Cotton Research and Development Corporation

Project CRC 19C

Identification and remediation of nutritional stresses in cotton crops

Final Report

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Background to this research

Fertilizer use: Australian cotton has been grown on relatively fertile soils, requiring mainly N and some P fertilizer. N fertilizer costs the cotton industry about $50M annually. The recovery of N fertilizer is commonly less than 50%, due to the nature of the cotton-growing soils, irrigation technology and fertilizer management. Phosphorus, potassium zinc and other fertilizers may cost the industry a further $25M annually. While much of our past research has concentrated on N fertility, we recognise that other nutrients are increasingly becoming limiting to cotton production. This is due largely to the removal (mining) of nutrients in produce, particularly cottonseed. Identification and remediation of nutritional stress at the earliest opportunity will be of benefit to the cotton industry.

Nutrition research: Research on N nutrition has been ongoing and will to continue in this project. However, the project will be broadened to include assessment of other nutrients (P, K, S, Mg, Ca, Zn, Mn, Fe, Cu, Na and B). Important issues such as premature senescence, P and K nutrition have been investigated previously, but with no definitive conclusion. Close collaboration with researchers investigating these specific issues will be continued.

Legume cropping: As a result of our N fixation studies with legumes, we have identified cotton cropping systems, which require substantially less input of N fertilizer. Legume crops (eg faba beans) have fixed up to 350 kg N/ha in our experiments and effective N-fixing legume crops have returned 150-200 kg N/ha to the soil. Cotton following these legume crops requires about half the N fertilizer required where cotton follows non-legume crops. Notably, vetch grown between annual cotton crops has fixed more than 200 kg N/ha. Because legume N is released slowly over a period of several years, this source of N is used efficiently by cotton.

Soil quality: Soil quality is also improved with legume cropping. Maintaining a healthy soil structure is important, particularly in heavy clay soils, and legume cropping may help in rehabilitating soil compaction cotton fields and improving drainage to reduce the effects of waterlogging.

Significance to the cotton industry

Improved methods of assessing crop nutrient status in early season cotton will allow growers to remediate their crops and improve fertilizer management practices. By optimising the nutrition of cotton crops, growers can avoid nutritional stresses that can reduce the economic viability of commercial cotton growing. Monitoring nutrient status of individual cotton crops will allow precise fertilizer recommendations to be formulated. Soil and plant tissue tests have been available to the industry for many years but this technology has not been widely accepted because of the time consumed in sampling procedures, cost, inexperience in interpreting analytical results and variations in laboratory procedures and reporting of results. Growers often use soil testing as their only indication of crop nutrition requirements. Plant tissue testing offers a better indication of crop nutrition than soil testing, but it has not been adopted in commercial cotton production. NIR technology has the potential to facilitate and reduce the costs of nutrient analysis of cotton plant material. Similarly, development of the SPAD chlorophyll meter to allow in-field assessment of crop N nutrition will reduce response time for making N fertilizer management decisions.

Cropping systems experiments are currently being used to evaluate the sustainability of various cotton systems. An important component is the inclusion of legume crops for grain or green manuring. This assists in maintaining desirable levels of soil organic matter, with improved soil quality, soil N reserves and availability of other plant nutrients. Legume cropping provides direct economic benefits to growers through reduced N fertilizer requirement and indirect long-term benefits through enhanced sustainability achieved by remediation of soil chemical and physical properties. Management practices which reduce reliance on chemical fertilizers and which conserve and improve our soil resources are environmentally responsible and ecologically sound.

Previous research has shown that legume cropping can improve soil structure and tilth. Because soil strength is reduced following legumes, root growth and exploration is enhanced in soil of lower strength, thereby enabling the plant to take up nutrients more effectively. Where soil structure and root growth are substantially improved, fewer irrigations may be required for cotton.

