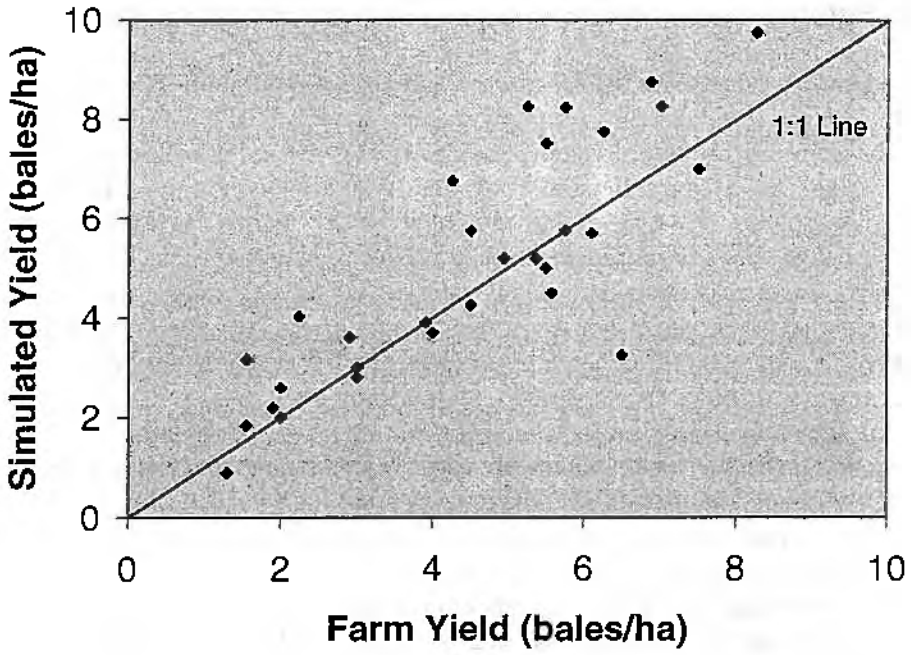

Figure 1. Predicted versus commercial cotton crop yields

Strategic Applications of Models

A common and useful application of crop simulation models is to explore alternative management options or new environments as general scenarios that are broadly relevant to a region or a group of farmers. The crop simulation models APSIM and OZCOT have been and are being used in a number of activities including:

- Provision of information to extension and agribusiness in assessing potential of dryland cotton production in present farming systems.
- Risk analyses for cotton production in new areas of northern Australia.
- Provision of information to extension services, agribusiness, financial, and insurance firms describing the risks and impact of different agronomic practices.
- Simulating farming systems to examine system sustainability and environmental issues such as soil fertility, economic returns and risks, organic carbon, and erosion.
- Examining the effects of seasonal climate variability on stream-flow and ultimate effect on crop yield potential.
- Simulating evapotranspiration of cotton crops in different regions to derive seasonal estimates of crop agronomic water use efficiency.

Tactical Applications of Models

The APSIM or OZCOT models can be used in planning for the current or upcoming crop. Decisions on crop choice, varietal selection, fertiliser rate, sowing date, plant population, row configuration and so on can be assessed based on knowledge of pre-plant soil water, soil chemical analysis and seasonal climate outlook. Based on this information, the models can provide an assessment of expected crop performance in the upcoming season by simulating what would have happened under these same conditions in past years for which climate records exist. Some examples for cotton production are the choice of planting a crop as either solid or single skip row configuration under low starting soil water conditions, or even considering sorghum crop as an alternative option.

The Future

Developing the FARMSCAPE approach and tools to the point of commercial delivery is presently the main focus of research using cropping systems models (CRDC project CSP98C Delivering to industry the benefits of cropping systems models). A market now exists for timely and high quality interactions based on soil monitoring and simulation amongst a significant sector of the dryland farming community. One preferred delivery mechanism is to establish and support an Accredited Adviser Network of agribusiness and private consultants for delivering simulation and related products. Research is also focused on expanding efforts to include irrigated cotton production systems and include other agribusiness service sectors (bank lenders, crop insurance, product inventory, marketing advice, etc.). Other activities that involve cropping systems models that are planned, about to commence or are presently being undertaken involve:

- Using models to assess the impact of water use efficiencies in the farming system.
- Developing a more user friendly cotton model.
- Investigating the impact of climate variability and forecasting.
- Simulating the farming system trials.
- Incorporating the effects of compensation into the cotton simulation model.
- Using cropping system models to assist in area wide management.
- Linking cropping systems models to site specific farming projects.

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Acknowledgements

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Development of management options for dry season cotton production in Northern Australia.

S.J. Yeates, G.R. Strickland, G.A. Constable, G.P. Fitt and S.J. Addision.

Background

Limitations on the availability of irrigation water in eastern Australia has sparked considerable interest in the possibility of re-establishing cotton in the tropical north of Australia, where extensive areas of land and good supplies of water are available. With a history of major insect problems any proposal to re-establish cotton production required a new perspective. Due to the severe pest pressure associated with summer cropping, a new industry should be based on a winter cropping strategy and transgenic (Ingard) varieties. To this end a joint CSIRO/Agriculture WA research project was developed to make preliminary judgements concerning agronomic potential and pest management scenarios. Support funds were provided by CRDC to ensure all experiments could be run effectively and to cover the staff training needed to provide a solid base of technical expertise in cotton research in the NW.

Expected outcomes at the commencement of the project.

The major outcome was the development of a technical package for growing dry season cotton, which could provide the basis for future work and the commitment of capital necessary for the development of irrigation, and ginning infrastructure.

Research Plan

In the absence of commercial ginning facilities, research in 1995 and 1996 revolved around a series of replicated field experiments of 15 ha in total. Two broad series of experiments covered (I) aspects of agronomy and varietal performance and (II) pest management options for dry season cotton production. .

The work was in collaboration with trials at Broome and at Katherine, NT.

The instillation of a 'research gin', at a cost of $800,000 by Colly Farms in partnership with the Ord River District Co-operative in 1997 facilitated the expansion of integrated pest management studies (IPM) to commercial scale areas on-farm (250ha total). In 1997 a set of 'best bet' agronomic practices, derived from trials in 1994 to 1996, were tested in these on-farm IPM areas.

Results

Crop adaptation

Over three seasons experimental yields were found to be very comparable with summer grown crops in temperate Australia (Table 1). Sowing from mid March to mid April was optimal for yield and permitted harvest from mid September to early October well prior to the likely commencement of wet season rains in November. A very synchronous boll opening which was due to rising end-of-season temperatures reducing the boll periods of later pollinated flowers ensured a prompt harvest.

Table 1: Comparison of small plot lint yields (kg/ha). Summer grown are the mean of 17 trials in 1996/1997, winter grown is the mean of 3 years 1995 to 1997 inclusively.

	Summer-grown temperate Australia	Winter-grown tropical Australia
Average Top 10 Varieties	2069	2043
Best	2529	2483
Range	1650-2529	1829-2483

Good progress has been made in identifying suitably adapted varieties, sowing date, nitrogen nutrition, in quantifying the effect of night temperatures on fibre quality, sowing densities and the management of growth regulators.

The expansion of pest management research on-farm in 1997, helped to fine-tune practices, but most importantly knowledge gaps and areas of further research were identified. For example, late scheduling of the final irrigation in a climate with rapidly increasing temperatures created difficulties with defoliation and resulted in trash discounts for lint. A greater understanding of the water usage and ripening processes in this climate is required. Other important knowledge gaps identified include: the interaction of early season Pix with tipping out by mirids; the need to understand compensatory growth mechanisms in response to mirid damage; weed management; the need for varieties that produce a longer fibre when grown in the dry season

IPM evaluations

The development of an IPM system to complement transgenic varieties is essential to sustainable production. An effective IPM system reduces the risk of pests developing resistance to Bt by lowering the number of pests surviving and / or being exposed to the transgenic crop. IPM should also include trap and refuge crops to minimise the necessity for insecticide use whilst providing a source of beneficial insects which can be recruited to assist in pest control.

The results in Table 2 show the lepidopteran pest control potential of INGARD® with or without supporting IPM. All systems based on transgenic varieties required an average of between 1.75 and 3 insecticide applications to control *Helicoverpa* compared to 7.5 sprays on conventional cotton. No conventional cotton was produced in 1997 but, in trials conducted during the preceding 3 years, between 10 and 15 insecticide applications had be necessary. Thus a significant reduction in pesticide requirement of at least 70% is inferred through the field performance of INGARD®.

Table 2. The mean yields and number and purpose of spraying in the IPM trial, Kununurra, 1996 and 1997.

Treatment	Mirid sprays	Aphid sprays	Helicoverpa sprays	Total sprays	Yield kg/ha
1. Siokra L23i alone	2.13	0.25	2.25	4.63	1,584
2. Siokra L23i + lucerne + Envirofeast®	1.48	0.15	2.	3.66	1,610
3. Siokra L23i + lucerne	1.25	0.13	1.75	3.13	1,756
4#. Siokra L23i + niger	1.5	0.25	3.0	4.75	1,630
5*. Conventional cotton + Envirofeast® + lucerne	3.0*	0	7.5	10.5	1,594

* includes rough bollworm as a target pest, grown 1996 only

grown 1997 only

[1] all treatments were sprayed when entomoLOGIC thresholds were reached

In both seasons all IPM treatments achieved adequate yields that were similar to conventionally sprayed conventional and INGARD® cotton. There was also a trend towards a lower insecticide requirement for IPM cotton than for stand alone INGARD® paddocks. Coincident with the lower spray requirement in IPM plots is a trend for higher numbers of predatory insects. Although predatory insect populations fluctuated during the season there was a trend during the mid and late season for numbers to be higher in the IPM treatments which included lucerne strips and / or the insect food spray Envirofeast®. A wide range of predatory insect fauna was identified in the samples. The most common were lady beetles (*Coccinella spp*), hover flies and lacewings (*Chrysopa spp*).

Trichogramma pretiosum abundance

Trichogramma pretiosum is recognised as the most important of parasitoids limiting the impact of *Helicoverpa spp* in northwestern Australia. The parasitoid often infests 60% or more (maximum 92%)

of *Helicoverpa* eggs and can therefore limit the damage potential of the pest. In terms of resistance management in INGARD® cotton the wasp is particularly important because it reduces the hatch rate of *Helicoverpa* eggs and consequently reduces the numbers of caterpillars exposed to Bt protein toxins.

Conclusions / Future Research.

The project successfully achieved its stated objective of *'developing a technical package for growing dry season cotton which could provide the basis for future work and the commitment of capital necessary for the development of irrigation and ginning infrastructure'*.

Agronomically existing research needed to continue in the areas of varietal performance, growth regulator management, model analysis and irrigation management. New areas of research will emerge from farm scale pest management areas. However, rotational systems, weed/disease management , plant compensation mechanisms, P nutrition, and **soil compaction** have already emerged as areas for future research.

Pest management work will expand in area with an anticipated 1000 ha to be sown in 1999. This expansion has two objectives: First, to evaluate IPM strategies at a realistic scale. Second, it provides a 'test farming' phase, which has been shown in the past to be essential for new industry development in NW Australia, (see Robertson G.A., and Chapman A.L. (1985). The Ord Irrigation Scheme. P 485. In: R.C. Muchow (ed), *Agro-research for the semi-arid tropics: North-west Australia*, University of Queensland press, St Lucia, Queensland.).

The availability of two gene Bt varieties combined with reliable preditation by *Trichogramma pretiosum* is critical to the sustained success of dry season cotton growing in NW Australia.

Cotton rotations and soil quality in vertosols

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A survey of cotton growers in 1992 (CRDC Project DAN 76C) showed widespread interest in the use of rotation crops, plus a need for more information about the benefits of legume rotations and the effect of rotation management on subsequent cotton crops. To investigate the effect of rotation crop type and management on soil properties, cotton growth and yield, and economic returns, 3 irrigated field trials (located at Merah North, Wee Waa and Warren in NSW) and 2 dryland trials (located at Warra and Emerald in Queensland) were set up in 1993. During the first phase of this project monitoring of soil and crop growth was limited to the irrigated sites in NSW (CRDC Project DAN 83C). From 1996-1999 monitoring of soil properties was done in all five experimental sites (CRDC Project DAN 108C). The rotations sown at each site were as follows:

WARREN: Continuous cotton, long-fallow cotton, fertilized wheat, unfertilized wheat, lablab, faba, field pea. The lablab was replaced with continuous cotton from 1997 onwards. All rotations were followed by irrigated cotton.

MERAH NORTH: Continuous cotton, long-fallow cotton, unfertilized wheat, lablab, lablab (with P & K removed by cotton replaced as fertilizer applied after lablab was harvested), faba. All rotation were followed by irrigated cotton.

WEE WAA: unfertilized wheat, fertilized wheat, faba with grain harvested, faba where grain was not harvested but incorporated during land preparation. All rotations were followed by irrigated cotton.

WARRA: long-fallow cotton, wheat, chickpea, double-cropped wheat. All rotations were followed by dryland cotton.

EMERALD: wheat-sorghum, sorghum, wheat, long-fallow cotton, wheat (sprayed before maturity). All rotations were followed by dryland cotton.

At all sites, rotation crop stubble was incorporated, with minimum tillage being practiced at Warren, Merah North and Emerald and reduced tillage at Wee Waa. Soil measurements were made in all sites with the aim of detecting changes in soil quality, and included pH, electrical conductivity, exchangeable cations, dispersion, air-filled porosity, strength and organic matter. Changes in soil moisture, crop growth, development and yield of all rotation crops and cotton; and economic returns were monitored. Nitrate-nitrogen was monitored by project staff only at Wee Waa and Warren.

Amelioration of soil compaction was best where cereal crops such as wheat which have a long growth period were sown. This was because the fine, fibrous roots of the cereal crops were able to penetrate the large numbers of soil micropores which occur in a compacted soil and thereby facilitate and intensify the wetting/drying process more than the thicker and lower numbers of roots in the tap-rooted rotation crops. A wheat crop growing for a longer period may subject the soil to more wetting/drying cycles than a soil under shorter-season crops.

