The Australian Cotton Industry's Best Management Practices Manual

Allan Williams
Executive Officer, Australian Cotton Growers Research Association
"Kia-Ora" Narrabri NSW 2390

Introduction

The current, first edition of the Best Management Practices Manual ("Manual") was developed as part of the joint research program "Minimising the Impacts of Pesticides on the Riverine Environment", which was funded by the Cotton Research & Development Corporation, the Land & Water Resources Research & Development Corporation and the Murray—Darling Basin Commission. The continued development and implementation of the Manual is being overseen by an industry "BMP Management Group", which has representatives from the Australian Cotton Growers Research Association, CRDC, the CRC and Cotton Australia. The current edition focuses on pesticides management, with sections on farm design and management, pesticide storage and handling, application of pesticides and integrated pest management.

How the Manual Works

During the consultation phase for the development of the Manual, it became apparent that a framework was needed with which to 'surround' the best practice statements. After investigating best practice programs in agricultural settings in North America it was decided to use the "Self-Assessment' concept, first developed in Wisconsin by Farm*A*Syst and now used throughout the United States, and currently being used extremely effectively in Ontario, Canada through their Environmental Farm Plan program. The original 'best practice' booklets are now resource documents placed at the end of the manual to be used when developing action plans for reducing the risk of activities identified as such during the self-assessment process.

Self-assessment

The initial stage of the Manual leads the farmer through a series of self-assessment worksheets, which are grouped under four main headings: farm design and management, pesticide application, integrated pest management and pesticide storage and handling. Issues relevant to each heading and relating to the risks associated with the use of pesticides are highlighted on the self-assessment worksheets.

Each of these self-assessment worksheets is designed to allow the cotton farmer to assess and rank the potential risks on their farm relating to the use of pesticides. These risk-rankings are then used to identify high priority areas for the development of action plans that will help minimise that risk.

The rankings go from low to moderate to high to extreme (from 1 to 4), and are designed to provide an indication of the relative risk that may result from an activity in the given circumstances. Thus a ranking of 1 for a particular issue means that that issue poses a relatively low risk; rank 2 could be a moderate risk; rank 3 a high risk and rank 4 a more extreme risk.

Rankings of 3 to 4 mean a higher level of risk, and any issue which attracts these rankings are prioritised for the development of action plans to reduce the degree of risk.

Hazard Analysis

Although the self-assessment worksheets address a number of important issues relating to pesticide use in the cotton industry, they are by no means complete or exhaustive due to the broad complexity of the farms, operating conditions and practices existing in an industry as diverse and sophisticated as cotton.

Thus a framework which will assist cotton farmers to identify all the critical issues they face on their own farm, leading to the development of a more comprehensive farm plan (in effect a farm specific set of best management practices) has also been included in the Manual. This framework takes the form of hazard identification and analysis, and is designed to break down the task of establishing farm specific best practices into a series of steps which are manageable.

The starting point is to list the activities which occur on a cotton farm and then identify the hazards associated with these activities and for which best management practices will be developed and applied. Rather than provide a prescriptive set of practices users are guided to develop their own best management practices and check these against some standard issues (included in the manual). This process alerts people to the key issues and the potential problems while allowing them to develop a set of practices with accompanying monitoring systems which suit their specific circumstances and operations.

Planning

The key to success in using the Manual is in developing action for those areas or issues identified as posing a significant risk.

Once the self assessment sheets (and the hazard analysis if applicable) have been completed, those areas requiring attention have been identified and ranked. The solutions chosen for the identified risk areas are documented, as are the monitoring and review processes implemented to evaluate the effectiveness of the plans, together with the person responsible for seeing the plan is implemented.

Supporting documentation, which provides some guidelines or management options for the development of action plans, is included in the form of "Best Practice" booklets. Further resources to assist cotton farmers in their planning process are also listed under each self-assessment heading, including other published material and relevant legislation.

The Manual provides a flexible framework for cotton farmers. It recognises that cotton farming takes place under a wide range of environmental, commercial and social conditions. These varying conditions may place differing constraints on a cotton farmer. By using a planning framework, cotton farmers are able to identify any particular constraints that they may be operating under, and then plan the most appropriate method for them of overcoming that constraint.

By using the Manual, cotton farmers will be developing practical farm plans which minimise any impacts of cotton farming on the environment, as well as demonstrating their commitment to responsible resource management.

The Manual therefore has two distinct components, one addressing the best management practice guidelines, while the second is directed at providing cotton farmers with a framework they can use to document and plan the environmental aspects of their farming operation. It needs to be stressed that the BMP Manual is more than just a technical list of best practices. In fact, BMP could just as easily stand for best management planning.

This planning framework aims to provide a flexible process that will address the need to manage the natural resource base, and also meet producer's need (and thus addressing the first two issues raised by the first drafts, how is it used, and how are non-applicable practices catered for). It enables the user to

- objectively assess their current situation
- document decisions made to improve situations identified as being a potential risk
- monitor the effectiveness of those decisions.

Implementation

Implementation of the Manual is being organised through the local cotton grower associations, (the active involvement of growers at a local level is essential for the success of the Manual) who will be responsible, together with the local Cotton Australia Regional Manager and/or extension officer, for distributing the Manuals, maintaining the record of recipients and organising the training meetings that cotton farmers will attend to be shown how to use the Manual. Centralised coordination and support for these activities is also provided.

The brief description of the process is as follows:

- Cotton farmers are made aware that the Manual is available. This is being done through the various industry publications and communications streams from the local grower association, as well as relevant media publications (eg the Australian Cotton Grower).
- Generally, an introductory meeting is held, where the Manuals are distributed (together with a short "How to Use" guide, which contains worked examples), and a brief introduction to its development and content is given.
- Once farmers have received the Manual, a training day is organised where they are shown how to compete the Manual. The trainers will be primarily Cotton Australia field staff, supported by cotton industry extension and development officers.

Once the cotton farmer has competed the Manual, a follow up meeting is organised with the farmer to ensure he has completed the relevant parts of the Manual.

Survey Results

A survey of 50 cotton farmers who have received the Manual was conducted recently. The following encouraging results were reported:

96% stated that BMP was important or very important for the industry
72% had started filling in the Manual
54% had started developing action plans
64% have made changes to their farm operation as a result of the Manual.

Auditing and Certification

An independent auditing process is viewed by many people (not least of the Government regulatory authorities) as critical to the long term credibility of the BMP program. That there needs to be an audited BMP process if the BMP program is to maintain its credibility is generally accepted by those involved in discussions and negotiations with external stakeholders to the industry. Not only does this auditing have to exist; it has to cover a substantial number, (if not all) growers.

However, the issue of auditing farms is potentially incredibly contentious for growers. While there have been strong indications of support from the growers involved in the various workshops held it must be remembered that these are the keen, early adopters of BMP, and resistance to auditing, for what ever reason:

- Fear of opening themselves to prosecution

- Unwillingness to allow 'outsiders' on to the farm to be critical
- Fear that a certification system will penalise non-conformers

is still a valid concern that needs to be addressed.

It has been claimed that the Grains industry's attempts to introduce a QA system for food safety reasons have been delayed at least 18 months because of the way the issue was introduced to that industry—as an edict from above, with little consultation.

Therefore it is critical that there is a planned consultative process on the issue of auditing is instigated.

Pilot program to investigate auditing

The Cotton Research & Development Corporation Board has commissioned the investigation of appropriate and feasible independent compliance checks of BMP for growers. Subsequently the BMP Management Group's Independent Assessment Committee has explored various models that may be suitable for the cotton industry.

The objectives set by the Independent Assessment Committee were:

- To investigate the auditing and certification requirements with the view of certifying growers to the ISO 14000 series of standards, or compatible industry standard
- Upon investigation, to recommend an certification framework for the industry

Secondary aims of the committee were that the system:

- minimise costs to the growers; and
- Implementation and certification of growers can be closely monitored and controlled by the industry.

The intention of the committee is to pilot this certification framework this season, with a view to phasing the framework into the industry at large the following season following the necessary consultation (which needs to be widespread). There are numerous issues associated with the development of an auditing/ certification system, and the pilot study aims to identify as many of these as possible for further discussion and refinement.

Certification for growers

The general scheme is based on a staged or tiered approach, with each stage representing more sophisticated document control requirements, as well as increasing levels of independence in the person conducting the compliance check. The three stages are first party (self-assessment), second party (industry level) and third party (external).

There are several questions and issues pertinent to the certification model for growers. These are:

- Who conducts the audit?
- How is the audit conducted?
- Who pays for the audit (and the associated costs)?
- What reward is received for successful completion?

From a researcher perspective, how adherence to 'technical' best practices (particularly complex areas) is audited is also an issue—who is qualified to perform such an audit?

ISO 14000.

The preferred model is ISO 14000. It is an international standard, agreed to by the Federal Government, which has impeccable credibility. For example, under the proposed National Classification Framework, developed by Supermarket to Asia, ISO 14000 was classified at the top level 5; ISO 9000 rated level 3, while SQF 2000 rated level 2.

There are however some challenges:
An individual ISO 14000 document would cost an individual farm a minimum of $25,000, and potentially up to $70,000 to develop—the challenge is to create a generic document that any cotton farmer could use to satisfy the requirements of the standard. Luckily there is already a cotton farm certified to ISO 14000! By developing a 'template' document, and the process to demonstrate how it is maintained and updated, the need for every farm to be audited annually can be avoided, and the auditing frequency stretched out to a three-year cycle, dramatically reducing costs.

Logistics
As indicated above, the auditing system would need to have virtual industry wide coverage for it to be seen as credible. The system we are currently investigating allows for an internal audit every year, and an external audit (if desired) every 3 years (note that requirements for any system was that costs to growers be minimised, hence the 3 yearly audit when normally ISO14000 requires at least annual external audits).
Based on 1200 growers, this means that every year, 1200 internal and 400 external audits would be required!

The fees for external auditors run to about $1000 per day. No doubt the industry would be able to negotiate reduced fees, however, the resources required are still substantial, and need to be fully investigated. On the above figures, total costs could be as high as 1$Million per annum in auditing costs alone. Nor does this figure take into account the training and resource costs:

- for both growers and the industry people helping them complete the documentation required
- For the industry personnel to enable them to conduct the 2nd party audits.

It also assumes of course that there will be enough people to service such a requirement, and that all audits are successful.

These figures assume 100% industry involvement in an auditing program, and that figure is not going to be required immediately. However, the industry needs to make decisions about any move to an auditing system fully aware of the potential costs involved in a fully-fledged system before it commits itself.

Future Modules

The current timetable for the development of future modules for the Manual is as follows:

	First draft	Final draft
Pesticide storage and handling	March 99	June 99
OH&S	May 99	October 99
Second Edition/revised first edition	June 99	October 99
ISO 14000 compliant version	Dec 99	Mar 00
Dryland (cotton & grains)	Mar 00	June 00
Water management	?	?
Bush care	?	?