Increases in sub-soil salinity was observed at Warren and Merah North, but not at Wee Waa. Sharpest increases in salinity occurred during the cotton phase of a rotation. Deep core samples taken by Mr. John Friend at the Warren site suggests that salt is moving beneath the root zone in the irrigation water. The increase in salinity was followed by an increase in sodicity at Merah North (NB. Na accounts for about 70% of the cations in the irrigation water at Merah North). The increase in sub-soil salinity appeared to inhibit root activity of the legumes in these sites.

Soil organic matter declined over time in all treatments at Warren and Merah North but remained stable at Wee Waa. In the dryland sites (Warra and Emerald) soil organic matter remained stable or increased in the double-cropped cotton-wheat or cotton-sorghum-wheat rotations, but decreased with the other rotations. Short-term increases in soil N were substantial after leguminous crops in all sites. Significant declines in exchangeable K was observed at Warra, although this also occurred at Warren and Merah North to a limited extent. Least decline in exchangeable K occurred with leguminous rotation crops, and may be related to K exported in wheat and cotton harvests. Legumes (their seed material in particular) had an allelopathic effect on cotton growth and yield at Wee Waa. Displacement of exchangeable Ca and Mg by agrochemicals during the cotton phase of the rotation was observed in the irrigated sites, and was subsequently confirmed in subsidiary field and pot experiments (a joint experiment with Mr. G. Roberts). Additional observations were also made (a joint project with UNE/World Bank fellow Mr. J. N'Kem) at Wee Waa on soil faunal populations and their effects on soil physical and chemical properties.

Disease occurrence (mainly black root rot) was highest with continuous cotton at Warren but has increased with time in all treatments with greatest rate of increase occurring with leguminous rotation crops. Long-fallow syndrome was observed at Merah North with long-fallow cotton during the first cotton crop, but was absent thereafter. Long-fallow syndrome did not occur at Warren, but arbuscular mycorrhiza incidence increased with time in cotton sown after all rotation crops. The occurrence of long-fallow syndrome at any one site is probably due to an interaction between soil quality, rainfall during the fallow phase and the presence or absence of suitable host crops, and not as previously thought caused only by the absence of a suitable host crop.

At the irrigated sites, gross margins/ha were in the order of continuous cotton >> cotton-fertilized wheat > cotton-unfertilized wheat = long-fallow cotton ≥ cotton-legumes. A similar pattern appears to occur in the dryland site at Warra. When gross margins were evaluated on the basis of ML of irrigation water supplied, they were in the order of cotton-unfertilized wheat > cotton-fertilized wheat = long-fallow cotton ≥ cotton-legumes >> continuous cotton.

Response pattern of soil macrofauna to a cotton-based rotation under wheat cropping at two N levels.

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The level of soil disturbance and chemical use associated with cotton production systems greatly alter the environment for soil invertebrate communities causing a reduction in their abundance and biological functions. The introduction of a rotation crop in the system could restore soil ecosystem integrity and encourage a soil community of similar biological functions to that of natural habitats. The response of cryptozoic macrofauna community to the disturbances associated with cropping was evaluated with respect to abundance when wheat (*Triticum aestivum*) in a cotton-based rotation was sown at two different N fertilisers rates: 120 kg ha^{-1} and No N fertiliser. The experiment was established in 1993 and was in the third wheat rotation phase in 1997 during this study. Soil macrofauna abundance in the system was evaluated through pitfall trapping at three different periods of the growth cycle of the crop at 6WAP (weeks after planting), 15WAP and 23WAP respectively. Similarly, changes relating to soil macrofauna habitat structure and food supplies were evaluated by % wheat ground cover, soil temperature and surface litter transformation during this period. Changes in soil properties were monitored at the beginning (6WAP) and prior to harvest (23WAP).

Litter (woody and non-woody) transformation was found to be similar in both the high and low fertiliser treatments, with significant decreases across the sampling periods. There was significantly more wheat ground cover in the high fertiliser treatment than in the low. However, soil temperature and soil macrofauna populations were higher in the low fertiliser treatment than in the high. The relative distribution of soil macrofauna in each of the systems, followed the same pattern between the sampling periods. Therefore, it was possible to use ants to depict the changing patterns of macrofauna abundance in the systems and compare the invertebrate community recovery within each of the systems to nearby remnant vegetation. Most soil properties were similar in both treatments, with more exchangeable cations recorded in the treatments than in the remnant control plot. Generally, macrofauna abundance increased with time after planting probably due to seasonal changes and the reduced effects of disturbance during planting. Also, changes in surface litter transformation was inversely related to macrofauna abundance and organic matter levels in the systems. It is possible that, like in other cropping systems, changes in ant abundance may facilitate the monitoring of changing patterns in the recovery of soil biological communities and activities in cotton-based systems.

The Central and NorthWest regions water quality program: focus on herbicides.

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Introduction

The Central and North West Regions Water Quality Program (CNWRWQP) commenced in 1991 in response to community and industry concerns regarding the possible affects of irrigated agriculture on river health. The program has developed into an integrated surface water monitoring program incorporating the testing for pesticides, nutrients and physical parameters as well as biological monitoring. Rivers and streams are sampled before, during and after the summer spray season to compare off season and in season water quality results. Comparisons are also made between stretches of rivers within areas of irrigated agriculture with areas upstream of agriculture. This information allows assessment of the impact from agriculture on the environment, performance assessment from year to year on the levels of pesticides found in each basin and assists in identify trouble areas. The aim of this program is to provide the community, agricultural industry bodies and govemment with useful information regarding the water quality of regional waterways.

Study Approach

Approximately thirty sites are sampled from the MacIntyre, Gwydir, Namoi and Macquarie River basins and the Darling River at Bourke (Figure 1). Water samples are tested for the presence or absence of 34 agricultural chemicals including insecticides, herbicides, defoliants and their metabolites and breakdown products; these are collectively termed as 'pesticides'.

The sampling schedule follows the Cotton Resistance Management Strategy for northern NSW (Shaw A.J. and Harris W., 1997). Sampling is performed weekly over the peak summer spray season, monthly over winter and fortnightly over the shoulder periods.

Results and Discussion

The herbicides which are most commonly detected by this study include atrazine, diuron, fluometuron, metolachlor and prometryn. Other herbicides which are occasionally detected include pendimethalin, simazine and trifluralin. These herbicides are used on a variety of broadacre crops which include; cotton, cereals, sorghum and sunflowers.

The transport pathways for agricultural chemicals reaching rivers and streams include direct spillage and over spray, spray drift, runoff and tailwater releases and dust and vapour transport. There has been a lot of focus on the transport pathways of the insecticide endosulfan and the chemical properties and farm practices which drive these pathways. However, there has been less investigative work performed on other agricultural chemicals such as herbicides. In cases where these herbicides are used for non-irrigated cropping, direct runoff from field to river is a significant transport pathway.

During 1997/98, two sites within the study area frequently recorded high levels of herbicides. These were Thalaba Creek within the Gwydir River basin and Coxs Creek at the bottom of the Liverpool Plains system. There were two contamination incidents on Thalaba Creek in the spring and summer of 1997. High levels of fluometuron (31µg/L) were detected in October 1997. The source of contamination was uncertain. Spray records from the nearby property indicated that fluometuron had not been sprayed recently. It has been suggested that direct spillage or vehicle washdown at the road bridge may have caused the contamination. The creek was not flowing at the time and therefore fluometuron continued to be detected at this site for five weeks. The second incident occurred in December 1997 when a suite of pesticides were detected after heavy rain. It was thought that a possible source of these chemicals was runoff from dryland broadacre farming north of Narrabri. The

topography around this area is very flat and there are a complex series of flood runners which allow flood waters to travel long distances into the Thalaba Creek system.

Coxs Creek in the upper Namoi River catchment was the most affected site of the Namoi River catchment. Atrazine, fluometuron, metolachlor and prometryn were all detected regularly and at high levels between October 1997 and March 1998. Coxs Creek is an intermittent stream, draining intensive dryland cropping areas of the Liverpool Plains. It appears that on at least two occasions, a rain event delivered high levels of herbicides into the creek. As the creek ceased to flow, these chemical laden waters remained ponded, and subsequent sampling detected their decreasing concentrations as they degraded in the environment or until another event flushed the contaminated water down the system.

Rainfall which causes runoff from dryland cropping and where irrigation systems are unable to retain runoff are the principle sources of agricultural chemical contamination in rivers during storms. During a storm on the Gwydir River in January 1998, the herbicides diuron, prometryn, fluometuron and atrazine were detected. The storm duration was three days, over which time 116mm fell at Moree and 185mm fell near the sampling site. The first runoff from agricultural land often contains the highest amounts of chemicals (Figure 2). During this event, the maximum recorded concentration for diuron was 24µg/L, which is well below drinking water guidelines (40µg/L) but well above the guideline for residues in irrigation waters (0.002µg/L) (ANZECC, 1992). Prometryn had a maximum concentration of 6µg/L. The peak of these two herbicides was associated with the very first rise of the river indicating that they were washed from land close to the sampling site. Fluometuron had a maximum concentration of 9µg/L, which occurred later in the storm event, indicating that it was washed from areas further upstream than diuron and prometryn. Storm events such as these can cause acute exposure of the riverine biota to relatively high levels of chemicals.

Conclusions

Whilst much attention has been focused on endosulfan and atrazine which are the most commonly detected pesticides in the central and north west regions of NSW, the herbicides diuron, fluometuron, metolachlor and prometryn are also frequently detected. These herbicides are used on both irrigated cotton and dryland broadacre cropping. Their presence in surface waters have been associated with rainfall which irrigated cotton systems were unable to contain and runoff from dryland cropping on the Liverpool Plains. There are no guidelines available for these chemicals regarding the levels which may be detrimental to aquatic biota. However, both irrigation and dryland farm management practices should be employed to minimise both high level acute and low level chronic contamination of the rivers of NSW.

Acknowledgments

This project is jointly funded by the water users of the MacIntyre, Gwydir, Namoi and Macquarie valleys, whose ongoing concern, contributions and support are gratefully acknowledged.

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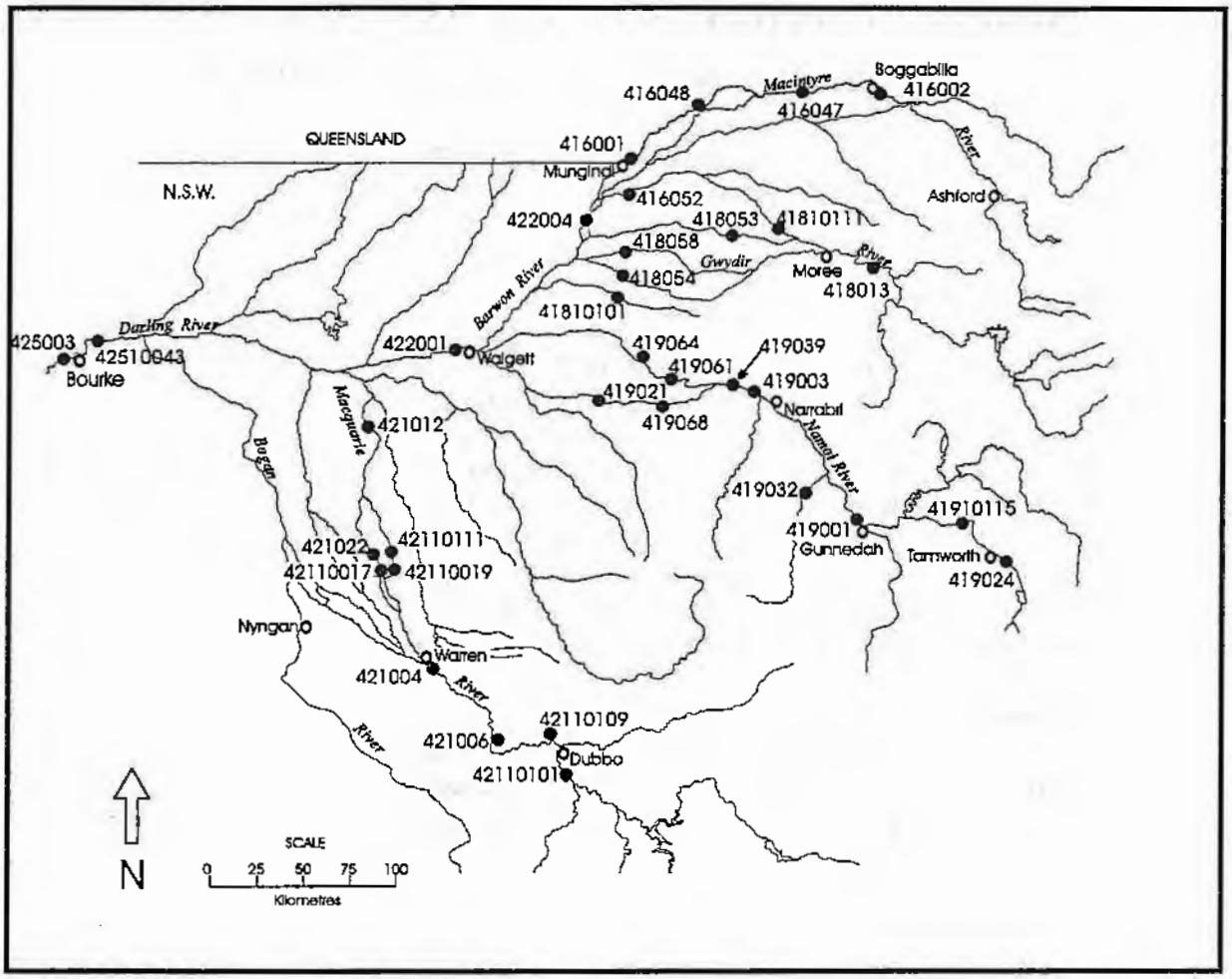

Figure 1. CNWRWQP sampling sites for 1997/98.

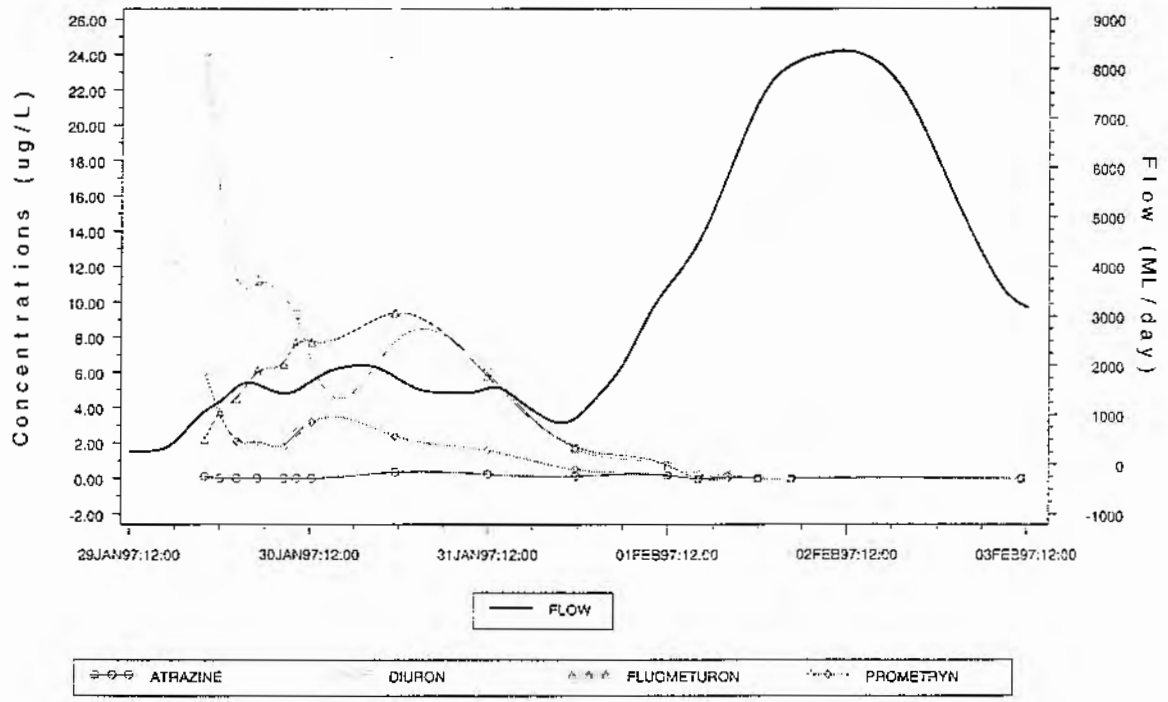

Figure 2. Flow and pesticide concentrations for a storm event on the Gwydir River in January 1997 for diuron, fluometuron, atrazine and prometryn.

Binding of herbicides by soils: Implications for off-farm transport from a cotton farm

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Introduction

Herbicides are widely used for weed control both in dryland and irrigated cotton production in Australia. A fraction of the herbicides applied to cotton farm is transported to rivers and other surface waters by runoff (Cooper 1996). Recent monitoring conducted by the NSWDLWC (Cooper and Muschal 1998) show that residues of some herbicides (atrazine, diuron, prometryn and fluometuron) are also being transported into rivers in cotton growing areas of Northern New South Wales. An understanding of herbicide properties, sorption and degradation is necessary to develop management practices for minimising herbicide movement to surface and groundwater. Among the various processes, sorption is one of the key processes affecting the persistence, biological degradation and transport in soil (Koskinen and Harper 1990). In this study we examined the binding affinity of four herbicides in three major cotton growing soils of Northern New South Wales.

Experimental details

Herbicides: Four herbicides (diuron, fluometuron, prometryn and pyrithiobac-sodium) commonly used to control broadleaf and grasses in cotton production have been selected for this study. These herbicides varied in their physical and chemical properties.

Soils: Three contrasting cotton soils (Wee Waa, Narrabri and Midkin) which varied in their texture and organic carbon content were used in this study (Table 1). The field-moist soils were collected and passed through a 2 mm sieve.

Table 1 Important characteristics of soils

Soils	pH (0.01 M $CaCl_2$)	OC (%)	Clay	Silt (%)	Sand
Narrabri	6.85	0.70	55.9	29.9	12.2
Midkin	5.46	1.27	24.6	48.1	27.3
Wee Waa	5.54	0.65	15.2	21.3	63.5

Herbicide binding studies

A batch equilibrium technique (Baskaran et al., 1996) was used to measure the binding capacity of the herbicides. Known concentrations of herbicide solutions equivalent to field application rates were added to soil samples (1:2 soil solution ratio) and shaken in an end-over-end shaker for 24 h at 25 ± 2°C. The suspensions were centrifuged and the concentration of herbicides in solution was measured using HPLC. Herbicide binding to soils was calculated as the difference between the added concentration and the equilibrium solution concentration.

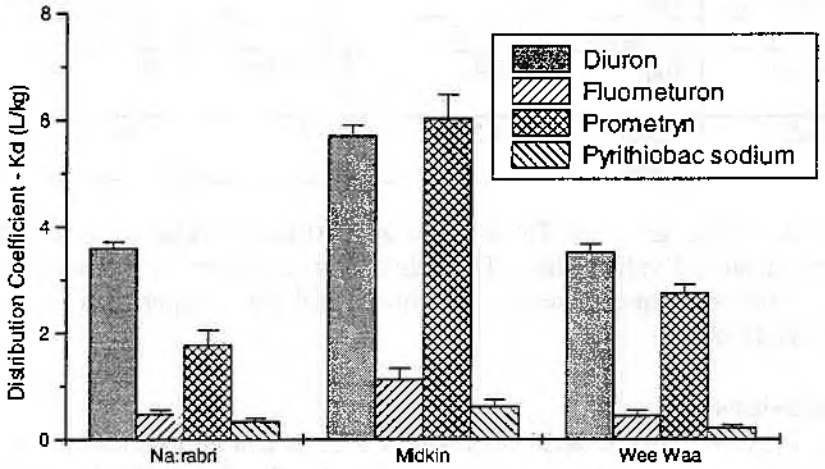
Results and Discussion

Herbicide binding by soils

The extent of herbicide binding by soils was expressed as distribution coefficient, (Kd) which is the ratio of herbicide concentration in the soil to that in the soil solution. Kd = soil concentration/solution concentration. The Kd values of herbicides for the soils examined are presented in Fig 1. The degree of binding of herbicides decreased in the order diuron > prometryn > fluometuron > pyrithiobac sodium, which is consistent in all the soil types. Water solubilities of the chemicals tends to increase in this same order (see Table 2) and showed an inverse relationship with Kd values of herbicides.

The binding affinity of herbicides varied between soils. Midkin soil sorbed greater amount of herbicides than the Narrabri and Wee Waa soils. The larger organic carbon content of the Midkin soil

(see Table 1) is most likely responsible for the greater binding observed for the herbicides in this study. Interestingly, Wee Waa sandy soil with lower organic carbon and clay content (Table 1) sorbed greater amount of prometryn than the Narrabri soil. This suggest that in addition to organic carbon, the protonation of a chemical can also contribute to increased binding. For the triazine chemicals maximum binding occurs at their pKa (Weber 1970; Baskaran et al., 1996). Prometryn has a pKa (4.5) that is near to the pH of the Wee Waa soil (Table 1) indicating a higher degree of binding than that for Narrabri soil. The results of this study indicate that both soil and herbicide properties are greatly affecting the binding of herbicides.



Implications for off-site transport

The off-site transport of chemicals to contaminate waterways greatly depends on three factors, soil sorption or binding, water solubility and persistence. Soil binding is measured by Koc (Kd normalised to organic carbon content), which is the tendency of the chemical to be attached to soil particles. Higher Koc values (> 000) indicate a chemical that is strongly attached to soil and is less likely to move unless soil erosion occurs. Lower Koc values (< 300 - 500) indicate that chemicals tend to move with water and have the potential to leach or move with surface runoff. Solubility is a measure of how easily a chemical may be washed off the treated site, leached into the soil, or move with surface runoff. Chemicals with solubilities of less than 1 ppm in water tend to remain on the soil surface. They tend not to be leached, but may move with soil sediment in surface runoff if soil erosion occurs. Chemicals with water solubility greater than 30 ppm are more likely to move with water either through the soil profile or surface runoff. This is true for non-ionic chemical than the ionisable and ionic chemicals. Persistence of a chemical is measured in terms of half-life. In general, the longer the half-life, the greater the potential for chemical transport to non-treated sites. Relative risk assessment was also made for most commonly used herbicides in accordance with water solubility, sorption or binding and persistence and presented below:

Table 2. Relative risk estimates for most commonly used herbicides

Herbicide		Application rate	Water solubility	Sorption coeff. Koc	half-life	Relative risk rating for transport	
Common name	Trade name	(L/ha or kg/ha)	(mg/L)	(ml/g)	(days)	Leaching	Runoff
Diuron	Aguron, Diurex	1-2	36	480	90	Medium	High
Fluometuron	Cotoran	0.8-1.7	110	100	85	High	High
Glyphosate	Roundup	1.5-2.5	11,600	24000	47	Low	Medium
Metolachlor	Dual	2.0	488	200	90	High	High
Paraquat	Gramoxone Nuquat	1.5-3.0	700,000	1000 000	74	V.Low	Medium
Pendimethalin	Stomp	3.0-9.0	0.3	5000	90	Low	High
Prometryn	Gesagard	1.1-4.5	33	400	60	Medium	High
Pyrithiobac sodium	Staple	0.240	705,000	30	60	High	High
Trifluralin	Tridan Yield	1.4-2.8	0.22	8000	60	Low	High

The risk ratings given in Table 2 are approximations and may vary depending on environmental factors at an individual site. The ratings for transport by leaching or surface runoff do provide relative risk estimates however, and are useful for comparisons between products (Baskaran and Kennedy 1998).

Conclusions

Binding affinity of four herbicides widely used in cotton production was investigated in three soils of varying texture and organic carbon content. The binding of herbicides followed the order: diuron > prometryn > fluometuron > pyrithiobac sodium. Midkin soil with higher organic carbon content sorbed greater amount of herbicides. Both chemical and soil properties are contributing for binding of herbicides in this study.

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Cotton pesticides in perspective: minimising their impact on produce and in riverine ecosysytems

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Extended Abstract

Despite measures taken to reduce reliance on chemicals (e.g. Ingard cotton), production of the Australian cotton crop still involves significant inputs of pesticides, with the potential to contaminate other agricultural produce and riverine ecosystems. In research mainly funded by the CRC and the CRDC since 1990, the environmental fate and transport of pesticides used in cotton growing have been extensively monitored with the objective of minimising their impact as chemical residues. Techniques for field sampling and analysis have been validated in a quality assurance program (Kennedy *et al.,* 1998a). In this research, there was initially a focus on endosulfan, as the major insecticide applied on cotton farms, and as a model for other chemicals. However, the focus has now shifted to other chemicals.

Positive outcomes of the research that can help provide more sustainable practices are:

- Information on the field dissipation of endosulfan, in farm soils and surface water, as well as on nearby pasture. In summary, dissipation of endosulfan from cotton fields occurred mainly by volatilisation in the first 2-3 weeks after application; endosulfan isomers on cotton plants, including the metabolic product on foliage and in soil, endosulfan sulphate, are quickly metabolised, with half-lives of 3-4 days. Two weeks after application, only 2-3 % of the amount applied in one spraying remained in the foliage. Unfortunately, some persistence of endosulfan in the field occurs because of the formation of endosulfan sulphate - the oxidation product - with a 'half-life' in soil of about 100 days. However, by the start of the new growing season only 1-2% of the endosulfan applied remained on field as endosulfan sulphate, so there is little or no long-term accumulation (Kennedy *et al.,* 1997).

- A CRDC-funded study of the degradation of endosulfan on pasture showed that endosulfan residues fell to acceptable levels within about 3-4 weeks, dependent on the distance from the line of spray application. This research has enabled recommendations to be made regarding the period for which pasture onto which endosulfan has drifted to be withheld from grazing stock us, to be made (Kennedy *et al.,* 1998b).

- Runoff waters contain 1-2% of total endosulfan transported or dissipated off field in one season, with the possibility of major storms accounting for 50% of this amount; for soluble chemicals, the relative significance of lateral leaching rather than vertical leaching of chemicals in these grey-cracking soils (Vertisols) is emphasised. The emphasis on recycling irrigation water within the farming system is thus strongly justified. Careful adherence by nearly cotton farmers to recycling and the gradual closure of possible 'leakage' points into the river in modest storms over the past ten years as an outcome of voluntary negotiations between farmers and NSW Land and Water Conservation has probably made a strong contribution towards the apparent lessening the impact from endosulfan of runoff on riverine systems (Cooper, 1997).

- Immunoassays (ELISA) provide rapid, inexpensive, field tests for pesticide residues. These provide much more comprehensive data sets and can allow decisions regarding the release of contaminated water and in assessing the progress of remediation. The development of ELISAs has been continuing in our research (e.g. see Lee *et al.,* 1997), the most recent immunoassays

being developed or validated including IGRs (flufenoxuron, lufenuron, chlorfluazuron, etc.) (Wang *et al.*, 1998) and for Staple (pyrithiobac-Na) (Wang *et al.*, report to Du Pont, 1998).

- Field research protocols needed to generate data for registration purposes have been developed. To meet requirements for registration, new pesticides must satisfy many strict criteria established with respect to efficacy, safety in application, human and environmental health. Field research methodology is now available for one area only concerned in meeting these requirements - that of monitoring the fate of pesticides on farms to provide the information required by the National Registration Authority (NRA). Techniques for measuring aerial drift and volatilisation, transport to surface waters and degradation rates on foliage, soil and water have been well developed, in research conducted using the cotton industry as a model. These techniques are now being applied in pre-registration trials for new pesticides and herbicides for several pesticide companies, including Cyanamid, Du Pont and Dow (various reports, 1997, 1998).

- Significant progress towards safer use of pesticides in cotton growing has been made. This is result of the preparation of a database indicating risk factors with particular pesticides and herbicides and a better understanding of the mechanisms of transport. The adoption of better management practices effectively reducing these risks is already contributing towards more sustainable cotton production.