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Possible future directions for SOILpak

David McKenzie
PO Box 2171, Orange NSW 2800

Introduction

The latest version of SOILpak for the Australian cotton industry will help growers of irrigated and dryland cotton to increase their profitability. This will be achieved by improving the accuracy with which they assess and monitor their soil fertility, and by providing better soil management options. 'Best practice' soil management will also help cotton growers to minimise the environmental impact of their activities.

Published by NSW Agriculture, and entitled 'SOILpak for Cotton Growers, Third Edition', the manual will help cotton growers and their advisers to deal with such challenges as:

- soil assessment when interpreting yield maps,
- on-going monitoring of soil condition (perhaps as part of an 'ISO' accreditation scheme),
- prevention of salinity and erosion problems,
- maximising water use efficiency,
- soil survey prior to the development or redevelopment of cotton fields.

The manual also contains detailed information about the measurement and management of soil compaction. It is an improved version of material supplied in the previous edition of SOILpak by Daniells and Larsen (1991). The evolution of SOILpak has been described by Daniells *et al.* (1996). An outline of the contents of the new SOILpak manual was presented at the 1998 Cotton Conference (McKenzie 1998).

The main messages in SOILpak are:
.Measure soil condition, and relate it to the features of an 'ideal' soil for cotton;
.Aim to overcome soil limitations to crop growth, where economically viable;
.Once soil conditions have been optimised, avoid damage.

SOILpak is inter-linked with the NUTRIpak and MACHINEpak manuals, and with the 'Best Management Practice' documents for pesticide use. It has a loose-leaf format, and is accompanied by a portable pocket version of the information required for soil examination in the field.

Most of the revisions to SOILpak are based upon soil research and extension activities funded by the Cotton Research & Development Corporation and the Cooperative Research Centre for Sustainable Cotton Production. Interviews with leading cotton growers also provided valuable information.

Extension staff from the major cotton producing districts in eastern Australia were introduced to a draft of the latest edition of SOILpak at a 'Train the Trainers' course at Narrabri in October 1997 (supervised by McGarry & McKenzie). This was followed by 'hands-on' soil management training courses for cotton consultants, agronomists and leading growers at Warren and Moree in November 1997, at Emerald in June 1998 and at Dalby in July 1998. Another four courses will be held soon after cotton harvest in 1999. The courses have confirmed that the most effective way of extending the contents of SOILpak is via the use of soil inspection pits on commercial cotton farms.

The SOILpak initiative is closely linked to activities of the Technology Resource Centre at the Australian Cotton Research Institute, Narrabri. Their staff intend to make the SOILpak manual available to users via the ACRI Web site, as well as supplying 'hard copies' when necessary. This arrangement will make it easier for users of SOILpak to be supplied with updates to chapters. For those clients without access to the Internet, revisions will also be available from district advisory staff. This regular updating process means that the SOILpak manual will continue to be a 'Best Management Practice' document.

Below are some issues that are relevant to the future use and refinement of SOILpak for cotton growers.

Future challenges and opportunities

For SOILpak to reach its potential, the following questions need to be addressed:

- The linkage between SOILpak and the 'Best Management Practices' manual for pesticide use needs to be defined more clearly by cotton industry leaders.
- An accreditation system may be required for advisers who use the measurement and interpretation procedures in SOILpak.
- More case studies about soil management should be documented and reported in publications such as 'The Australian Cottongrower' ñ this will help to promote the SOILpak concept. However, a coordinator is needed to direct this task.

It is rumoured that in the near future, irrigators may have to submit 'Land and Water Management Plans' when buying, transferring or renewing water licences in Queensland and New South Wales. A major aim of these plans is to encourage irrigators to use their water more efficiently. Procedures for carrying out the necessary soil survey work are described in SOILpak, although further research will be needed to refine them. Water is the most limiting of natural resources used by cotton growers, but it is likely to become even scarcer as competition from other rural industries becomes greater, eg. viticulture which, it is claimed, can generate more jobs per megalitre of water than irrigated cotton production. Wine industry leaders strongly emphasise the need for detailed soil assessment prior to the development or re-development of land for irrigation. This allows irrigation systems in vineyards to be well matched with soil hydraulic properties, so water tends to used very efficiently.

The introduction of 'Carbon Credit' schemes for the control of global warming may prove to be beneficial for cotton growers, who appear to be in a good position to accumulate carbon in their soil. General principles about this topic are presented in SOILpak, but much remains to be learnt about the management of soil organic matter under cotton.

Other research topics that deserve more attention include:

- To minimise waterlogging, a system is needed for the prediction of irrigation management and bed architecture from field measurements of soil structure.
- The ideal topsoil and subsoil structure for water conservation requires definition.
- A system is needed for the objective assessment of soil structure after tillage for pupae control.
- We still have much to learn about how to manage soil structural stability.

Finally, it is recommended that a technical committee be appointed to ensure that the regular updating of the SOILpak manual remains at a high standard.

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NUTRIpak - Progress Report

Maris Rea
CRC for Sustainable Cotton Production

Progress on NUTRIpak (the print companion to NutriLOGIC) has been slower than expected following a year crammed with rigid deadlines for the Fifth Year Review, Cotton Conferences (National and International) Proposals for a new CRC and production of the Annual Report. However we do have a bright, professionally designed folder, a fair amount of information has been amassed and, despite the jerky start to the cotton season, we hope to pin down researchers at ACRI so that copy can be finalised.

At present we have headings for:

*** Feeding the Crop**	dealing with all aspects of nutrition, from assessing requirements to nutrient uptake, remobilisation in plant and nutrient removal
*** Nutrients (Macro and micro)**	Information on Major and minor nutrients
***Nutrient Interactions**	more info needed here
***Soil testing**	How to test, where to send soil for analysis, and how to interpret reports
***Tissue testing**	(as for soil testing)
***Cropping Systems**	Rotations, Stubble management, VAM etc
*** Fertiliser Application**	What, when & rates for various fertilisers, etc
*** Future developments**	A look at future developments

What we need now is YOUR professional input and expertise to ensure the final publication meets the **practical needs** of the cotton farming community. Your opinions - suggestions - on how the material should be presented are requested.

Workshop sessions with all researchers involved in crop nutrition are planned for this month (date to be advised) when deadlines will be set for a mid-year publication of NUTRIpak.

Evaluation of NutriLOGIC

Sandra Deutscher
CRC for sustainable Cotton production, CSIRO Plant Industry, Narrabri

About NutriLOGIC

An important factor to enable a profitable and sustainable cropping system is good soil condition. In many cotton growing regions soil nutrition is one of the main ingredients crucial to produce a good cotton crop. It is therefore essential to keep the balance between the nutrients coming in and out of the system. Yearly soil tests and in-crop petiole tests can provide the information to do so, provided they are interpreted correctly by a trained agronomist or by using NutriLOGIC.

NutriLOGIC is a user-friendly computerised support tool for Nitrogen fertiliser management. NutriLOGIC is a component of CottonLOGIC, a decision support system developed by the CSIRO and CRC for Sustainable Cotton Production to provide the cotton industry with access to the latest research available.

There are two basic components in NutriLOGIC;
- an assessment of the soil nitrate levels for fields,
- the assessment of the petiole nitrate levels in the corton crop.

This system can be employed to inform the user of whether a fertiliser is needed for a given field or cotton crop, and if so give an estimation of the rate required for optimum yield.

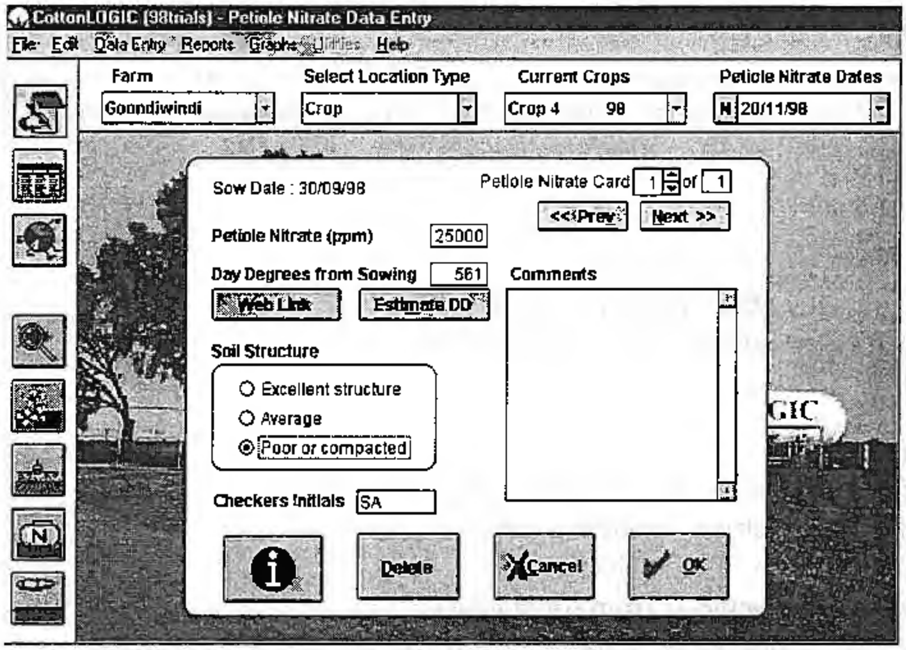
The soil nitrate analysis applies to **fields only**, giving a quick interpretation of the Nitrate value from your soil test. The results are derived from three parameters which must be entered into the data entry screen;

1. Soil Nitrate (ppm) (from a specialist laboratory or your own device)
2. Soil Structure (a qualitative analysis of your soil– refer to Soilpak)
3. Regional data (recognised through the CottonLOGIC farm set-up)

The petiole tests carried out on the cotton crops throughout the season relies on four parameters;

1. Petiole Nitrate (ppm) (from a specialist laboratory or your own device)
2. Soil Structure (a qualitative analysis of your soil – refer to Soilpak)
3. Day Degree (which is either estimated through NutriLOGIC or can be assessed from the CRC web site **http://cotton.pi.csiro.au/tools**)
4. Regional data (recognised through the CottonLOGIC farm set-up)

Figure 1 NutriLOGIC data entry screen for a petiole test.