Implications of results, uptake and adoption

These results on the fate of endosulfan and other agrochemicals have significant implications regarding environmental care in cotton farming. Although the dissipation of endosulfan by volatilisation and degradation on foliage is relatively rapid, sufficient residues remain in plant material to pose a risk if plant residues are taken off-farm. It is preferable to allow foliage to degrade on cotton fields, ensuring pesticide breakdown on-farm. The decision of the cotton industry to prohibit the feeding of cotton trash to livestock since this program began (as an outcome of the experience with Helix) is therefore very soundly based.

The study has shown that an important factor in the extent of environmental risk is the degree of soil exposure during pesticide applications. Thus, high cover from the cotton canopy can mitigate against high concentrations of pesticide in soil and the pesticide load in runoff. The advent of transgenic Ingard cotton, not requiring early applications of endosulfan when soil is highly exposed, is therefore most welcome.

The results of this study focussed on endosulfan have already found application in the development and application of best practices by the cotton industry, which this research supports.

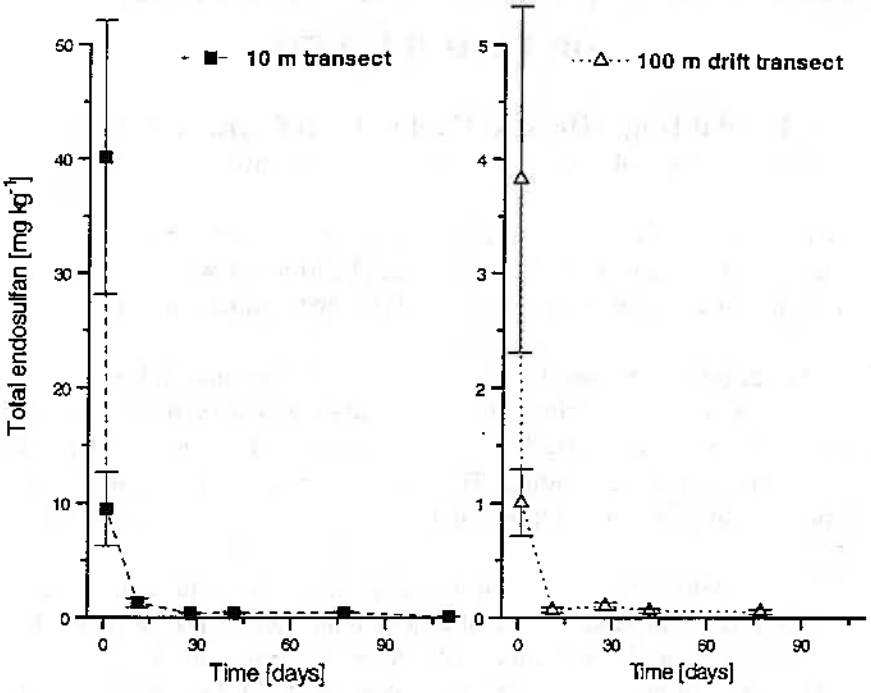

Figure 1: Degradation of endosulfan on pasture. These data (Kennedy *et al.*, 1998b) indicate that a quarantine period of approximately 4 weeks is needed to achieve acceptable residue concentrations in 'drifted' pasture for livestock.

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Wang, S.

Containment of potential chemical contaminants on cotton farms

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Environmental responsibility from cotton farmers requires that any applied chemicals (pesticides or fertilisers) be contained at the point of application, or within farm boundaries. The aim of this project was to investigate novel techniques to aid farmers in meeting this responsibility.

Initially, adsorption of endosulfan (α- and β- endosulfan and endosulfan sulfate) and metolachlor to a range of sorbents (including soil and coal) was investigated in the laboratory. The adsorption of endosulfan to soil is controlled by the organic matter fraction of the soil, is extremely rapid and occurs due to hydrophobic bonding. The two more hydrophobic isomers (α- and β-) showed much greater affinity for soil than endosulfan sulfate.

The initial field work was based on the hypothesis of containing sediment and sorbed endosulfan on the cotton field through the use of a flocculant such as polyacrylamide (PAM). In 1995 PAM was a new technology and interaction with Allied Colloids allowed the efficient and even application of PAM in irrigation waters at Auscott, Warren (field 34).The method of application of PAM is one of the most important factors influencing the success of the treatment (as many cotton growers will testify). The trial was held in January and the field had recently been cultivated. Thus the soil was highly erodible and being late in the season, contained mostly endosulfan sulfate residues (as opposed to the applied α- and β- endosulfan isomers.) Application of PAM at 3 ppm (3 mg kg^{-1}, or 3 kg Ml^{-1}) proved significantly more effective than an application of 1 ppm in controlling erosion. Analysis of endosulfan content of samples showed an increase in pesticide content with increasing sediment concentration in samples. Further work was carried out in a much larger trial with Mark Silburn and a team from QDNR Toowoomba. This confirmed the efficiency of PAM in reducing erosion (on markedly different soil types) and it was also found that a stubble retention treatment and reduced irrigation inflow rates were equally as effective in reducing erosion.

A rain simulation trial was also held at Auscott, Warren (field 30) with Mark Silburn and the team from QDNR. It was shown that PAM was not effective in reducing erosion or movement of sorbed endosulfan under rainfall conditions. There are several explanations for this result, including the intensity of the rainfall applied and the method of application of PAM prior to the rainfall. Accordingly, there was no difference in movement of endosulfan residues from PAM treated or control furrows.

The problem of containment of aqueous (or non-sorbed) endosulfan residues on farm led to the use of a coal filter bed in a tail drain at "Cumberdeen", Wee Waa during an irrigation in January 1998. Again, most of the endosulfan present was in the form of endosulfan sulfate and in laboratory studies this showed a lower affinity for coal than the α- and β- isomers.

Previous work in this department (from both the CRDC and the CRC) and from others focused on the fate and transport of endosulfan in the cotton farming system. This is one of the first projects to look at containing the residues on farm and whilst most of the project has involved further work with endosulfan we have briefly studied the characteristics of metolachlor. Further work in this department is now heavily focused on other herbicides (see Baskaran and Kennedy, this publication, for details.) Waters (this publication) has also studied the use of PAM and stubble retention in containing pesticide residues.

Funding for this project was provided through the CRC for Sustainable Cotton Production. Assistance was also provided by the CRDC for L. Hugo to travel to the 1998 IUPAC International Pesticide Congress (London) to present a poster on rain simulation and pesticide transport.

Best Management Practices to minimise chemical transport from cotton production systems

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Introduction

The 1997-98 cotton season proved to be a very successful year with approximately 20% of growers adopting management practices to reduce off-site movement of pollutants with grower interest increasing. Paddock scale monitoring of sediment, pesticide and nutrient movement from rainfall and irrigation runoff, commenced on several farms in the Emerald Irrigation Area in October 1997. The treatments that were agreed upon were: Wheat stubble/cotton double crop vs conventional cotton, Polyacrylamide (PAM) applied to irrigation water vs conventional cotton and the use of vegetative filter strips in the tail drain.

Wheat cotton double cropping

- The area of wheat/cotton double cropping has increased from 30 Ha in 1997/98 to 150Ha for the 1998/99 season and commitment from several new growers for 1999/2000 season
- Soil erosion from wheat/cotton double crop treatment was reduced by 70% over 6 irrigations (Figure 1)
- Early season sprays were reduced by 3 on the wheat stubble/cotton treatment compared to the conventional cotton
- 20% increase in predator numbers on wheat/cotton double crop compared with conventional treatment early in the season
- Wheat/cotton double cropping has the potential to produce enormous benefits environmentally, agronomically and economically
- Suitable machinery is needed to plant cotton into stubble before widespread adoption of double cropping will occur

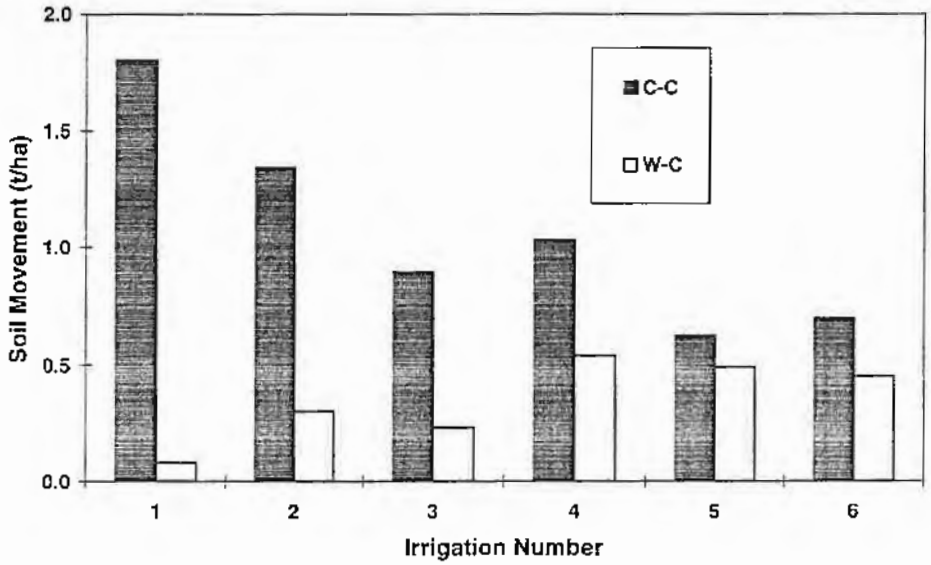

Figure 1: Soil movement by irrigation for wheat/cotton double crop (W-C) and conventional cotton (C-C) 1997/98 season

Polyacrylamide applied to irrigation water

- Polyacrylamide use has increased from zero growers using the product in 1996/97 to 8 growers in the 1997/98 season
- The addition of Polyacrylamides (PAM) to irrigation water reduced soil movement by 80% over 6 irrigations.
- Further development work is required to improve PAM application techniques and application rates

Future direction

- future work will continue with wheat stubble / cotton and PAM treatments
- work will focus on assessing the effectiveness of these treatments under rainfall runoff conditions and increasing adoption
- further detailed work will continue to gain a better understanding of the lower insect pressure/higher predator numbers due to the wheat stubble
- The work has been expanded into NSW with Steve Kimber of the NSW Department of Agriculture instrumenting similar trial sites for the 1998/99 cotton season

Conclusions

The 1997 cropping systems forum identified the need for environmental work to look at reducing sediment and pesticide runoff and stubble retention systems. This project is addressing these issues. The use of flocculants will be effective in reducing irrigation soil loss, however soil erosion by rainfall runoff is by far the major contributor to the problem (eg 1998/99 wet season has led to a 3–4 fold increase in soil loss). A wheat/cotton rotation provides the most effective system to date to cater for both irrigation and rainfall runoff. The system has the potential to produce enormous benefits environmentally, agronomically and economically for the industry.

Dust, nutrients, endosulfan, cotton farms and riverine environments

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Abstract

Measurements for organic matter, nutrients and pesticides of both emitted and deposited dust in the Narrabri - Gunnedah area during the 1996/97 growing season were made. Results indicated that wind erosion from roads is more significant than the cotton fields and that erosion rates are related to the mass of loose erodible sediment. Endosulfan fluxes off roads are potentially high (20 micro grams (Φg) per metre length of road). Dust emission from a vehicle travelling at 80 km/h on an unsealed road (3.7 grams per metre travelled) was about double that for inter-row cultivation at 8 km/h (1.7 g/m). Endosulfan source strength was marginally higher for inter-row cultivation (3.6 Φg/m) than for vehicle on the unsealed road (3.1 Φg/m). Unsealed roads are a greater source of endosulfan because of the greater frequency of vehicle movements, however, emissions are only a problem for the few days after aerial spraying. Dust deposition was greatest near roads and decreased logarithmically with distance. Endosulfan source strength (combination of dust and vapour) is highest close to roads with a measured peak deposition rate of 35 Φg/m5 at 100m for a 2 day period. When endosulfan deposition rates were measured over longer periods (weekly), on-farm deposition rates of 0.35 Φg/m5/day and off-farm rates of 0.16 Φg/m5/day were recorded. When these deposition rates are applied to a non-flowing river, of 1 m depth, calculated endosulfan concentrations are 100 times less than that measured in rivers at the same time as this study, implying that dust is not a major pathway of endosulfan to the riverine environment. Best management practices can reduce the risk of off-site contamination of sensitive areas.

Introduction

Dust is a product of wind erosion and the disturbance of the soil by anthropogenic activities. Therefore, it is associated with natural wind events as well as farming, mining and urban activities. There is increasing interest in the emission, transport and deposition of dust because of the off-site impacts dust can have. These impacts are both positive (increased nutrient deposition to vegetation communities and reduction in acid rain) and negative (reduction in photosynthetic rates of vegetation, reduced visibility and human health issues. Dust has this impact because it is a mix of minerals, organic matter and the chemicals attached to these components. Recent studies in the Namoi Valley have looked at (1) dust emission rates from roads and cotton fields, (2) dust deposition rates both on- and off-farm, (3) the dust associated endosulfan levels, and (4) the dust associated nutrient levels.

Methods

Dust emission by wind from roads and fields was measured with a portable field push type wind tunnel. Samples for nutrients, endosulfan and particle-size analyses were taken at 0.3 m height in the wind tunnel. Dust emission by anthropogenic activities was measured with high volume filtration system mounted on a vehicle which followed behind the dust emission source in the configuration as shown in Figure 1. Samples for particle-size and endosulfan analyses were taken at 0.6 m height (Leys *et al.* 1998).

Dust deposition was measured with dry deposition traps (DD) and endosulfan deposition with foil covered with polybutene, a sticky substance to catch the dust (PB), mounted at 2m height. The traps were arranged in transects away from a busy road and a field that was sprayed with endosulfan. A second set of traps were located at four sites along the Namoi river to measure dust, nutrient and endosulfan deposition rates to the riverine environment. These traps were downloaded weekly and as such collected total deposition of endosulfan via the aerial pathway (Larney *et al.* 1998).

Dust Emission By Wind

The study demonstrates that road surfaces represent an important source of wind erosion on cotton farms. The wind erosion potential, as measured by sediment flux in a portable field wind tunnel, of an unsealed road was 53 times greater than that of an adjacent cultivated cotton field in northern New South Wales. The road was more erodible because it was flatter and composed of smaller, more erodible soil aggregates than the field. The endosulfan emissions were 1.6 times greater for the cotton field than the road because the endosulfan concentrations on the road dust were only 1% that of the field dust. Nutrient analyses were not possible due to the small sample sizes. These finding suggest that dust emissions were greatest from roads compared to the adjacent cotton fields, but the endosulfan emission, nine days after application, were higher from the field because of the higher source strength of endosulfan on the field soil. If roads are accidentally over-sprayed or have chemical drift deposited on them, they could then become a significant source of endosulfan emission.

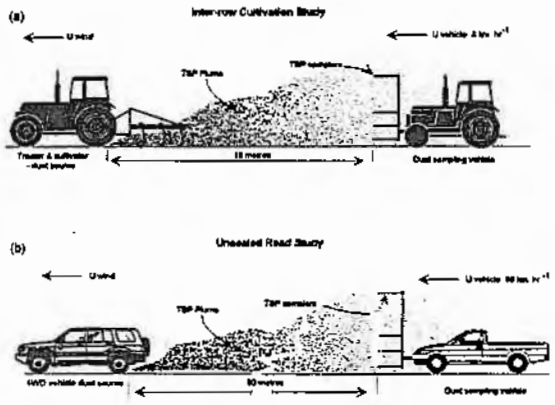

Figure 1. Dust emission sampling configuration for dust and endosulfan sampling.

Dust Emission By Anthropogenic Activities

Wind erosion is not the only way that dust is emitted into the air on a cotton farm. Recent United States studies indicated that vehicle movement on unsealed roads (Stetler and Saxton 1996)and cultivation (Clausnitzer and Singer 1996) are major dust sources. A vehicle travelling at 80 km/h on an unsealed road was a greater source of TSP emission (3.7 g/m travelled) than an 8 m wide inter-row cultivator travelling at 8 km/h (1.7 g/m). However, the particle size distribution of the TSP from inter-row cultivation was finer (mode of 19-22 Φm) than that from vehicular traffic on unsealed roads (mode of 32 Φm) and hence may be transported further. Endosulfan source strength from inter-row cultivation was 3.6 Φg/m of travel (or 0.45 Φg/m^2) which was only 6.0H10^{-4}% of that applied, 4 days after endosulfan application. This was slightly higher than the endosulfan source strength from vehicular traffic on an unsealed road (3.1 Φg/m of travel), only 2 days after spraying. On unsealed roads, particle-associated endosulfan mass fractions declined rapidly with time due to volatilisation and photodegradation and a decrease in endosulfan-enriched source sediment due to removal by repeated vehicle passes. These findings suggest that anthropogenic activities are a regular source of dust on-farm during dry weather. Endosulfan source strength will be highest shortly after spraying because the levels of endosulfan decline rapidly over the following days.

Dust Deposition and Associated Endosulfan

Dust deposition was measured (1) from vehicular traffic on an unsealed road on a cotton farm, (2) around a cotton field in the 11-65 hr period after endosulfan application, and (3) over a 3-month period at on-farm and off-farm (non-target) locations around Narrabri and Gunnedah. Endosulfan deposition was measured for points 2 and 3 above.

(1) Dust deposition rates decreased logarithmically away from the road ranging from 0.013 g/m^2/vehicle at 1 m, to 0.002 g/m^2/vehicle at 100 m from an unsealed road. Only about 15 % of the emitted dust travelled beyond 100 m from the road under the light wind conditions.

(2) Dust deposition, which was caused by vehicle movement on unsealed farm roads around the sprayed field, in the 11-65 hr period after endosulfan spraying varied from 0.30 g/m^2 at 10 m to 0.14 g/m^2 at 1000 m from the field.

The highest endosulfan deposition values in this post-spraying period were 95 Φg/m^2 at 5 m, 35 Φg/m^2 at 100m and 13 Φg/m^2 at 1000m from the field, measured with polybutene traps. However, we believe that these endosulfan deposition rates include both vapour and dust associated endosulfan, because the polybutene traps absorb endosulfan vapour as well as collected airborne particles. Caution must also be exercised in using the endosulfan deposition data reported here because the absorption / release rate of endosulfan from the polybutene traps is not known at this stage. Separating the dust and vapour contributions is not possible from the current study but we believe that dust contributions are 1-10% of the total endosulfan deposition. In the absence of any other data, and acknowledging the above mentioned limitations in the methodology, it is possible to calculate the endosulfan concentration in a 1 m deep, non flowing river at 100 m from the field: giving a concentration 0.035 Φg/L, which is above the ANZECC guideline of 0.01Φg/L but below the river concentration of 0.06 Φg/L measured during the study period (Cooper 1996).

(3) Over a 3-month monitoring period (December 1996-March 1997), the average daily dust deposition rate was 0.188 g/m^2/day. The average daily deposition rate (which could include drift+dust+vapour) of endosulfan was 0.16 Φg/m^2/day for the off-farm sites compared with 0.35 Φg/m^2/day for the on-farm site. Acknowledging the above mentioned limitations in the methodology, calculation of the off-farm endosulfan deposition rate into a 1 m deep non flowing river, results in a concentration of 1.6H10^{-04} Φg/L which is well below the ANZECC guideline of 0.01Φg/L and that of the measured levels of endosulfan in rivers of the study area in 1995/96 (Cooper 1996). This highlights the danger of using time averaged data that does not truly indicate the peaks of exposure that could occur if unfavourable meteorological and dust emission conditions occur.

Dust Deposition and Associated Nutrients

The dust samples for the 3-month sampling period were also analysed for total nitrogen (N) and total phosphorous (P). About 33 % of the deposited dust was organic matter. Deposited dust was enriched in nutrients compared to the soils of the area, with an 8-fold increase for total N and organic matter, and about 3-fold for total P. Total N deposition was about 1.24 g/m5/yr and total P about 0.29 g/m5/yr. Predicted nutrient concentrations in a slow flowing river (0.0039 Φg/L of N and 0.0008 Φg/L of P) are only a very small fraction of measured nutrient concentrations. However, predictions of the concentrations in a still pond (3.41 Φg/L of N and 0.78 Φg/L of P) after 1 month of deposition are about 50% of measured nutrient concentrations.

Implications of results and mitigation methods for dust and endosulfan movement

The mitigation methods discussed below can be viewed as part of the best management practice to reduce dust emissions. If however, pesticide spray drift is reduced to roads, the major source of dust, then endosulfan emissions are further reduced and the need for dust emission control becomes less of an issue. However, the following recommendations would reduce the risk of endosulfan emissions to negligible levels.

(1) Avoid spraying to edges of fields adjacent to roads, thereby avoiding pesticide contamination of roadways

(2) Avoid cultivation of fields and vehicle movement on roads within 100 m of sensitive areas when wind direction is off-farm. If recommendation 2 is not feasible, then

(3) Locate unsealed roads greater than 100 m away from sensitive areas.

(4) Reduce vehicle speeds on sprayed roads and cultivate when soil is moist.

(5) Reduce the loose erodible material on unsealed roads by watering, grading or use of adhesives.

The other approach is to filter the air of the dust with interception barriers, such as wind breaks. Current research is looking at the efficiency of vegetation for filtering dust.

Conclusions

These studies indicated the importance of dust movement off-farm and indicate that there is generally minimal impact on the environment from dust associated endosulfan emission from agricultural activities. Nutrient deposition occurs more often than endosulfan deposition and is significant in dry times when the rivers are not flowing. Therefore, when unfavourable meteorological and dust emission conditions occur close to rivers, then environmental impact is plausible. The research indicates that land managers can mitigate the impact of dust emissions by implementing best management practices (Williams 1997) which can minimise the movement of dust and associated nutrients and pesticides. The reduction of spray drift to roads and the reduction of cultivation and vehicle movement within close proximity to sensitive areas when the wind is blowing, should minimise endosulfan deposition in average weather conditions (ie wind speeds less than 5 m/s). The use of wind breaks could provide additional protection to sensitive areas.

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Best Management Practices for maximising whole farm irrigation efficiency in the Australian cotton industry

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The CRDC irrigation program has commissioned a three year project to investigate, quantify and promote best management practice for whole-farm irrigation efficiency within the cotton industry. The project is investigating on-farm engineering and management techniques to improve water use efficiency and involves the:

- performance benchmarking of current irrigation practices;
- development of simple techniques to measure irrigation performance at the furrow, field and whole farm scales;
- identification of appropriate alternative water management practices; and
- promotion of BMPs to improve on-farm water use efficiencies.

The initial field work is being conducted on four farms in the Goondiwindi area and consists primarily of a volume balance analysis for the water storage, distribution, application and recycling systems. In-field monitoring is also being conducted on farms in the Emerald area in collaboration with the pesticide monitoring program and water use data already being collected by other irrigators will also be incorporated where appropriate. Measurements undertaken either continuously or for each irrigation on the Goondiwindi farms include: rainfall, evaporation, storage volumes, channel flows/depths, storage/channel seepage rates, in-field inflow/outflow application rates, root zone soil-water recharge, advance characteristics and furrow flow depths. These measurements enable the assessment of losses within the systems, the evaluation of the performance of the in-field component and the identification of alternative management strategies using modelling techniques. While these measurements are necessary for the benchmarking of current irrigation practices and the identification of alternative practices, they are too time consuming and expensive to be used routinely in commercial irrigation management. Hence, this data will be used to focus subsequent research and the development of simple monitoring techniques on the major loss mechanisms.

Rainfall in the lead up to the season has resulted in only one irrigation so far being conducted on the Goondiwindi farms. However, water management issues that have already become apparent include:

- there is a wide range of variability in seepage rates from both storages and channels;
- distribution channels and head ditches often have substantial dead volumes;
- inflow and advance rates vary widely both between furrows and within single furrows during applications. This appears to be due to variability in head applied during application, non-uniformity of flow distribution into furrows and differences in infiltration due to cultural practices;
- field slopes are not always appropriate leading to problems with water advance; and
- inadequate capacity of many tailwater drains leading to inundation at the end of fields.

Development of pedotransfer functions to predict hydraulic properties of cotton-growing soil in eastern Australia

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Water-use efficiency has emerged as an issue of great importance to the irrigated cotton industry in recent years, due to the combined pressures of the cost of water and the cost to the environment of excessive water application and subsequent solute movement. Although some research has been carried out to quantify the various components of the cotton field hydrological cycle under current management regimes, this work has necessarily been restricted to a small number of sites due to the expense of collecting such data. Consequently, given the inherent variability of soil and its management by growers, the information that has been gathered may only be indicative of a small proportion of cotton-growing farms and fields in northern NSW and southern Queensland.

The development of pedotransfer functions, however, may offer a solution to the problem of obtaining accurate soil hydraulic information that is laborious and expensive to collect. Pedotransfer functions are simply relationships that allow the mathematical prediction of difficult-to-measure properties (e.g. hydraulic properties) from other more fundamental soil properties which are comparatively easy to measure (e.g. texture, bulk density). These functions have been quite extensively developed in Europe and the United States in recent times to facilitate the surrogate measurement of hydraulic properties across catchments and landscapes, but there remains a dearth of such functions for Australian conditions. This has been largely due to the fact that few extensive data sets of hydraulic and more fundamental soil physical properties have been collated in this. Only in the last 4 or 5 years has there been a concerted attempt to develop pedotransfer functions to predict soil hydraulic properties from surrogate measurements, but none of these functions have been derived using data from cotton-growing regions or soil types.

The few recent Australian pedotransfer functions referred to above have been developed by measuring soil physical properties such as texture, bulk density, aggregate stability and organic matter content, and relating them to hydraulic properties such as saturated hydraulic conductivity, near-saturated hydraulic conductivity, the soil moisture characteristic, air-entry potential and available water content. Given that a significant amount of soil physical information has been recently obtained from cotton-growing areas of northern NSW through a number of CRC and CRDC-funded projects, a similar approach could be adopted to produce pedotransfer functions applicable to these areas. Texture, bulk density and organic matter content data has, or is, being collected from a number of northern NSW cotton-growing valleys through soil baseline studies, while various measures of aggregate stability have also been made by different groups working in these valleys. It is the range of relevant soil hydraulic properties that requires more thorough investigation and then correlation with these fundamental soil physical properties; no extensive data set of soil hydraulic properties relevant to the management of irrigated cotton exists for the cotton-growing regions of eastern Australia. Such relevant hydraulic properties would intuitively include saturated and near-saturated hydraulic conductivity, the soil moisture characteristic and some measure of water availability to plants (e.g. least-limiting water range). Also, a further fundamental property that should be incorporated into hydraulic pedotransfer functions to improve accuracy, is that of soil structural form. A number of researchers have asserted that some soil hydraulic properties are difficult to predict without some measure of the macro-structure. The image analysis technique, which has already been used to characterise structural form on a number of cotton-growing soil types, appears an

ideal method of providing potentially crucial information such as the pore-space distribution, pore continuity, and aggregate size distribution of soil.

The benefits of generating pedotransfer functions relevant to the cotton-growing regions of eastern Australia are significant. An increasing amount of research work crucial to the on-going viability of the cotton industry, including that dealing with the prediction of salinity, prediction of the movement of chemicals (e.g. pesticides, N, P) through the landscape, and crop growth modelling, all rely on accurate soil hydraulic information. The development of pedotransfer functions to predict soil hydraulic properties from easy-to-measure soil physical features will allow such research to proceed without the expense of laborious soil hydraulic measurements, or without the concern of using doubtful estimates of necessary hydraulic input data. Additionally, the availability of pedotransfer functions for hydraulic properties will facilitate the rapid assessment of likely impacts of alternative management strategies (such as different rotation crops, seedbed preparation techniques, and the use of various chemical ameliorants) on cotton-field hydrology by requiring only measurements of fundamental soil properties to be made.