CottonLOGIC (98trials) - Petiole Nitrate Data Entry

Farm: Goondiwindi

Select Location Type: Crop

Current Crops: Crop 4 98

Petiole Nitrate Dates: N 20/11/98

Sow Date : 30/09/98

Petiole Nitrate Card 1 of 1

Petiole Nitrate (ppm) 25000

Day Degrees from Sowing 561

Comments

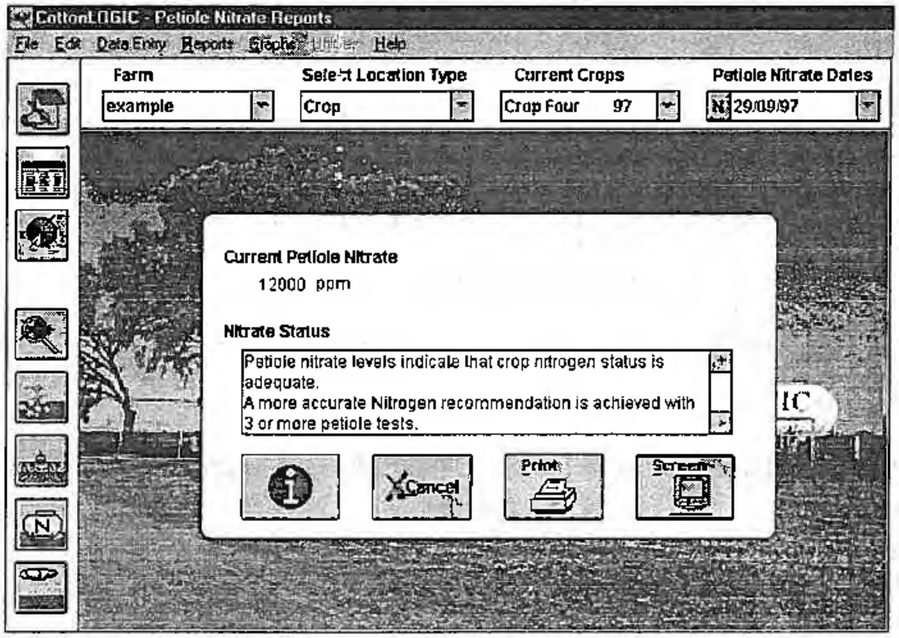
Soil Structure

○ Excellent structure
○ Average
● Poor or compacted

Checkers Initials SA

The reports from NutriLOGIC give the Nitrate status and an estimated amount of Nitrogen fertiliser required per hectare to achieve maximum yield in the current region.

Figure 2 Petiole Nitrate Screen Report



CottonLOGIC - Petiole Nitrate Reports

Farm: example

Select Location Type: Crop

Current Crops: Crop Four 97

Petiole Nitrate Dates: N 29/09/97

Current Petiole Nitrate
12000 ppm

Nitrate Status

Petiole nitrate levels indicate that crop nitrogen status is adequate.
A more accurate Nitrogen recommendation is achieved with 3 or more petiole tests.

NutriLOGIC Trials

Objective

To continue the development of NutriLOGIC, by validating the Nitrogen fertiliser recommendations through an examination of Nitrogen responses in a range of cotton growing regions.

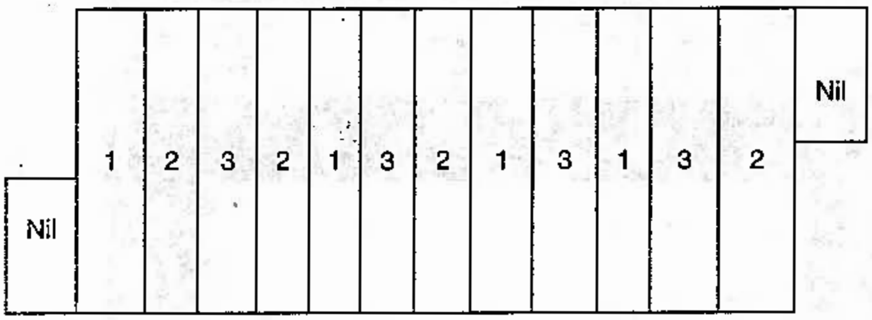
Treatments

1. NutriLOGIC Recommendation
2. NutriLOGIC Recommendation – 40 units N
3. NutriLOGIC Recommendation + 40 units N
4. Nil strips.

Methods

- Field selection can vary ie. Either back to back or rotation.
- Identification of soil characteristic/properties
- Soil test carried out in July (to 30cm).
- Apply appropriate treatments from soil analysis
- Petiole test carried out between 600 – 750 DD.(taking note of climatic data eg. temperatures, cloudy periods, rain, etc.) and also 10 days after the first test.
  - Apply appropriate treatments from petiole analysis.
- Yield estimates from hand picks and/or plots weighed with picker scales.

Experimental design (preferably situated in the middle of a field)



Trial Up-date

Seven trial sites have been selected throughout the cotton growing regions;

1. Myall Vale	2. Narromine
3. Boggabri	4. Moree
5. Mungindi	6. Goondiwindi
7. Theodore	

Having a very wet start to this season, six out of the seven sites delayed their Nitrogen applications until after planting. Five out of the seven sites have carried out post-plant side-dressing and have completed the treatment applications. This season is the first year of NutriLOGIC trials, therefore results will not be available until after the cotton harvest.

Adoption of precision agricultural practices

Alex. M^{c}Bratney
CRC for Sustainable Cotton Production
Email:- *Alex.McBratney@acss.usyd.edu.au*

The Mid-Western states of the US are the birthplace and heartland of Precision Ag. Two recent surveys give us some pointers to the pattern of adoption of PA practices. To date there have been no surveys on adoption rates in the cotton industry.

The two surveys were carried out by the Department of Agricultural and Consumer Economics, University of Illinois (http://w3.aces.uiuc.edu/ACE) and the St Louis, Missouri-based magazine PRECISIONAG ILLUSTRATED (http://www.precisionag.com).

Table 1. The number of respondents to two recent adoption surveys of Precision Ag among US Mid-West grain growers

	University ofIllinois (End of '96)	*PRECISIONAG ILLUSTRATED (April '98)*	*Total*
Number of growers	**754**	**306**	**1060**

The PRECISIONAG ILLUSTRATED survey, carried out by Bob Wanzel, published in the April/May 1998 issue, wrote to 306 farmers with at least 240 hectares of corn and soybeans in Illinois, Indiana, Iowa, Minnesota, Nebraska & Ohio. The average respondent was farming about 900 hectares split 60:40 between corn and soybeans.

The UNIVERSITY OF ILLINOIS survey, authored by Madhu Khanna, Onesime Epouhe and Robert Hornbaker was more comprehensive in number and type of grower but from a smaller geographic spread. They carried out a mail survey of 754 'cash grain' farmers located in Iowa, Illinois, Indiana and Wisconsin in 1997. There was no constraint on farm size.

The basis for the two surveys are somewhat different. Both surveys asked fairly similar questions about the use of PA practices. With some judicious interpretation it is possible to combine the results of the two surveys. I have divided the results into two major headings:- *information gathering* and *information use.* The major kinds of within-paddock *information gathering* investigated were –

- *Yield mapping,* this includes yield monitoring of grains, associated ground positioning and production of yield maps.
- *GPS,* ground positioning using global positioning satellite technology for crop scouting and making maps of field boundaries. The surveys were not clear on the overlap with positioning for making yield maps or soil sampling. No mention was made of the proportion with differential correction or of those used for machinery guidance.
- *Soil mapping*, which largely means grid soil sampling of fields on 90m grids for a range of nutrients and subsequent mapping of these nutrients. No details on the type of mapping was given. Other possible approaches to obtaining this information wasn't mentioned.

The major kinds of within-paddock *information use* investigated were all variable-rate technologies:–

- *Variable-rate fertiliser,* both the mix and the amount can be varied across the field. Most farmers surveyed were varying the amount of a single fertiliser.

- *Variable-rate herbicide*, generally only the dose rate is varied across the field according to or potential weed pressure.
- *Variable-rate seeding*, both the seeding rate and the mix of cultivars can be varied. Information on the practice of mixing cultivars is still very sketchy.

The technology generally exists to carry out these practices but the information needed or decision-support may be lacking. With 1060 farmers surveyed (Table 1) the following results appear (Table 2)

Table 2. A combined summary of the two surveys on PA adoption

Information Type	Operation	UNI. OF ILLINOIS (End '96) %	PRECISIONAG ILLUSTRATED (April '98) %	Weighted Average %	Estimated 50% Adoption (years)	Estimated 90% Adoption (years)	Estimated 90% Adoption. January
Information gathering	Yield Mapping	10	38	18	3.7	6.1	2002
	GPS	12	42	21	4.1	6.9	2003
	Soil Mapping	13	40	21	4.3	7.5	2003/4
Average		*12*	*40*	*20*	*4.0*	*6.8*	*2003*
Information using	Variable-rate Fertilizer	12	21	15	4.2	7.0	2003
	Variable-rate Pesticide	3	5	4	6.2	9.2	2005
	Variable-rate Planting	2	5	3	6.3	9.0	2005
Average		*6*	*10*	*7*	*5.6*	*8.4*	*2004*
Overall average		**9**	**25**	**14**	**4.8**	**7.6**	**2004**

It is clear that adoption rates of information gathering procedures (20%) is ahead of information using procedures (7%). In addition to collating the published results, adoption rates were modelled by the classical S-shaped curve (see Figure 1) using the percentages from the Illinois survey as the rate after one-year. The weighted average figure in Table 2 is the rate after the time given in the PRECISIONAG ILLUSTRATED survey. This was generally 2.2 years. The results also shown in Table 2, which can only be indicative because of the small amount of base data, seem reasonable. Provided economic conditions remain the same it would seem that 90% of Mid-West grain farmers, at least the kind interviewed in these surveys, will probably have adopted the information-gathering methods of PA by January 2003 and the information-using methods of site-specific management using variable-rate technologies by January 2004. The transfer of adoption of information gathering to information use is dependent on good decision-support models however. If these don't become available then I expect the adoption of site-specific management to be slowed down. Neither survey really addressed this issue. Future surveys need to address the question of decision support head on.

Adoption patterns are likely to be a bit different in Australia because yield monitoring and not grid soil sampling is the initial driving force. I also sense the surveys were based on slightly larger more progressive farmers – so adoption rates for Australian grain farmers across the board might be smaller, but the impact in Australia will be significant. I do expect the Australian cotton industry, well-known for its acceptance of new technologies, to show adoption rates as large as the ones shown here. As a guide for Australian cotton industry I would add 2 to 3 years to the expected adoption dates in Table 2 however. For cotton this schedule may be very similar to developments in the US.

And for those who are wondering whether any of this is worthwhile, in the PRECISIONAG ILLUSTRATED survey, 77% reported a return on investment of break-even (36%) or better (41%).