This proposed project, therefore, will address the current gap in our knowledge of relating easily observed or measured physical properties to more difficult-to-measure hydraulic properties. This will be done by measuring the range of topsoil and subsoil hydraulic properties described above at a large number of sites across the cotton-growing valleys of eastern Australia, and then mathematically correlating this data to either already-recorded or concurrently-recorded physical data (texture, structure, organic matter, bulk density) from the same sites. Site selection will be strongly influenced by the availability of previously-measured soil physical data, and will initially focus on the three CRC management systems sites and their valleys. A successful conclusion to this project will be the formulation of a number of pedotransfer functions to predict various soil hydraulic properties relevant to growing cotton from easy-to-measure variables. Such pedotransfer functions could then be used by a wide range of research groups who require accurate soil hydraulic information (e.g. salinity, pesticide, nutrient and water balance research groups).

Controlled traffic farming in dryland cropping systems

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Introduction

Controlled Traffic Farming (CTF) overcomes the conflict in farming operations between a firm and compacted soil surface -the optimum for field traffic, and loose and friable soil - the optimum for crop growth. CTF is a system in which the crop zone and traffic zone are permanently and distinctly separated. Combined with zero tillage and crop rotations, CTF has the potential to optimise soil structure, reduce runoff and soil erosion, and increase water availability.

The farm efficiencies and soil compaction control benefits of CTF are accepted by farmers, but the major constraint to adoption is concern about the implications of down slope layouts on soil erosion. CTF layouts will direct runoff flow along wheel tracks, crop rows, tillage furrows, etc. For controlled traffic layouts to successfully control soil erosion, the following rules have been developed:

1. The controlled traffic lines must drain to a safe disposal point - no reverse flows, no low spots When runoff occurs, the goal is safe disposal into a contour bank or waterway.
2. All the runoff generated within a controlled traffic line must be retained in it - no cross flows.

A study commenced in 1993 to measure runoff, soil loss, soil compaction and crop production in a down slope CTF layout where these rules are achieved by permanent beds and furrows, and crop rotations are used to provide a range of cover and antecedent soil water conditions during the year.

Materials and Methods

The study site is near Emerald (148° 10'E, 23° 32'S), central Queensland. The region has a semi-arid, sub-tropical environment with summer dominant rainfall. Long term mean annual rainfall is 639 mm and evaporation 2265 mm. The soil is a shallow black cracking clay.

Nine plots, 550 m long and 8 m wide are oriented down a 1.0% slope. Each plot consists of permanent one or 2 m wide beds. Traffic is restricted to the furrows between these beds. Dryland cotton, wheat and sorghum are grown as rotation crops.

Since late 1994, runoff and soil loss have been measured from bed and furrow units of each plot. A total of 17 runoff events have been measured. Soil compaction control was assessed in a 2 m transect across a permanent wheel track ("WT") and root bed ("bed") using a recording cone penetrometer in January, 1997. Increments of 1.5 cm to 45 cm depth, and 10 cm intervals across the transect were used.

Results

Runoff and Soil Loss

During 1998, nine rainfall events, varying in amount and intensity, have produced runoff. Table 1 shows the effect of cover on runoff, suspended concentration, total soil loss and erodibility from two runoff events when all plots had similar soil water contents due to previous rainfall. Dryland cotton stubble produces less than 10% ground cover, while wheat stubble produces greater than 40% ground cover. Total rainfall for January-October 1998 was 640 mm, with 35-130 mm runoff and 1.5-20 t/ha soil loss.

Table 1 - The effect of ground cover levels on runoff, suspended sediment concentration, total soil loss and erodibility for two rainfall runoff events

	25/9/98 (Rain = 46 mm, I_{30} = 44 mm/hr)				9/10/98 (Rain = 24 mm, I_{30} = 32 mm/hr)			
Cover (%)	Runoff (mm)	Susp. Conc. (g/L)	Total soil loss (t/ha)	Erodibility (t/ha/mm)	Runoff (mm)	Susp. Conc. (g/L)	Total soil loss (t/ha)	Erodibility (t/ha/mm)
0-20	26	13.1	3.32	0.13	9	12.8	1.33	0.15
20-40	22	14.4	3.32	0.15	5	12.8	0.85	0.17
40-60	12	5.0	0.55	0.05	1	3.0	0.06	0.06

Increasing ground cover levels decreased runoff and soil loss. Runoff, suspended sediment concentration, total soil loss and erodibility decreased dramatically when ground cover levels were greater than 40%. Maximum runoff rates were similar between these events, producing similar sediment concentrations and erodibility. Suspended sediment concentration decreased from 12-14 g/L with less than 40% cover to 1-5 g/L when cover levels were greater than 40%. The implications are very significant, as suspended sediment moves long distances in rivers and carries enhanced levels of nutrients and pesticides, and generally has high off-farm environmental impacts. Runoff samples have been collected from these runoff events for nutrient analysis, but are yet to be analysed. Erodibility decreased from 0.13-0.17 t/ha/mm when cover levels were less than 40% to 0.05-0.06 t/ha/mm with greater than 40% cover. These results imply that if annual runoff from low cover was 100 mm, total soil loss would be an unacceptable 15 t/ha but maintaining high cover would reduce runoff to below 50 mm and total soil loss to only 2.5 t/ha.

Compaction

The WT was trafficked three months prior to the soil structure sampling. The bed had not been trafficked since 1993. Penetration resistance below the WT was higher than the bed (Figure 1).

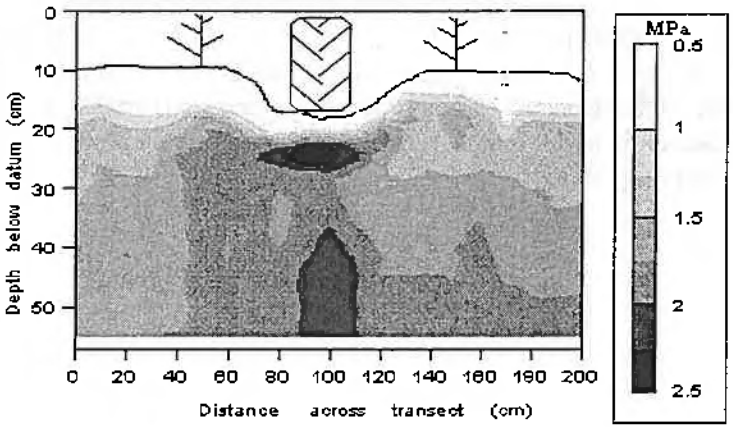

Figure 1 - Penetration resistance (MPa) across a 2 m transect of a permanent wheel track and bed. The surface profile, wheel track and plant rows are shown.

Values over 2 MPa occurred within 5-10 cm of the soil surface directly below the WT, and again at 20-40 cm below the soil surface. This narrow band of high resistance is only 20 cm wide. Penetration resistance over 2 MPa is considered to restrict the taproot penetration of cotton. At 10-20 cm below the soil surface, the average penetration resistance was 1.69 MPa below the WT, and 1.48 MPa in the bed.

These results show no evidence of soil compaction in the bed, or lateral spread from the WT. Any soil structural damage is restricted to a zone 40-60 cm wide directly below the WT.

Implications for Sustainability

Can dryland cotton systems be sustainable? This research shows that the key is high cover levels (greater than 40%) at all times. High cover can only be achieved by cereal rotation crops (wheat or sorghum) and zero tillage. Long fallows between cereal harvest and cotton planting will reduce cover to unacceptable levels. This leaves dryland cotton growers with few options. Opportunity cropping with the goal of maintaining high cover seems the only option. This implies planting a cereal crop as soon after cotton harvest as possible with a high probability of a poor crop, followed by another cereal crop to build up the cover. Cotton should only be planted into high cover and managed carefully to maintain the cover. Skip-row cotton is particularly vulnerable and specialised herbicide equipment may be required. In current dryland cotton systems, total soil loss and particularly the movement of suspended sediment will be too high. The main role of cover is to reduce suspended sediment concentrations to reduce the environmental impacts. It must be noted that suspended sediment is independent of slope, since flat, low cover areas will produce high suspended sediment values when runoff occurs, even if total soil movement is not obvious.

CTF provides the basis for a sustainable farming system. Directly, CTF improves natural resource management and reduces off-farm impacts by controlling soil compaction and facilitating zero tillage and cover maintenance. In addition, CTF supports better production systems and farm efficiencies by providing opportunities for zonal management - planting and fertilising between stubble rows, directed spraying of insecticides and herbicides, etc. It may also be necessary to plant before the profile is full of water. It must be high priority to incorporate these principles into dryland cotton systems. Clearly, the cotton/wheat/long fallow/cotton rotation is not sustainable.

A key requirement of CTF is layout design to achieve the two rules on runoff management. There are very few cotton consultants with the necessary skills and even fewer with experience. In Queensland, DNR staff can provide advice but in New South Wales this service is apparently no longer available. Our experience also shows that the keys to adoption are grower participation, adult learning and action research

There are also implications for the irrigated cotton industry. The current bare fallow prior to cotton planting is not sustainable and Dave Waters' research (these proceedings) offers clear solutions. The challenge for irrigators in terms of resource management and environmental impact is management of runoff from rainfall. The key from our research is high cover achieved by cereal crop rotations and zero tillage, but this requires major changes to current practices.

Estimation of crop water use efficiency of irrigated cotton farms in the Namoi Valley

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Introduction

The current debate on allocation of water between domestic, agricultural and environmental sectors imposes increased significance to water use efficiency of cotton farms. A research project funded by the CRDC has been initiated to investigate the water use efficiency within the cotton industry at both crop and farm level. In this study we are looking at two major components of water use efficiency: (a) the agronomic aspect of water use efficiency which is the amount of yield (lint) produced per unit amount of water used in evapotranspiration during the growing season and (b) the engineering aspect of water use efficiency which is the percentage of total seasonal water usage at the farm level used as evapotranspiration.

Using the information already available in the hands of individual producer's the current status of water use efficiency is being assessed. One of the major objectives of this project is to establish water use efficiency benchmarks at a regional level using information gathered from selected progressive farmers. As the first stage of this project a methodology was developed to calculate a number of water use efficiency indices. The preliminary results for cotton water use efficiency in the Namoi Valley is presented in this paper.

Defining water use efficiency

A number of different sources of water inputs (precipitation, irrigation and stored soil moisture) are available for irrigated cotton crops. A proportion of the total available water in the field is utilised by the crop mainly through evapotranspiration and yield produced. During this process a number of efficiencies can be defined considering inputs and outputs at different stages of the production process. The following equations indicate the definitions used in this project to calculate different water use efficiencies.

1. Crop water use efficiency (kg/ha/mm) = lint yield (kg per ha) / seasonal ET(mm)

This can also be expressed as bales per ML.

2. Farm water use efficiency (bales/ML)=total yield (bales)/total seasonal water usage (ML)

The total seasonal water usage includes pumped water from rivers and bores, the amount used from storage, water harvested during the season, effective rainfall and soil moisture reserves depleted during the season. The amount of soil moisture reserves can be from pre-season rainfall, pre-irrigation or moisture stored during the fallow.

3. Total water use efficiency = seasonal ET (mm)/ total seasonal water usage (mm)

4. Irrigation efficiency = net irrigation intake (mm) / total irrigation water applied (mm)

The net irrigation intake is the cumulative soil moisture increases from successive irrigations. Total irrigation water applied includes pumped water from rivers and bores, the amount used from storage and the water harvested during the season but excludes rainfall.

Data collection

A number of progressive farmers from the Namoi valley were contacted to provide historical water management information. The basic information requested from producers was as follows.
For selected fields: neutron probe readings, dates of irrigation, sowing and harvesting dates, lint yield, soil type and land use history.

At the farm level: daily rainfall data, total cotton area, total number of bales produced, total amount of water pumped (for cotton) from river and bores (ML) and the total amount of water harvested (ML).

Estimation of seasonal evapotranspiration.

Estimation of seasonal evapotranspiration is one of the major prerequisites in calculating crop water use efficiencies. A spread sheet model was developed using EXCEL to estimate the soil water balance in a cotton field on a daily basis by combining observed neutron probe soil moisture data with simulated daily evapotranspiration (ET). The water balance was calculated using the following equation.

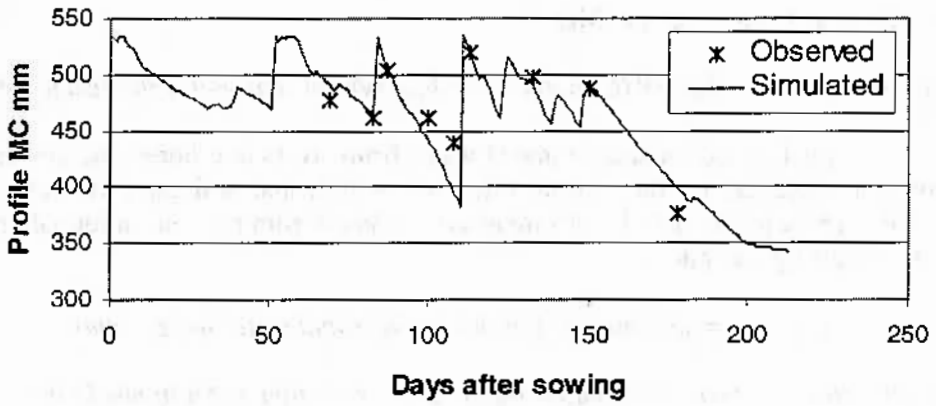
$$SMC = Pre.SMC + ER + I - ET$$

SMC = soil moisture content in mm, **Pre.SMC** = SMC of the previous day
ER = effective rainfall mm, **I** = amount of irrigation intake in mm

Daily ET was simulated using the modified Ritchie model (Ritchie, 1972). It was assumed that the soil moisture content at sowing (starting date) was equal to the maximum water holding capacity (WHC) of the soil. The WHC of the soil was estimated from the observed soil moisture content. It was assumed that the soil could absorb water from a rainfall or an irrigation event until its maximum water holding capacity was reached with the rest of the water leaving the system as run-off and being harvested for future use. The amount of water infiltrated into the soil was calculated by taking the difference between maximum WHC and moisture content prior to rainfall or irrigation. Due to the low saturated hydraulic conductivity of the soils in the Namoi Valley, lateral, upward and downward (deep percolation) water movements have been considered negligible.