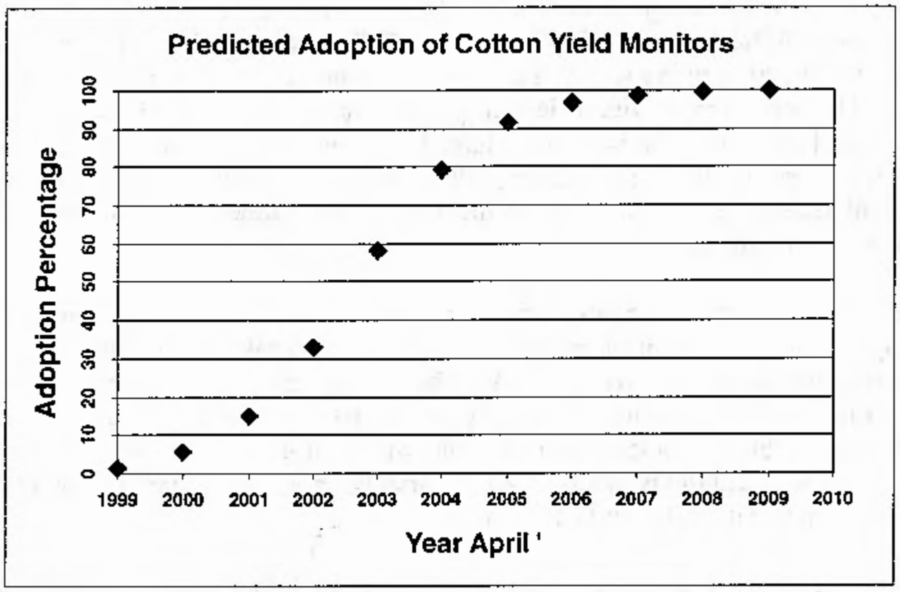


Fig. 1 A likely adoption curve for cotton-yield mapping in Australia.

The Cotton Research and Development Corporation and CRC for Sustainable Cotton Production are currently funding two projects aimed at aiding the adoption of Precision Agricultural techniques to the Australian Cotton Industry. These projects, one on information gathering and the other on information using, will ensure that the cotton industry will be in a position to benefit from this more information intensive approach to farming.

Support for writing this article was kindly provided by the CRC for Sustainable Cotton Production, the Cotton Research & Development Corporation and the University of Sydney.

Managing yield variability in Australian cotton fields

Craig Stewart
CRC for Sustainable Cotton Production, The University of Sydney.
Email: c.stewart@agec.usyd.edu.au

Following on from the preliminary positive results highlighting within-field yield variability in Australian cotton districts, the CRDC (project US44C) and CRCSCP (project 5.2.2) have initiated a second study commenced for the 98/99 growing season aimed at developing a possible information using approach for this variability. The collection of within-field crop data emphasising localised patterns in crop growth and soil characteristics, has created the need for establishing new management strategies in closer alignment with natural field diversity. Farmers investing lots of time and money into collecting and analysing site-specific data will receive no profit either financially or environmentally from their investment if this information is not well utilised.

A management approach that recognises the variability which exists within agricultural fields, is the variable-rate application (VRA) of crop inputs such as seed, fertiliser and pesticides. Two methods for implementing this approach currently exist. Map-based variable-rate application systems, which adjust inputs using a differentially corrected positioning system based on an electronic map of field properties, and sensor-based variable-rate application systems which utilise data from real-time sensors to alter inputs, on-the-go. This technology can be used to variably apply important crop production inputs in the form of seeds, dry chemicals and liquid chemicals.

For seeding this is achieved by either adjusting the speed of the seed metering drive on planters or disconnecting the planter's seed metering systems on row-crop planters and using another drive mechanism to vary seeding rate on-the-go. Variable applicators for dry chemical products such as granular fertilisers or pesticides, come in the form of either spinner spreaders or pneumatic applicators. Spinner spreaders are normally used for adjusting one input via spinning discs located at the rear of the applicator, while pneumatic spreaders use metering controls on centrally located bins to vary single or multiple products. There are a number of methods available for applying liquid chemicals variably. These commonly include changing the system operating pressure for fine adjustments and altering travel speed or nozzle size for coarse adjustments. When variably applying anhydrous ammonia, a regulator valve is required to control the flow as vapour pressure varies with the amount and concentration of the ammonia in the tank and with temperature. As measuring flow rates of ammonia gas is difficult, a thermal transfer unit is used to convert vapour to liquid for metering and application.

With the Australian Cotton Industry reliant on the extensive use of both fertilisers and agrochemicals to achieve high yields, customising application rates will bring about financial benefits through more efficient input application while simultaneously addressing concerns associated with environmental contamination by the industry. While the technology to apply variable-rate inputs already exists, what is required is the development of a methodology to divide a field into a series of 'management zones' that reflect the differences in yield potential. This second study aimed at establishing this for fertiliser application, will involve, firstly, quantifying the degree of variability of essential soil properties within cotton fields, and secondly, using these results to test various methods of differentially applying fertiliser according to the localised requirement.
Issues to be addressed in this project include:

1. the cost, time and complexity of variable-rate fertiliser application
2. advantages of a proactive (anticipating total before sowing) versus a reactive (response to crop uptake) approach to fertiliser application
3. the merit of increasing yield versus reducing fertiliser usage in cotton farming systems

Much of the research to date into determining variable-rate fertiliser has been conducted on grain cropping systems, although the same principles will apply for managing cotton. In broad terms, the aim is to subdivide the field into a number of homogeneous 'zones', each encompassing a dominant characteristic that influences crop growth, and applying a different rate of fertiliser in each zone and monitoring the yield response. The basis for this calculation will be the yield potential or expected yield of each 'zone' determined by a function of the water balance, soil fertility and the climate.

In this project, advances in mobile electromagnetic (EM) mapping, yield mapping and remote sensing are being employed to determine each zone. The information gathered from these techniques is being integrated, to generate 'Equifertiles', representing areas that equate in their potential productivity. This allows directed soil sampling of each equifertile to be carried out to determine available soil nutrients important for cotton growth. Deficiencies or excesses of the nutrients can be identified. Fertiliser rates can then be adjusted accordingly for each 'zone', using the recommendations of NutriLOGIC, a decision-support tool developed by the CRCSCP, CRDC and CSIRO released recently as part of CottonLOGIC. The success of this approach to cotton management will be measured by either the ability to increase yield, profitably within a field, or reduce environmental impact by achieving similar yields for lower fertiliser application rates. Techniques for applying variable-rate fertiliser formulated from this research will form part of a decision-support system that will permit farmers to fully utilise the benefits from site-specific information gathering.

Support for this research is kindly being provided by the Cotton Research & Development Corporation, CRC for Sustainable Cotton Production and the University of Sydney.

Collecting high resolution cotton yield information

Broughton Boydell
CRC for Sustainable Cotton Production

CRDC project US36c
CRC Project 5.2.1

Spatial variability and temporal stability as measures of potential manageability

The recent experience of North American grain growers indicates that widespread adoption of precision agriculture techniques did not occur until a combine mounted yield monitor was available and proven to be relatively accurate. There are a number of reasons for this "key component" being the limiting step behind adoption rates however the most obvious is that until you absolutely know that you have variability in a field, and can quantify this variability to a dollar figure, you are unlikely to pursue a more complicated management path. Once the variability is documented however and proven to be significant, economic pressures take over and force attention to be focused on the obvious problems associated with putting single rate applications across whole fields where the yield and thus agronomic requirements vary dramatically.

Current developments with cotton-picker mounted yield monitors:

To date in Australia there have been no readily available cotton picker mounted yield monitors. Although some systems (Zycom (USA) and Micrro-trak (USA)) have been available on a limited basis, these have generally been seen as experimental. During the 1998 cotton pick in Australia it appears that four companies were performing developmental trials on cotton picker yield monitors. These include the likes of the major North American manufacturers CaseCorp and John Deere as well as the successful grain yield monitoring company AgLeader(USA) and the Perth based agricultural electronics company Farmscan. In addition to these developmental activities the already available Zycom and Micro-trak yield monitors were trialed by some farmers. While the widespread availability of reliable yield monitors is still possibly a year away, this accelerated development activity means that more Australian cotton farmers will have the opportunity to collect quantitative information on cotton yield both within and between fields in the near future. In an attempt to anticipate the obvious question " I have variability in yield in my fields, what can I do with this knowledge?" the Cooperative Research Centre for Sustainable Cotton production (CRCSCP) with Cotton Research and Development Corporation (CRDC) funding initiated investigations into the spatial variability if cotton yield within and between Australian Cotton fields in 1997. Using picker mounted yield monitors maps were collected in 1997 and 1998. Detailed results of these investigations have been reported other documents (Boydell, McBratney and Whelan, Cotton Conference Proceedings 1998) however on average it appears that there is indeed significant variability in cotton yield within fields with yield likely to vary by as much as 2 bales per hectare over 150 meters.

Using yield data to help identify management zones

While the recently collected Australian cotton yield variability results apparently validates the "potential" to increase management efficiency through management at a sub-field level, it does little to answer management questions "what to do". One management approach using this yield data gaining popularity amongst early PA adopters in North America and Europe is based on the identification of "zones" within a field or across a farm requiring similar agronomic inputs. The number of zones is related to the degree and magnitude of yield variability and probable agronomic requirements. Subsequently the management at this zone level would result in more accurate input application. In general it has been proposed that dense data such as yield data should be used to develop these zones however to accurately develop these they should use a series of years of data in order to ensure that zones are indeed similar from year to year and suited to management over years.

A picker mounted yield monitor equipped with GPS to allow yield mapping appears to be the only way to quantify yield variability successfully on a very dense scale however, the process is destructive, and information unavailable for years past. Due to the variability in yield both within a field and between years, it is a common recommendation for grain growers pursuing a zone management approach in the northern hemisphere to collect yield maps over a sequence of years to ensure that the zones do indeed remain in the same place from year to year and also suggest similar relative management good year or bad. This sequence may then be used to establish the degree of predictability of yield at a point in a field and the possible delineation of "zones of similarity", which, may be developed into true "management zones" if some form of differential treatment may be taken to increase the effectiveness of management .

Farsite satellite yield estimates as a retrospective yield data source

In 1998 IAMA began to actively market "Farsite", a cotton "yield estimate map" as a means of collecting cotton yield data prior to picking. Although the exact means of deriving these yield estimates is proprietary, the basic method involves the collection of satellite images for cotton fields in January when a large part of the crops yield potential is already determined. Lush and healthy crop canopies reflect light differently to poor stands and water stressed or diseased crops. This difference in reflection is then combined with a proprietary calibration to generate a yield estimate on a 25m x 25m basis.

While current marketing initiatives focus on the use for "Farsite" to provide early current season yield estimates to be used in marketing decisions, the availability of archived satellite imagery means that there is potential to generate yield estimate maps for seasons past. As a first stage to the investigation of Farsite imagery as a source of information upon which to base delineation of management zones, 11 years of consecutive yield data were collected for three fields on Colly farms central. While this investigation has only recently begun, preliminary analysis indicates that this data may be used to identify regions of similar relative production for a series of years. Research continues into a number of factors relating to "Farsite imagery including the reliability of individual yield estimates and the number of years that would be typically required to generate a useful and reliable indication on the stability of management zones over time. Added confidence in Farsite estimates may be gained by "validating or ground truthing" the farsite yield estimates with high quality picker-mounted yield data for years when both layers of information are available.

Bare soil aerial photography as an indicator of soil properties:

The manageability of spatial variability is based on a number of factors however the predictability of the yield at a point in the field and the identification of a management action that may be implemented to capitalize in this information are the major areas of interest to farmers. While the yield at a point is the ultimate measure of gross return, the soil at a point with its ability to supply the crop with moisture and nutrients is a major yield influencing factor. Subsequently, an additional approach to the investigation of yield variability with a particular focus on those factors which may exhibit strong influence over the years would be soil type mapping. Traditionally soil is characterized by collecting a number of soil cores and mapped by interpolating (averaging) values between discrete and sparse (due to the cost) samples. In 1998 a very simple approach to creating zones of similar soil types (and potentially agronomic requirements) was investigated based on the surface soil colour captured on an aerial photograph. In this investigation, regions of similar soil colour within a field were delineated and sampled to determine their similarity in terms of soil physical and chemical properties. Preliminary results are encouraging with the method being successful at identifying regions where the physical characteristics (sand, silt, clay) were similar within zones and significantly different to the adjoining zones. The obvious merit in this approach is that it may be used to augment or direct the rather expensive soil sampling previously required to sample soil type and thus use less samples to generate a more accurate map of soil management zones.

Towards the operational phase of Precision Agriculture

While the long term aim of a precision agriculture management scheme is to manage sites individually (perhaps as small as 1-row by 1m) based on requirements, the above mentioned methods of determining regions or zones represent a far more practical and achievable method of implementing a more locally efficient management scheme. This zone management approach then relies on available information collected at a cost-effective scale to begin the operational phase of precision agriculture. High density and relative reliable yield map data may be used with less dense soil sampling data and remotely sensed qualitative information may be carefully combined to confirm features of similar properties within a field and investigated to identify regional agronomic requirements.

Continuing CRDC project:

Currently I am developing techniques for making potential management zones for 11 consecutive year's Landsat TM data using the Farsite algorithm. As the project continues into the 1998/99 season I hope to continue to accomplish the following:

1. Determine the quality of high resolution yield estimates from picker yield monitors
2. Collect yield maps for 99 locations across all cotton growing areas of australia in an attempt to characterise probable yield variability and management opportunity in cotton growing areas.
3. Investigate yield similarity zones as a basis for development of "management zones".

Targeting weeds with precision agriculture - future possibilities

Grant Roberts
CRC for Sustainable Cotton Production, NSW Agriculture, Australian Cotton Research Institute, Narrabri, NSW

Background

As the precision agriculture concept moves forward with new ideas and equipment, the major focus is directed towards measuring yield, soil properties and improved fertiliser application. However, the concept of precision agriculture or site-specific farming is ideally suited to weed management row crops such as cotton. Technology already exists to implement more site targeted weed management strategies and the concept is compatible with the push to develop more integrated weed management approaches that rely less on large applications of broad-acre residual herbicides.

The reduction in price and improvement in accuracy of Global Positioning Systems (GPS) has meant that GPS can realistically be attached to conventional pieces of machinery. This combined with Differential GPS allows accuracy to 1m or less with this limit being reduced all the time. While GPS systems are not essential for precision weed control they will certainly be used for other forms of precision agriculture and their increased use on farm equipment will allow them to perform multiple functions.

This paper is designed to promote discussion and awareness of new techniques that will be available for weed management in cotton in the future utilising the precision agriculture concept.

Precision Methods of Weed Management

1. Field level

A useful management tool is the use of arial photography to make colour, infra red, thermal or other types of maps of fields. This technology is useful for large patches of weeds to be identified, monitored and helps in deciding areas to be controlled. Colly farms has utilised this technology to determine the amount of *Polymeria longifolia* in a field and repeated photography will be an indication if cultivation through these patches is contributing to its spread. A similar concept may be able to be achieved with satellite technology using a vegetative index based on energy reflectance vs energy absorbed. In both cases there needs to be a distinct measurable difference between the crop and weeds and the resolution of this technology limits it to broader management issues rather then individual weeds.

Often large patches of weeds (eg Nutgrass) in a field are known by the farm manager and their position is easily identified. Of more importance could be the use of GPS mapping systems where drivers of planting or ground spraying rigs utilise the GPS to record patches of smaller isolated patches manually. This then provides an opportunity for returning to the site at a later date and a permanent record of the weed.

Dealing with weed patchiness may be as simple as adding additional spray booms and tanks to existing ground application spray rigs. This would allow more than one herbicide to be sprayed out in the one pass of the field, selecting the appropriate herbicide or combination in known weed patches. This idea would seem suitable perhaps in post-emergent spraying where grass weeds were not continuous across the field or the use of pre-emeregants such as Zoliar on nutgrass patches.

There are at least five newly developed row guidance systems (using GPS, mechanical or video guidance) that can be fitted to tractors to improve their accuracy when row driving. Manufactures claim accuracy as high as 2cm from the centre line. This will allow greater accuracy in inter-row cultivation, directed spraying and shielded sprays with more confidence next to the plant line. As vision guidance systems improve to accuracy at the single plant level there will be even more opportunity to increase selective weed control using mechanical methods. In addition the use of vision guidance systems that can identify individual weed species open up unlimited possibilities of selecting different herbicides for different weeds and at multiple rates.

3. Individual Weed Level

It is rare that some grasses or other weeds are not throughout the entire field, often in very low numbers or isolated patches. The question is then one of 'thresholds' and at what level these weeds are economically damaging. We currently have limited knowledge in this area and the research required to answer the question is extremely complex, time consuming and expensive. Experiments to determine thresholds are usually complicated by mixed weed populations and multiple emergence of weeds throughout the growing season making results difficult to interpret. In addition there is the social issue of utilising herbicides as 'insurance policies' rather than actually targeting a known population. As such a large amount of herbicide is applied as a preventative 'insurance' strategy usually using herbicide rates for the highest expected population. Because these are often residual herbicides there is little indication if the herbicide was required or not.

Even so the weed detection sensors that have been developed at the Tamworth Crop Improvement Centre and by Reece Equipment would allow very accurate detection of single weeds. Targeting these weeds rather than broad-acre applications of herbicide has the ability to reduce herbicide inputs between 50-75% or greater depending on the weed density. These units are impressive and prototypes have already been demonstrated in commercial field crops with spray nozzles attached to the weed detecting sensors in hooded canopies. The technology could be easily adapted to any row crop but is particularly suited to cotton and would be rapidly taken up by the industry once it is has been tested at the commercial level.

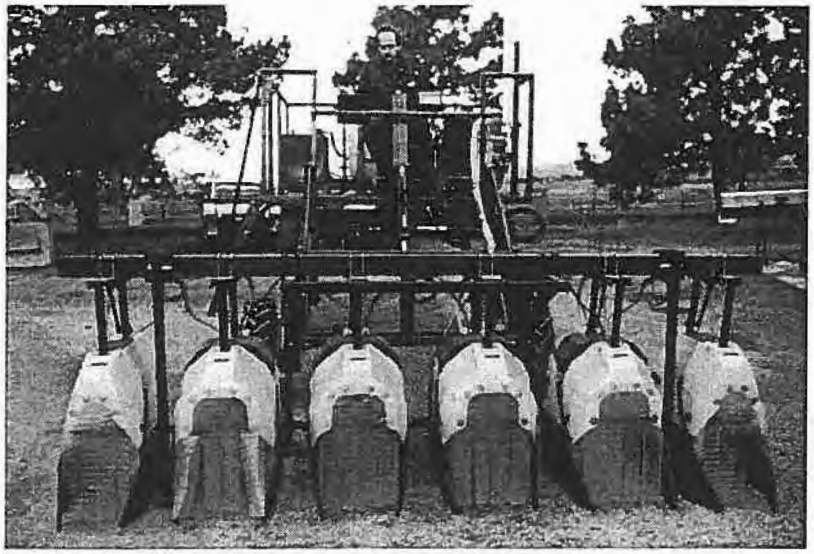
Conclusion

An issue that will continue to be raised in the future is the type and amount of herbicides that are being found in off target areas, particularly the riverine environments. This issue will not go away and the cotton industry will have to respond. One option is to limit the amount of herbicide applied to fields such that off target effects are minimised. In most options it is not practical to completely remove the herbicide from the field, but site specific targeting of the weed would be a improved option. Simply less herbicide means less potential for off target effects to occur.

Knowledge of the fields history and an estimation of what type and how many weeds are likely to be present in the field is an important first step in deciding if more precise weed control can be utilised. In fields which are suspected of having heavy weed pressure, an initial broadacre application of residual herbicides will be the most economic methods of control. Following up with site specific targeted methods of weed control is therefore only appropriate when a net benefit can be shown for the field (either reduced cost or a clear environmental gain).

In addition the economic returns from growing cotton can be highly rewarding and it would seem appropriate that the industry could afford to develop more complex, accurate and site specific methods of applying herbicides in order to protect its own future and minimise costs for the long term. The cost savings will come in reduced labour and a reduction in total herbicide use.

This high clearance research spraying rig has been developed by Warwick Felton and Paul Nash from NSW Agricultures Tamworth Crop Improvement Centre. The shielded canopies on the front enclose the weed detection sensors and associated spray nozzles.



Large boll loads are an important predisposing factor for premature senescence in cotton

Philip Wright
CRC Sustainable Cotton Production, NSW Agriculture, Narrabri

Abstract

Premature senescence has been occurring with increasing frequency in Australian cotton crops. The work reported in this paper was carried out to characterise the disorder and to make an examination of its causes. Plants with severe symptoms had 55-66% heavier total boll mass and their leaves had only about half the potassium and three quarters the phosphorus concentration of unaffected plants. Hence, affected plants had less leaf potassium and phosphorus to meet the demand of a bigger boll load.

Materials and Methods

Ten plants healthy plants were compared with ten affected plants, growing closely adjacent on two dates (29/1/98, 20/2/98) at a site near Warren, NSW (32° S, 148° E) in a crop of the variety Sicala V-2 in which severe symptoms had developed. The comparisons were made on a fully irrigated crop on 1 metre beds during late boll filling. The comparisons were made between paired plants with and without the symptoms, growing within 20 cm of each other. Leaf gas exchange measurements were made on the youngest fully expanded leaf using an infra-red gas analyser (Licor 6400) on clear, cloudless days between 11.00 am and 2.00 pm. Plant heights and boll numbers were recorded before each plant was partitioned into leaf, stem, tap root and bolls. Dry weights for these fractions were taken after drying at 80 °C for at least 48 hours. The plant parts were then analysed for nutrient concentrations using atomic absorption spectrophotometry (K, Mg, Ca, Na), near infra-red analysis (N) and inductively coupled plasma emission spectrometry (P, S, Mn, Fe, Zn, Al). Paired t-tests were used to compare affected and unaffected plants.