An example of simulated soil moisture contents (120 cm profile) and the observed soil moisture contents were plotted and is given in Fig. 1. In order to improve the accuracy of estimation, the simulated moisture figures were adjusted using the observed values. Whenever the observed values are available during the simulation process, the simulated value is replaced by the observed value and the simulation is continued from that point until the next observed value is met.

Fig 1. Simulated and observed moisture content



The water balance model computes water use in different components and estimates the amount of transpiration and soil evaporation separately. It also estimates the amount of effective rainfall, the net irrigation intake and soil moisture reserves used during the growing season. The soil reserve used is calculated by subtracting the soil moisture content at harvest from the soil moisture content at sowing.

Data from a number of individual fields on each farm in each season were analysed using this model to estimate total seasonal ET, effective rainfall and net irrigation intake. The average figures of the

above-mentioned parameters for farms and seasons were made using the individual field results. As a preliminary stage of this project water management data for the last two seasons from six selected producers (about 50 fields) in the Namoi Valley have been analysed and are presented in this paper.

Results

The average water use from different sources is given in table 1. At the farm level, it was observed that the total seasonal water usage on a cotton crop in the Namoi Valley was around 10 ML per ha, which includes 4-5 ML from irrigation.

Table 1. Water use summary in Namoi Valley.

Season	96/97	97/98
ML/ha pumped	4.71	5.16
ML/ha effective rainfall	3.21	3.08
ML/ha harvested	0.87	0.72
ML/ha used soil reserve	1.32	1.26
ML/ha total water usage	**10.10**	**10.22**

The average yields for the 96-97 and 97-98 seasons were 7.71 and 8.32 bales per ha and the seasonal total estimated evapo-transpiration were 764mm and 781 mm respectively. Water use efficiency indices calculated for the last two seasons are given in table 2. The average crop water use efficiency was 2.26 and 2.43 kg/ha/mm for 96-97 and 97-98 respectively, approximately 1 bale per ML. However, there was considerable variability in crop water use efficiency; from 2 to 2.8 kg/ha/mm.

Table 2. Water use efficiencies for Namoi Valley

Season	96/97				97/98			
	Mean	Max.	Min.	SD	Mean	Max	Min	SD
Crop WUE Bales/ML	**1.00**	1.09	0.91	0.08	**1.07**	1.23	0.90	0.11
Farm WUE Bales/ML	**0.84**	0.92	0.76	0.07	**0.83**	0.96	0.68	0.10
Bales/ML (Total irrigation water)	**1.77**	2.47	1.20	0.47	**1.50**	1.88	1.03	0.35
Total water use efficiency	**0.84**	0.85	0.83	0.01	**0.78**	0.90	0.65	0.11
Irrigation efficiency	**0.68**	0.90	0.54	0.14	**0.63**	0.79	0.42	0.16

Discussion

Brian Hearn's (1997) provisional benchmark for crop water use efficiency is 3 kg/mm/ha and the average values for the Namoi valley for the last two seasons are below the benchmark suggesting that there is considerable room for improvement of crop water use efficiency on some farms; especially considering the range of values estimated in each year. The irrigation efficiencies observed for the last two seasons were 68% and 63%. This means that about 32% to 37% of irrigation water has been lost within the farm. These losses may have occurred in storage, in the conveyance system or in applications. The University of Southern Queensland is currently conducting a research project to identify these points of losses.

Future work

The study is being extended to other major cotton growing areas and will result in a comprehensive water management database for the cotton industry to assess the current status of water use efficiency at crop level and farm level. Water use efficiency benchmarks will be developed on a regional basis. Tools to assist cotton irrigators to maintain proper records of on farm water use and to conduct their own comparisons with benchmarks will also be developed.

References

Hearn, A.B. (1997) Agronomic and economic aspect of water use efficiency in the Australian cotton industry. Cotton Research Development Corporation.

Ritchie, J. T. (1972). Model for predicting evaporation from a row crop with incomplete cover. *Water Resource Research* **8**, 1204-1213.

Understanding the salinity threat in the irrigated cotton growing areas of NSW

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Introduction

The current project (CRC1.5.2) is aimed at understanding the salinity threat at various levels including the field, sub-catchment and regional cotton growing areas. The project is funded primarily through the Cotton Research & Development Corporation (US22C). Supplimentary funding is also received from Salt Action and the Natural Heritage Trust in collaboration with the CRC for Sustainable Cotton Production and various community groups including the Coordinating Committee of Namoi valley waters users association, Gwydir Irrigators Association and Macquarie valley Landcare group. Collaborative links are also in place with various CRC projects including: CRC1.2.1 (Inakwu Odeh-US); CRC 1.5.4 (Ian Gordon-QDNR), and; CRC 1.5.10 (Janelle Douglas-UNE).

Fieldscale investigations

Traditional methods of generating soil information on the field scale have involved the design and adoption of soil sampling regimes and laboratory analysis. Due to the time consuming nature of this approach only limited soil information can be collected. Unfortunately, the maps created lead to errors in interpretation and possibly soil management. In more specific investigations, eg. soil salinity assessment and determination of irrigation\drainage efficiency, more detailed quantitative information is required.

Electromagnetic (EM) induction instruments measure the apparent electrical conductivity (EC_a) of soil and have successfully been used to estimate salinity and clay content to depth. To improve efficiency of data collection, a Global Positioning System (GPS) and two EM instruments were mounted onto a Mobile EM Sensing Systems (ie. MESS). This MESS allows rapid, repeatable and reliable collection of EC_a data (see Figures 1a and b) and includes: a 486 computer for data logging, display and instrument set-up; a Trimble™ Ag132 (GPS) which provides wide-area differential correction for real-time sub-meter accuracy; a Trimble™ FieldGuide GPS for positioning and guidance; and a Geonics™ EM38 for root-zone and Geonics™ EM31 for subsoil EC_a measurement. All components are mounted on a 4WD hydrostatic articulated tractor.

Figure 1a. From left to right, Trimble Ag132, GPS400, RMD and 486 data logger/control box.

Figure 1b. MESS deployed in a dryland cotton field located south-east of Moree, Gwydir valley.

To date the MESS has been applied to assess soil salinity in dryland cotton growing areas. Recently, work has also commenced in the field of precision agriculture. Other applications include assisting with dam site location and identification of leaking water storage's and channels, etc.,. The

MESS has also been used in estimating deep drainage and average soil EC_e at steady state using EC_a data and soil information coupled to a salt and leaching fraction model or Sodium-SaLF.

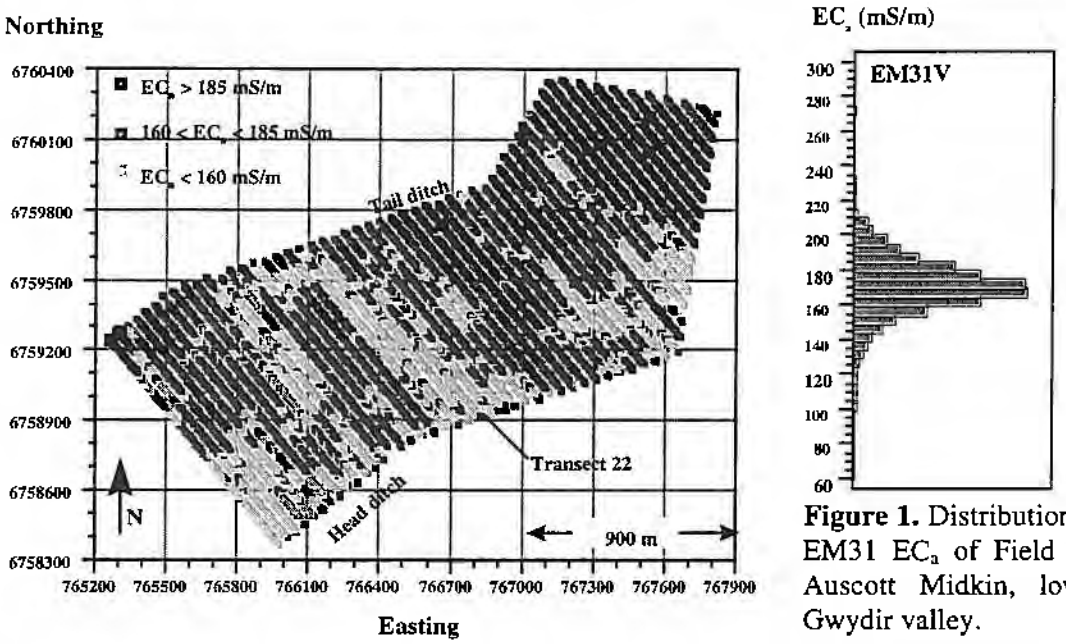

Figure 1. Distribution of EM31 EC_a of Field 11, Auscott Midkin, lower Gwydir valley.

The field selected for study, covered 244 ha and has a long history of problems associated with perched water tables and water logging. In order to map the spatial variability of soil types, estimate *deep drainage* and average EC_e at steady state, the MESS was used to generate EC_a data along 55 transects located 48 m apart (Figure 2). Figure 2 indicates low, intermediate and high soil EC_a as generated by the EM31 in the vertical mode of operation. The lighter shaded areas (EC_a < 160 mS/m) indicate parts of the field where a prior stream traveled and where sandier soil types are apparent. Similar EC_a patterns were obtained with the EM38 and suggests the instruments are responding to clay content. This is confirmed in the right hand panel that shows the distribution of EC_a is normally distributed.

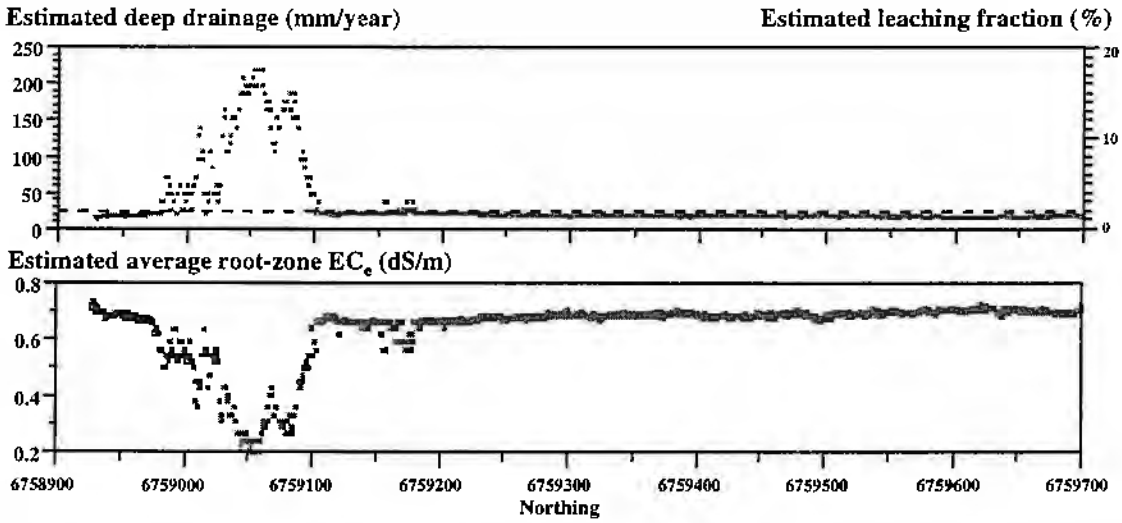

Figure 3. DD, leaching fraction and average root-zone EC_e estimated along Transect 22.

Soil samples were also collected at 69 sites and analysed for *CEC* and particle size analysis at 0-0.3; 0.3-0.6; 0.6-0.9; and, 0.9-1.2 m depths. Water samples were collected from nearby Carole Creek. Estimates of deep drainage were then made using Salf based on the assumption that 600 mm good quality irrigation water is applied and the farm receives an average rainfall of 584 mm. A relationship was established between EC_a and estimated DD. The results of this are shown in Figure 3

which illustrates that the majority of transect 22 has a *DD* of 25 mm/year and a *LF* of around 2 %. These estimates are comparable to those obtained by Douglas (1997) who determined *DD* using a soil water balance model for a similar soil in the lower Namoi valley. As for the area associated with the prior stream channel, *DD* ranges from 34-227 mm/year. The average estimated *LF* was 9.5 % in this area. As a result average soil EC_e would be low and indicative of a strongly leached profile. Soil EC_e determined here was similar to the estimates of average EC_e shown in Figure 3.

These results seem consistent with the farmer's. Owing to the location of permeable soil near the head ditch and due to the presence of a subsoil clay layer, the excessive *DD* leads to the creation of the perched water table or at least exacerbates the condition, causing excessive water logging. Fortunately, the perched water table is not interacting with a saline subsoil clay layer and no soil salinity is apparent.

Sub-catchment scale

Groundwater recharge is the process whereby the surplus of infiltration over evapotranspiration drains from the root-zone and continues to flow downward through the so-called vadose-zone toward the ground-water table. The vadose zone is the volume of deeper subsoil, where deep drainage or recharge occurs. This zone is as heterogenous as the topsoil but because of its inaccessibility is more difficult to measure and map. In areas where irrigation is carried out extensively and over prolonged periods of time, information to determine the quantity and fate of deep draining waters is required.

To generate this information in the lower Namoi valley we used a Geonics Ltd EM34-3. This instrument, along with some soil sampling, is being used to estimate recharge using chloride and salt balance modelling. The study area selected is approximately centred around the small township of Wee Waa, located in the lower Namoi valley, and covers an area of 2,048 square km. The area was chosen since it is one of the oldest irrigated cotton growing areas and because a large number of farms are concentrated in a relatively small area. In total 1869 EM34-3 survey points were collected. Figure 4 shows the spatial distribution of soil EC_a as achieved using the EM34-3 in the horizontal mode of operation and a spacing of 40 m. The data presented here strongly reflects the geological and geomorphological perceptions of the area and suggests possible soil types where deep drainage may be of concern. This is particularly the case where the instrument and the survey reflected the location and passage of prior stream channels of the Namoi River in a north west direction parallel with Spring Plains road and in a westerly direction where Pian Creek now runs. These areas are defined by lighter shaded areas where soil EC_a was generally low. It is in these prior stream areas where the soil is sandier in nature and where potential problems with excessive ground-water recharge needs to be investigated.