Results

Total dry weights of affected and unaffected plants were the same and they had the same dry mass of leaves (Table 1). In sampling set 1, affected plants had stem weights slightly less than those of healthy plants and lighter root weights but generally the most consistent difference was the heavier total boll mass (up to 68% greater) of severely affected plants. Trends for greater boll numbers and lesser heights were also detected (Table 1). Affected plants always had a greater average boll weights (30% and 9% for sampling sets 1, 2 respectively).

For all leaves in the canopy, K was reduced by more than 50% in severely affected plants while Na was increased by 27% and P was reduced by 25% (Table 2). Magnesium, S and N were all increased by about 20% and Al and Ca by between 10 and 16%. The concentrations of Fe, Mn or Zn were not significantly influenced.

Table 1. Plants with the symptoms of premature senescence had greater total boll weights and tended to have more bolls and to be shorter than unaffected plants

Plant part	Sampling set 1		Sampling set 2	
(g plant^{-1})	Absent	Severe	Absent	Severe
Leaf	18	16	16	18
Stem	16	13 †	17	17
Tap root	4	3 *	7	6
Boll	26	41 ***	41	68 *
Total	64	72	80	108
Boll number (# plant^{-1})	8	9	9	11 *
Height (cm)	-	-	80	75 †

† P<0.1, * P<0.5, ** P<0.01, *** P<0.001

Table 2. Potassium was the element that was most reduced in affected leaf canopies compared to unaffected plants. The percentage increase or reduction of elemental concentration averaged for sampling sets 1 and 2 is presented in the final column.

Element	Sampling set 1		Sampling set 2		Change
	Absent	Severe	Absent	Severe	(%)
K (%)	0.70	0.34 ***	0.85	0.40 ***	-52
Na (%)	0.42	0.49 *	0.38	0.52 ***	27
P (%)	0.27	0.21 ***	0.25	0.18 ***	-25
Mg (%)	1.04	1.16 *	0.70	0.94 ***	23
S (%)	1.06	1.21 *	1.01	1.29 **	21
N (%)	2.96	3.22	2.40	3.15 **	20
Al (µg/g)	389.2	449.5 **	436.9	508.9 **	16
Ca (%)	4.51	5.10 ***	4.67	5.10 *	11
Fe (µg/g)	90.25	92.64	88.32	102.65	-
Mn (µg/g)	37.65	36.28	67.64	77.48	-
Zn (µg/g)	15.16	13.69	10.09	10.35	-

† $P<0.1$, * $P<0.05$, ** $P<0.01$, *** $P<0.001$

Discussion

Premature senescence appears to occur when high yielding cotton cultivars create a very high demand for potassium (and other nutrients) inducing a potassium based problem late in the season. My work shows that boll load is the most striking difference between plants with and without the symptoms. Affected plants also had lower concentrations of K (and P) in their leaves exacerbating the imbalance between supply and demand, having significantly less K and P to meet the needs of a greater boll load (Table 3).

Table 3. Leaf supply of potassium and phosphorus for boll production in plants without and with symptoms of premature senescence.

Element	Sampling set 1		Sampling set 2	
	Absent	Severe	Absent	Severe
K (mg K g boll^{-1})	5.39	1.34 **	3.84	1.06 ***
P (mg P g boll^{-1})	2.01	0.82 ***	1.13	0.47 **

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

While this work clearly indicates the importance of boll load in predisposing cotton crops to becoming affected by premature senescence, several questions remain to be answered. For example, the condition is not seen in the majority of high yielding crops in Australia, indicating that heavy boll loads do not constitute a direct cause of premature senescence but rather the chief predisposing factor; other factors must interact with the high boll loads for a crop to get the problem. Soil compaction, waterlogging and cool cloudy weather during boll filling are reputed to trigger premature senescence in high yielding crops. But supporting data have yet to be published. Presumably these events trigger the onset of premature senescence by diminishing the plant's capacity to take up potassium from the soil, consequently the plant is less able to maintain an adequate supply to both support a large boll load and maintain adequate foliar levels.

Using an understanding of soil and plant P processes to explain the variability in cotton response to phosphatic fertilisers

Chris Dorahy[1,2], Graeme Blair[1] and Ian Rochester[2]
CRC for Sustainable Cotton Production
[1]Division of Agronomy and Soil Science, University of New England, NSW 2350
[2]CSIRO Cotton Research Unit, PO Box 59, Narrabri, NSW 2390.

Introduction

The 1997/98 season was the first year of research in a project initiated by the CRC for Sustainable Cotton Production, UNE and CSIRO to determine the critical soil and plant phosphorus (P) levels for cotton. The analysis of such data will then be used to explain the variability in crop response to phosphatic fertilisers.

Details of this research are given in Dorahy *et al* (1998). Responses to P application were not observed at any site, even on those with available soil P levels as low as 6 parts per million (ppm) Colwell P. Inconsistent, relationships were observed between soil P, plant P and lint yield. Further analysis of the data revealed that the role cations play, particularly Calcium, in P nutrition could be important and may provide evidence to explain why responses did not occur on these sites.

The objective of this paper is to address some of the key issues facing this project by presenting the data collected in the first season as an attempt to explain why cotton response to P application was not observed. In addition, research currently being undertaken will also be discussed to suggest means of validating the initial findings, which may lead to better methods of determining the P requirements of Australian cotton.

Are the current soil P tests reliable?

The Colwell and Lactate soil tests are the most commonly used methods of determining available soil P in cotton. However, on the sites studied, no relationships were observed between soil P, lint yield and plant P (early and late season uptake). **(Fig 1)**

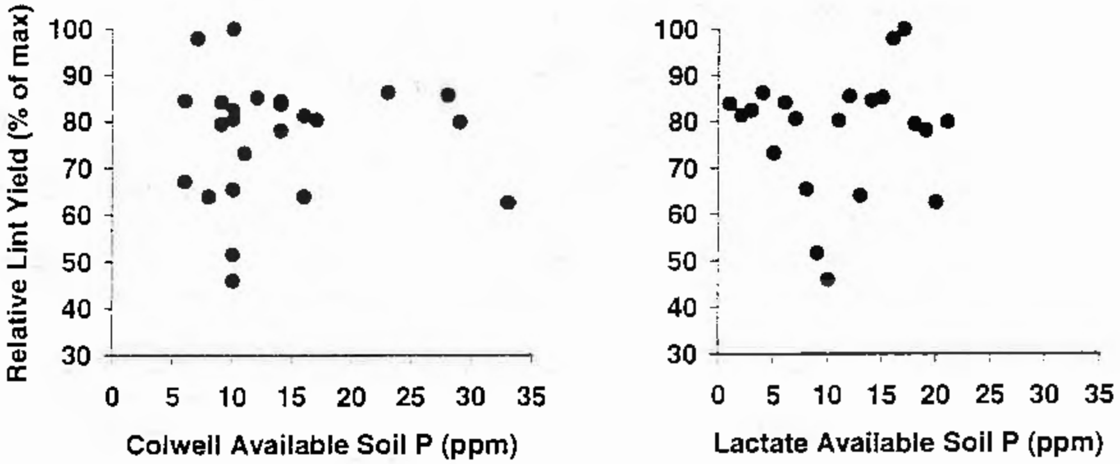


Fig 1. Colwell and Lactate soil available Phosphorus versus relative lint yield.

Lactate P. It is generally considered that cotton will respond to P application with soil P levels less than 5 - 10 ppm Colwell P. However, since no response was observed within this range, it can be suggested that the current tests are not reliable predictors of crop response. Alternatively, the critical soil limits could change from year to year. depending on season length and early season environmental conditions.

What is happening to applied P in the soil?

The phosphatic fertilisers used in these experiments were pre-plant banded applications, several months prior to sowing. However, it is likely that due to the alkaline nature of cotton soils (pH > 7.5) the applied P was quickly precipitated as insoluble calcium phosphate and rendered unavailable to plants. Evidence supporting this is presented in **Figure 2**, whereby, in a soil incubation experiment, less than 50 per cent of applied P was recovered by the Colwell P soil test. In addition, fertiliser recovery was lower on the more alkaline Warren soil. The precipitation reaction was rapid, indicating that equilibrium was established within 24 hours of application and may explain why responses to P application were not observed in the field.

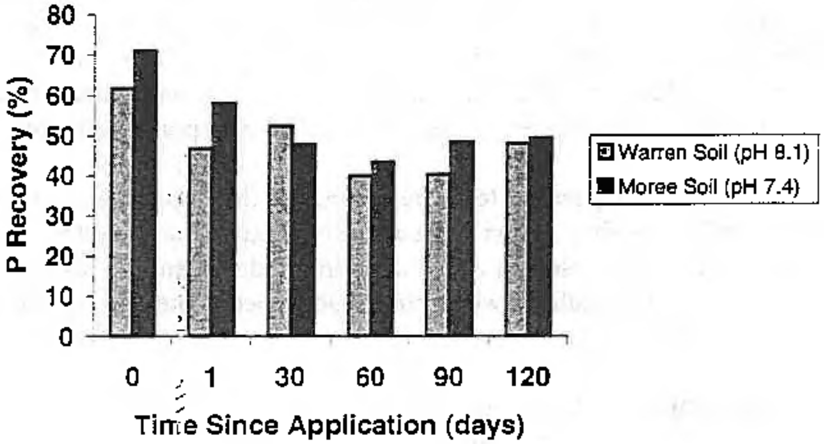


Fig 2. Phosphorus fertiliser (mono-calcium phosphate) recovery with time since application.

How does cotton meet its P requirements on low P soils?

The P requirement of cotton was adequately met by these soils, despite apparently low available soil P levels. This indicates that available soil P alone was not a good predictor of crop response. Soil pH and buffering capacity may provide some of the answers, since at alkaline pH, phosphorus is poorly soluble. This indicates that although the amount of P in solution may be low, in well buffered soils, there is still a large pool of labile P in the soil, which comes into solution when available P is depleted by growing roots. The Colwell P test has been criticised for not taking this (ie soil buffering capacity) into account. The Lactate test was developed to overcome this problem, but is considered unreliable for soils with Exchangeable Sodium Percentages (ESP) greater than 2 per cent (ie. most cotton soils).

Inherent soil fertility, as is generally indicated by Cation Exchange Capacity (CEC), is another factor which may govern P uptake by cotton and explain the lack of observed response. The soils used in these trials generally had high CEC, and uptake of these cations, especially Calcium, was highly correlated with both early and late season P uptake (**Fig 3**).

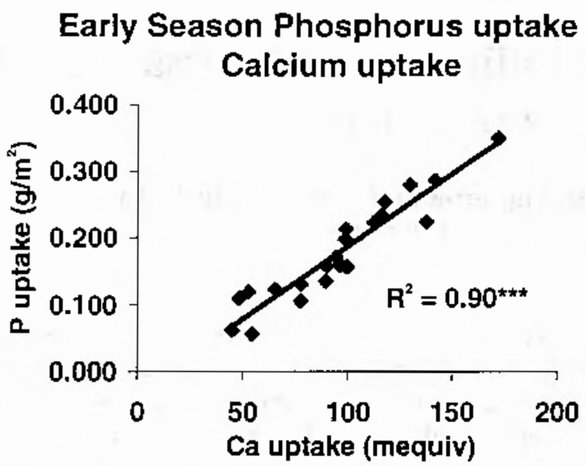


Fig 3. Early season P uptake versus calcium uptake.

This suggests a mechanism by which cotton may have access to the labile P pool in low available P soils. A high level of uptake of cations, especially Calcium, may cause an ionic imbalance within the plants. To compensate, H^+ ions are released from the roots which, solubilise precipitated P within the rhizosphere and enhance P ($H_2PO_4^-$) uptake thus increasing availability on apparently low P soils. This plant mechanism for acquiring P in soils of low P availability has been demonstrated for Corn, Rape and Buckwheat. Preliminary investigations have shown that the rhizosphere soil of cotton was 0.3 pH units lower than the bulk soil and lends support to this theory.

Summary

In summary, the results from the first season have demonstrated that on the sites investigated:

- the current soil tests were not good predictors of cotton response to P fertiliser application
- consideration of soil pH, CEC (especially Calcium), buffering capacity, organic matter and texture may provide more information on a soils ability to supply cotton with its P requirements, and thus improve the accuracy of P fertiliser recommendations
- P fertiliser recovery was low (less than 50 per cent)
- despite low available P, cotton plants were able to extract sufficient P from the soil to meet crop demands, due to seasonal conditions, well buffered soils or plant uptake mechanisms.

It is likely that all of these conclusions are interrelated and have formed the basis for research in the 1998/99 season so that they can be further validated. This research is encompassing a wider range of sites than were used in the first season and also involves some more detailed studies on P cycling, uptake, removal and recovery of P fertilisers using radioisotopes (^{32}P & ^{33}P). This will improve understanding of the phosphorus requirement of cotton, interpretation of soil and plant tests and lead to more efficient use of P fertilisers.

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Analysis of soil fertility indicators and versatility in the lower Namoi Valley

Inakwu Odeh, Eugenia Figueroa and Alex. B. McBratney
CRC for Sustainable Cotton Production, Dept. of Agric. Chem. & Soil Science, The University of Sydney

Introduction

Soil fertility is the most important soil quality indicator that needs to be measured and monitored. Through human history, decline in soil quality in general, and fertility in particular (due to negligence) had led to the demise of Great Empires. Recently, soil quality and its importance has received extensive attention due to environmental concerns. Soil quality has now formed the basis for the development of sustainable agriculture, and indeed it could be used for evaluating and judging the sustainability of soil management practices and land use systems (Wang and Gong, 1998).

Soil fertility can be defined as the capacity of the soil to supply nutrients and provide other physical and chemical conditions for optimal crop growth. Soil fertility, therefore, is a subset of soil quality, which defines the overall fertility and the soils capacity to sustain crop production, provide good conditions for soil organisms, imbibes and ameliorate environmental pollution and resist degradation (Larson and Pierce, 1994). The focus of this paper is on the analysis of chemical fertility and its versatility and distribution patterns in the lower Namoi Valley. In doing so, we emphasize the basic soil (chemical) fertility and its generality and are not specific to any particular crop. The principle is, however, relevant to the dominant crops grown in the area, namely: cotton, wheat and sorghum.

Table 1. Fertility scores for selected soil properties as indicators

Indicator	Range/Rules	Fertility	Score	Indicator	Range/Rules	Fertility	Score
pH	6.5≤pH≤7.5	optimal	27	ESP %	ESP≤6	optimal	27
	5.5<pH<6.5 or 7.5 <pH<8.5	possible	9		6<ESP≤14	possible	9
	pH<5.5 or pH>8.5	unlikely	3		ESP>14	unlikely	3
CEC mmol/kg (+)	CEC>250	optimal	27	EC dS/m	EC≤2	optimal	27
	120≤CEC≤250	possible	9		2<EC≤14	possible	9
	CEC<120	unlikely	3		EC>14	unlikely	3
Ca mmol/kg (+)	Ca>100	optimal	27	P mg/kg	P≥24	optimal	27
	50≤Ca≤100	possible	9		12<P<24	possible	9
	Ca<50	unlikely	3		P≤12	unlikely	3
Mg mmol/kg (+)	Mg>30	optimal	27	OM %	OM≥5	optimal	27
	10≤Mg≤30	possible	9		2<OM<5	possible	9
	Mg<10	unlikely	3		OM<2	unlikely	3
Na mmol/kg (+)	7<Na<20	optimal	27	N %	N>0.15	optimal	27
	7≤Na≤3	possible	9		0.05≤N≤0.15	possible	9
	Na<3 or Na>20	unlikely	3		N<0.05	unlikely	3
K mmol/kg (+)	K>20	optimal	27	C/N ratio	10≤C/N≤15	optimal	27
	3≤K≤20	possible	9		15<C/N<20	possible	9
	K<3	unlikely	3		C/N<10 or C/N>20	unlikely	3
Ca/Mg Ratio	4≤Ca/Mg≤6	optimal	27				
	1≤CaMg≤4	possible	9				
	Ca/Mg>6	unlikely	3				

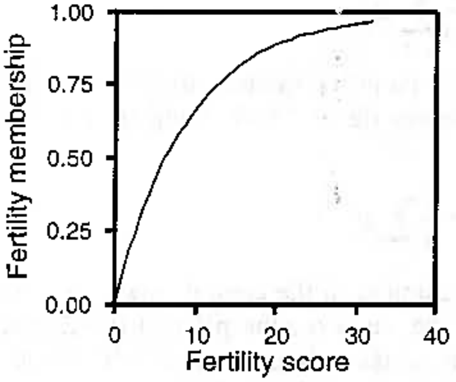
Materials and Methods

The study area is in the lower Namoi Valley near Wee Waa in northwestern NSW. The area is approximately 4200 km^2. The sampling design used was stratified simple random, with sites selected randomly from 14 strata. A total of 125 sites were visited and sampled at six depths: 0-10, 10-20, 30-40, 70-80, 120-130 and 190-200 cm, respectively. For the purpose of this analysis, only 0-10, 30-40 and 70-80 cm depths were used. Ten soil properties: soil organic matter (OM), pH, CEC, Ca, Mg, Na, K, P, N, EC, and the derivatives: ESP, Ca/Mg and C/N ratios were used for the analysis. These are all chemical fertility indicators. Each of the fertility indicators was analyzed based on a set of rules, for its optimal condition for crop growth. For example, rules for pH (in soil: water suspension) were: if $6.5 \leq \text{pH} \leq 7.5$ then the condition is optimal, if $5.5 < \text{pH} < 6.5$ or $7.5 < \text{pH} < 8.5$, then the condition is possible, and if $\text{pH} \leq 5.5$ or $\text{pH} \geq 8.5$ then the condition is unlikely. A set of all the rules used in the fertility scores and indicators are shown in Table 1. The rules for generating the fertility scores are by no means certain. They represent some ambiguities and vague terms used to describe the fertility scores. We therefore fitted a fuzzy membership function to the scores for each of the indicators, to gauge the degree of contribution to soil fertility by the indicators. The fertility membership grade, in each case is exponential function similar to the one used by Triantifilis and McBratney (1993):

$$\mu_I = e^{-0.109F_I}$$

where μ_I is the fertility membership grade of indicator I, F_I is the fertility score of the indicator I. Figure 1 illustrates the membership function in relation to the indicator scores. In this way, each of the indicators listed in Table 1 are transformed into membership grade of fertility. The fertility membership grade for each of the indicators for the three layers was mapped, using the geostatistical interpolation technique of kriging.

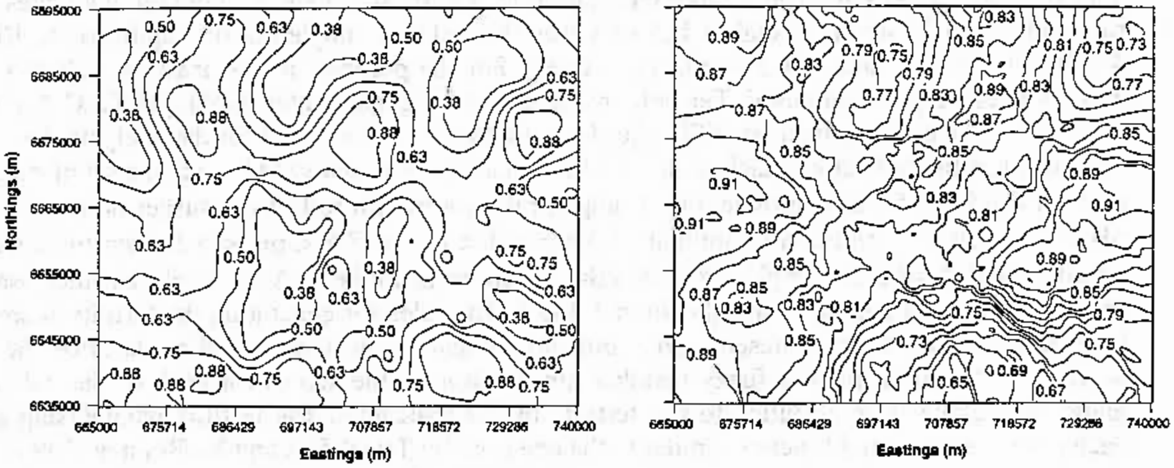
Figure 1. Membership function on the fertility score



Results and Discussion

As an illustration of examples, Figure 2 shows the continuous maps of the fertility grade for topsoil pH and available phosphorus. Both indicators show a mild limitation in terms of contribution to the soil fertility. In the case of the pH fertility grade map, the only area with less than 0.50 fertility grade is just east of Pilliga, which is the Pilliga Scrubland. The parent rock of the soil of the area is the Pilliga Sandstone, which had lost much of the basic nutrients during the process of rock formation and weathering. The relatively low fertility status of this area is evident for all the indicators listed in Table 1. However, available P is hardly shown to be limiting at all, although sampling at denser spacing would probably reveal some niches of low P availability in the Pilliga Scrubland.