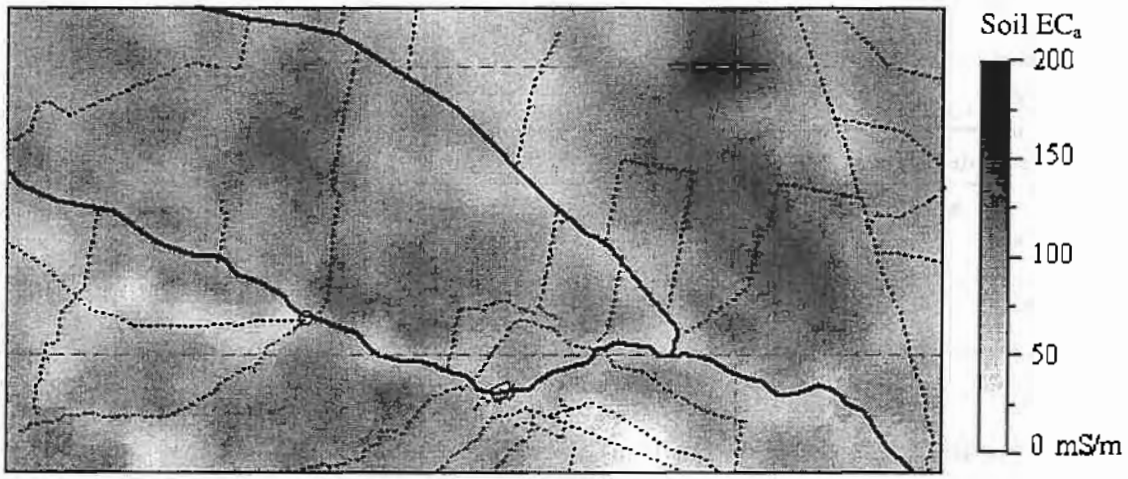

Figure 4. Map of soil EC_a obtained wiyh EM34-3 in horizontal mode and 40 m spacing.

In the prior stream channels it is also apparent that soil EC_a as measured using the EM34 at a 40 m intercoil spacing is slightly larger by comparison to soil EC_a as measured by the 10 m intercoil spacing. The reason for this would appear to be that the instrument with the coils aligned at a 40 m

interval is able to respond to the presence of a deep subsoil clay layer or some other conductive material, such as groundwater. This is best illustrated by considering the data presented in Figure 5 which shows in the upper panel the soil EC_a as measured at intercoil spacings of 10 and 40 m, from south of the ACRI near the Namoi River and its floodplain to Boolcarrol Farm some 30 km to the north. The lower panel shows the ratio of soil EC_a as measured using the EM34-3 at a 40 m and 10 m intercoil spacing.

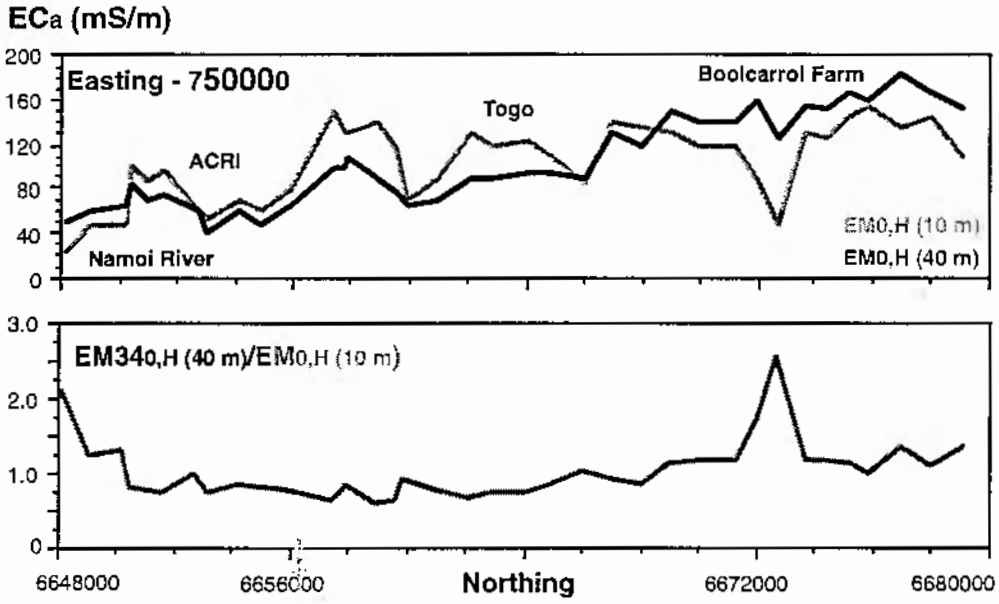

Figure 5. North-south transect of $EM_{0,H}$ at 10 and 40 m intercoil spacing.

What is apparent in the upper panel is the steadily increasing trend in EC_a from the southern part of the area to the north. This is consistent with increasing clay content and thickness of clay the further away we travel from the river floodplain. However, more significantly near the Namoi River the ratio of $EM_{0,H\,(40)}$ and $EM_{0,H\,(10)}$ is quite large as indicated in the lower panel. This suggests the instrument at the 40 m intercoil spacing is probably being influenced by groundwater at a depth of about 15-20 m. The reason for the even larger ratio on Boolcarrol Farm is most likely due to the presence of a number of relatively saline aquifers situated at depths of approximately 25 m in this general vicinity.

The work carried out to date suggests the EM34-3 instrument is capable of describing the spatial distribution of soil EC_a, the general physiography and geomorphology, and the geohydrology of the lower Namoi valley. Future work will involve coupling estimates of recharge to the soil EC_a information collected using models and from soil samples collected from the various land-use types for comparison

Regional scale

Irrigation with either moderate to highly saline and\or sodic water can create problems within the root-zone. Application of saline water for example can lead to increased salinity within the seedbed if there is insufficient leaching of the salts through the soil profile. Where there is excessive deep drainage, shallow saline water tables may be created and result in the concentration of salts within the root-zone through capillary rise. In order to determine the possible effect and long term sustainability of irrigated agricultural production in a particular area two things are necessary. The first is information about the spatial distribution of soil and water resources suitable and currently being used for irrigation. This can be collected by reconnaissance soil surveys or from already existing soil and water quality information. Secondly, soil\water balance models can be used effectively to estimate soil salinity build-up and deep drainage beyond the root-zone using this information.

Owing to the large area used for irrigated cotton production in the lower Macintyre and Gwydir valleys, a simple model that requires rudimentary soil survey data such as SaLF is being used. It is based on the assumption that soil leaching or deep drainage is related to hydraulic conductivity which in turn is influenced by the amount of clay (%), clay mineralogy (Cation Exchange Capacity/Clay %) and exchangeable sodium percentage (ESP). Once these soil properties and water quality and quantity parameters have been determined and entered into the empirically based model, estimates of leaching fraction (LF) deep drainage (DD in mm/year) and average root zone EC_e at steady-state are predicted. A small number of water quality parameters, such as EC_w, depth of irrigation water applied and annual rainfall, as well as the crop being grown is also required by the model.

Previously soil samples were collected and analysed for a small number of rudimentary properties including determination of clay, silt and sand fractions in the lower Macintyre and Gwydir valleys (CRC-1.2.1). In total 120 soil sampling locations were selected and visited in the lower Macintyre valley, predominantly located in irrigated cotton growing fields from Goondiwindi in the east of the valley to Mungidi in the west. In the lower Gwydir valley a slightly larger number of samples has been collected to date (ie. 153) near the township of Moree in the east, Garah and Telleregah and around Collarenebri in the west where a small number of additional samples are still to be collected. At each site six soil samples were collected including: 0-0.1, 0.1-0.2, 0.3-0.4, 0.6-0.7, 1.1-1.2 and 1.9-2.0 m. In addition we determined the cation exchange capacity (CEC) at four of the five root-zone depths. A small reconnaissance water sampling survey was also conducted in the lower Gwydir valley to assess the current water quality available for irrigation.

In total 21 water sampling locations were visited and found to have an average EC_w was 0.435 dS/m which is considered non-saline (ie. <0.7 dS/m) and well within acceptable limits for irrigation. The data also shows no significant increase in water salinity along the Mehi River which runs along the entire length of the lower Gwydir valley and suggests there is no salt loading caused by high water tables beneath irrigated cotton farms.

With the soil and water quality information generated, the Salf model was used to determine the current status of soil salinity within the root-zone and sustainability with respect to an average water salinity of 0.44 dS/m (ie. Gwydir valley). Each of the 273 sites were entered into the program and included the attributes of clay content and cation exchange capacity at four depths (ie. 0-0.1, 0.2-0.3, 0.6-0.7 and 1.1-1.2 m) and exchangeable sodium percentage at a depth of 1.2 m. We also assumed that at each site the average annual rainfall was 584 mm and that 600 mm of irrigation water is applied annually. In order to determine the effects of applying progressively more saline water with respect to increased soil salinity and deep drainage we also carried out simulations of adding water with EC values of 1.4 (slightly saline), 4.0 (moderately saline) and 9.0 dS/m (moderate-high salinity).

The results of some of the simulations are illustrated in Figure 6. The soil types or areas at risk if these water qualities were the only ones available (ie. EC_w of 4 or 9 dS/m) for irrigation can be shown using a geostatistical interpolation method known as indicator kriging. For example, if average soil salinity exceeds 4.0 dS/m we can anticipate that there will be a high probability (ie. 1) that some loss in production will occur if sensitive crops are planted. The probability maps illustrated in Figures 6a and b show the areas where soil salinity could be expected to be greater than this critical level in the lower Macintyre and Gwydir valley, if EC_w of 4.0 and 9.0 dS/m was applied, respectively.

Figures 6a and 6b suggest that moderately tolerant wheat and cotton crops would most likely be not severely restricted by the salinity levels in the soil when the moderate to high salinity water of EC_w 9.0 dS/m is used. However, area around Garah is of possible concern, but what is more clearly apparent is the areas least likely to be affected as illustrated by the white areas in Figure 6a (ie. proability < 0.5). The reason for this would appear to be that the soil is slightly sandier in nature, due to the closer proximity of these areas to the current MacIntyre and Gwydir River floodplains and prior stream channels. As a result fewer soluble salts will be stored in the profile. However, with the increased electrolyte concentrations soil permeability is also improved and would therefore lead to increased amounts of deep drainage.

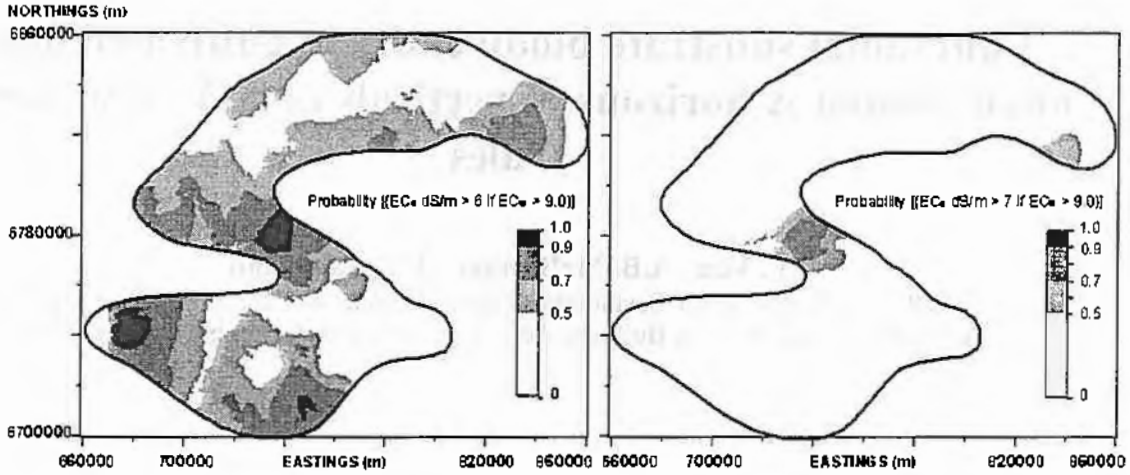

Figure 6. Indicator kriged map of: **a)** average root-zone $EC_e > 6$, and; **b)** average root-zone $EC_e > 7.7$ when water quality of $EC_w = 9$ dS/m is applied.

Future work

Future work will include the collection of deep soil samples in the lower Namoi valley to enable estimates of recharge to be made using simple chloride mass and salt balance models. Shallow samples will also be collected at paired sites of irrigated cotton and native areas to enable comparisons of deep drainage using SODICS in the lower Macintyre, Gwydir and Namoi valleys. Similar field, sub-catchment and regional level studies are also being carried out in other irrigated cotton growing areas including the upper Namoi and lower Macquarie valley. In both areas supplementary funding has been received from Salt Action.

Functional substrate biodiversity of cultivated and uncultivated A horizons of vertisols in NW New South Wales

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Concern over the effects of anthropogenic activities on soil 'quality' has fuelled efforts to identify and measure those factors that affect soil quality. Soil microbial diversity is one of many possible factors.

Our objective was to compare the functional diversity of microbial communities in cultivated and uncultivated vertisol A horizons, by measuring utilisation of 95 substrates. Samples from two paired cultivated uncultivated vertisol sites in the lower Namoi valley were tested for their ability to utilise the substrates on a Biolog plate.

Substrate richness, the rate of substrate use and the diversity of substrate use, as measured by the Shannon index, were calculated. At the final time point, substrate richness and functional diversity were significantly larger in the uncultivated sites than in the cultivated sites. The rate of substrate use was also greater in the uncultivated sites, although this may have been due to greater initial inoculum densities.

When site diversity values were compared with several soil physical and chemical properties, a relationship between organic carbon and functional diversity was apparent. According to the fitted broken-stick model, diversity increased up to 1.76% and remained constant above that value.

The implications of these results for soil quality will depend upon future investigations on the significance of soil microbial diversity as a component of soil quality.