Figure 2.



a) Contour map of membership that pH is optimal for crop growth

b) Contour map of membership that P is optimal for crop growth

In order to gauge the overall soil fertility of each layer and the soil profile down to 80 cm depth, we derived fertility versatility, a measure of how fertile a soil is with respect to all the indicators used. In other words, how amenable is the soil fertility in respect of many fertility indicators that contribute to the overall soil fertility? To answer this question we calculated the averages of the membership grade of the entire indicators for a given layer as fertility versatility for that layer using the expression:

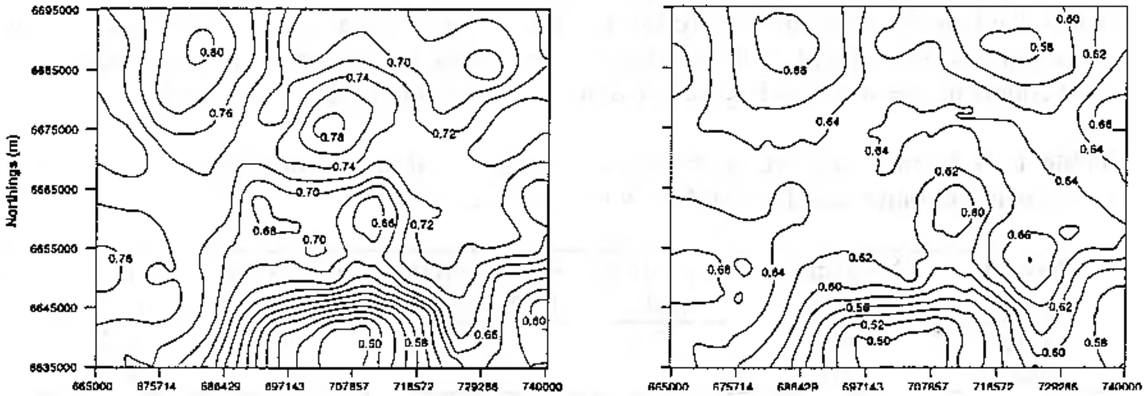
$$F_{Vl} = \frac{1}{p}\sum_{i=1}^{p}\mu_{il}$$

where F_{vl} is the fertility versatility for layer l, μ_{il} is the membership grade of indicator i for layer l, and p is the number of fertility indicators. To obtain the profile (0-80 cm depth) fertility versatility, we calculated the averages of the 3 layers as:

$$F_{V0-70} = \frac{1}{3}\sum_{i=1}^{3}\mu_i$$

The results of the layer fertility versatility are illustrated in the contour maps shown in Figure 3a for the topsoil and Figure 3b for the subsoil. Like the cases for the pH and P indicators, the layer fertility versatility is quite high for the study region, as the values hardly fall below 0.50. The only exception is the Pilliga Scrubland area, which shows versatility values below 0.50. The profile versatility (Figure 4) shows similar patterns. This shows that the contribution to the soil fertility by each indicator influences the overall versatility. Limitations by one or more of the indicators flows on to affect either the layer or profile (0-80 cm) versatility. On the whole the study area is very fertile based on the indicators used for our analysis. It is not surprising that the small section of the Pilliga Scrubland, east of Pilliga is used mainly for grazing or is part of the Pilliga State Forest.

Figure 3.



a) Contour map of topsoil fertility versatility (membership [0,1])

b) Contour map of subsoil fertility verstility (membership [0,1])

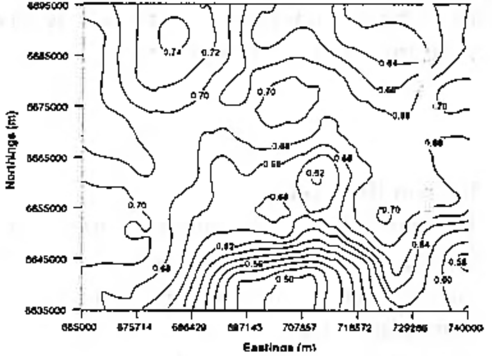


Figure 4. Contour map of profile (0-70cm) fertility versatility: E(membership) =[0,1]

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Nitrogen nutrition of cotton

Ian Rochester

CRC for Sustainable Cotton Production, CSIRO Plant Industry, ACRI, Narrabri.

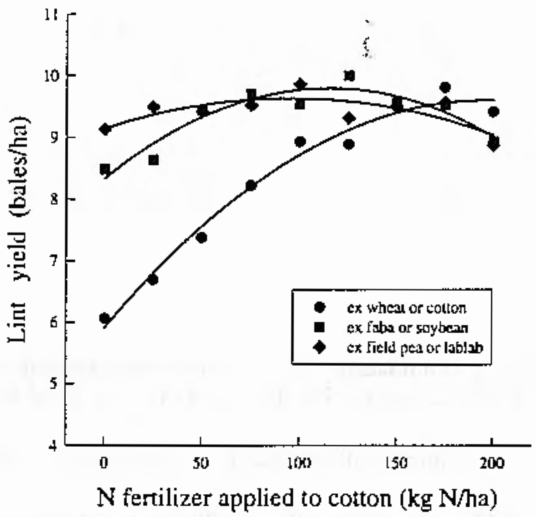
Legume rotation crops

Some legume crops have become important rotation crops in cotton cropping systems as growers realise the benefits these crops to following cotton crops. The amount of N fertilizer required by the cotton crop is substantially reduced following reasonable legume crops. In commercial fields, N rates have commonly been reduced by 50% and in some cases, no fertilizer N is needed (Fig. 1).

Table 1: N balance of rotation crops, pre-sowing soil nitrate, cotton petiole nitrate (950 DD) and performance of unfertilized cotton following legume crops.

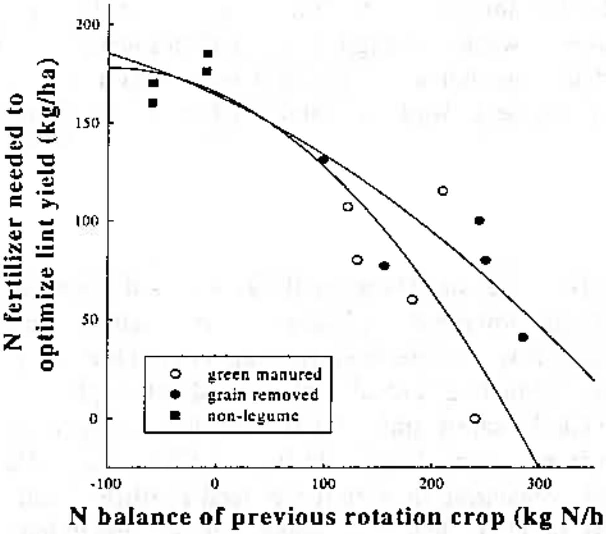
Previous crop	N balance (kg/ha)	Soil nitrate (mg/kg)	Petiole nitrate no N - (g/kg)	Crop N uptake no N - (kg/ha)	Lint yield no N - (b/ha)	N fertr needed (kg/ha)
cotton	-60	3	1	60	5.5	180
wheat	-10	7	4	90	6.6	170
soybean	250	14	8	140	9.1	80
faba bean	160	12	7	120	7.9	80
lab lab	210	16	12	160	9.8	0
field pea	190	15	10	140	8.4	70

Because some N is removed in harvested grain, an N balance (N fixed - N removed) is calculated for each rotation crop. This is the net amount of N which has been imported or removed by that crop, which is related to the amount of N fertilizer required to optimise lint yield in the next cotton crop.



Cotton lint yields

Typical N fertilizer response curves for cotton. Legume crops return much of the N they fix to the soil as organic N. Soil micro-organisms mineralize this N over time, making the legume N available to following crops, thus reducing the amount of N fertilizer they require. Following green-manured legume crops, little N may be required, slightly more with grain legumes, but substantially less than following cereals or fallow.



Use of legume N by following cotton crops
Large inputs of N through legume cropping reduce the amount of N fertilizer required. Our data indicate that between 30 and 40% of the legume N added to the soil is taken up by the next cotton crop. The remaining legume N will become available to future crops. Only a small fraction legume N is lost from the soil system, compared with fertilizer N, as legume N remains in the soil in organic material.

Prediction of N fertilizer requirement

The N fertilizer required by cotton can be predicted by pre-sowing soil nitrate and/or cotton petiole nitrate analysis. This is the basis for the nutriLOGIC program which also takes into account soil quality (compaction and predisposition to waterlogging) and cotton-growing district, as hotter areas require more N to optimise lint yield.

N fertilizer application near sowing

Because of the extremely wet winter we have just experienced, many growers did not apply any N fertilizer prior to sowing. Meetings were held to discuss the options available for N application, including side-dressings of MAP and other fertilizer management issues.

Toxicity of ammonia

The most influential factor in producing fertilizer injury in seedling cotton is the presence of gaseous ammonia in the vicinity of the developing roots. When ammonia-producing fertilizers (urea, anhydrous ammonia, MAP) are applied in alkaline soils, a proportion of the N remains as ammonia in the soil water and air space within the soil. The pH of the soil within a band of ammonium-producing fertilizer increases towards the centre of the band, causing the ammonium-ammonia equilibrium to elevate the ammonia concentration. .

$$\text{(acid soil)} \qquad NH_4^+ \Leftrightarrow NH_3 + H^+ \qquad \text{(alkaline soil)}$$

The root systems of crops are extremely sensitive to ammonia and patches of dead seedlings may become evident where N has been applied too close to the plant row. As the ammonium is nitrified, the soil pH declines, commonly below that of the soil surrounding the fertilizer band.

Timing of N application

Where growers opt to place anhydrous ammonia (or urea) below the plant line prior to sowing, they should ensure sufficient time has elapsed for the ammonia to have dissipated from the soil where the root system will develop. This may take up to 3 weeks for high N application rates. N applied more than 3-4 months prior to sowing is subjected to greater loss through denitrification and leaching. N applied as side-dressing after squaring may not be as well recovered by the crop as N applied pre-sowing.

Placement of N application

Ideally, N fertilizers should be placed away from the soil where seedling roots will grow, especially if that application is made close to sowing. For pre-sowing N applications (more than one month before sowing) the N can be applied beneath the crops row; if close to sowing, apply N to the side of the crop row. Where 2-metre beds are used, the centre of the bed is ideal. Urea should not be placed with seed. Low rates of MAP (up to 40 kg product/ha) can be safely applied with seed where seedbed moisture is good. Because the phosphate has an acidifying effect, this neutralises the alkalising effect of the ammonium, thereby reducing the ammonia concentration within the seed-fertilizer band. There is insufficient acid produce with applications of DAP, hence it should not be substituted for MAP applications with seed. Urea applied adjacent to the crop row prior to sowing and then watered-up, may be moved into the seedling root zone as urea is extremely soluble. This can cause seedling damage, especially where high N application rates are used. Water-run urea does not cause this problem.

Form of N fertilizer

Urea and anhydrous ammonia are normally equally well recovered by cotton. Urea is hydrolysed quickly (within days) in cotton growing soils. Water-run urea works well as the N is distributed throughout the soil volume from where the crop is extracting water. Water-run anhydrous ammonia does not work well as most of the ammonia is retained at the top of the field and severe losses occur from volatilization of ammonia from the (alkaline) irrigation water (up to 25% per hour) from high rates. Also, urea should not be applied to the surface of wet or moist soil where volatilization losses can reach 75% of N applied within 1-2 days. Urea can be applied to a DRY soil surface but it should be incorporated as soon as possible using cultivation or irrigation.