Project objectives

- ***Identify critical nutrient concentrations in cotton leaves***. Identify the ranges of nutrient concentrations (N, P, K, S, Mg, Ca, Zn, Mn, Fe, Cu and B) required by high yielding cotton crops. Determine critical nutrient concentrations in cotton plant tissues and organs during their development in a diverse range of cropping systems and environments to enable nutrient imbalances, toxicities and deficiencies to be identified.
- ***Develop techniques for rapid assessment of nutrients in cotton leaves***. Investigate the potential for using Near-Infra-Red (NIR) analysis to analyse cotton plant material for all (or most) nutrients. Compare the use of up-to-date NIR technology with currently used chemical analyses. Continue development of the SPAD chlorophyll meter to determine the N fertility status in pre-flowering crops in the field. Provide means of interpreting crop nutrient analyses and incorporate into the NutriLOGIC program.
- ***Continue development of N-efficient cropping systems using legumes***. Assess the value of green-manuring vetch species (and other legumes) grown between back-to-back cotton crops. Evaluate winter and summer-growing legume species, including those that may assist in controlling soil-borne pathogens. Determine the reduction in optimum N fertilizer rate and improvement in supply of other nutrients to cotton. Devise means of more accurately determining the N fertilizer requirement of these cropping systems.
- ***Assess soil quality improvement associated with legume cropping***. Identify the processes that contribute to soil quality improvement. In particular, investigate the quantity and types of organic compounds secreted from the roots of various crop species. Determine the extent to which these secretions from legume crops affect soil quality in field and laboratory experiments. Examine the longevity of these effects.

Methodology

Cotton leaves were samples throughout the 3 seasons from the Macquarie, Namoi, Gwydir and Macintyre valleys. Several farms and many fields were assessed within each valley. Nutrient analyses were conducted to indicate where imbalances or deficiencies or toxicities might affect cotton productivity. These leaf samples will be used to calibrate the NIR analysing system.

Winter growing forage legume crops were compared for productivity and N fixation, the best types were included in the cropping systems experiments.

The cropping systems experiments compared various rotation crops sequences in either back-to-back cotton or rotation systems. Nitrogen fertilizer requirement for each system was quantified by applying N fertilizer at discrete rates over a wide range.

Soil quality was assessed by using a cone penetrometer that measures the soil's strength and resistance to machinery and crop roots moving through the soil.

Results

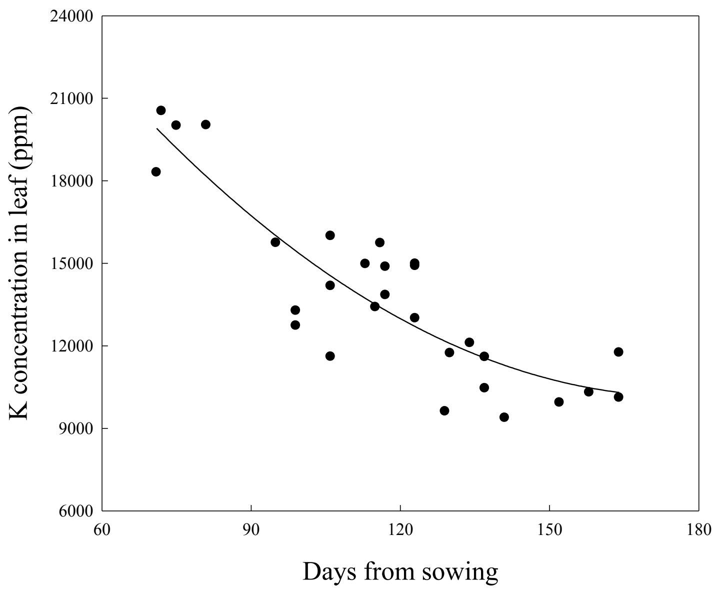
Leaf nutrient concentrations:

Cotton leaf samples were collected from many sites during each of the seasons during this project to determine nutrient levels. Almost 3,000 samples were collected and analysed from many cotton crops grown in several valleys from Emerald to Narromine. Many samples were collected from experiments at ACRI. Low levels of P, K and Zn were widespread while elevated levels of sodium (Na) were surprisingly common. Few cotton leaf samples were identified with low N content to indicate that N nutrition was inadequate.

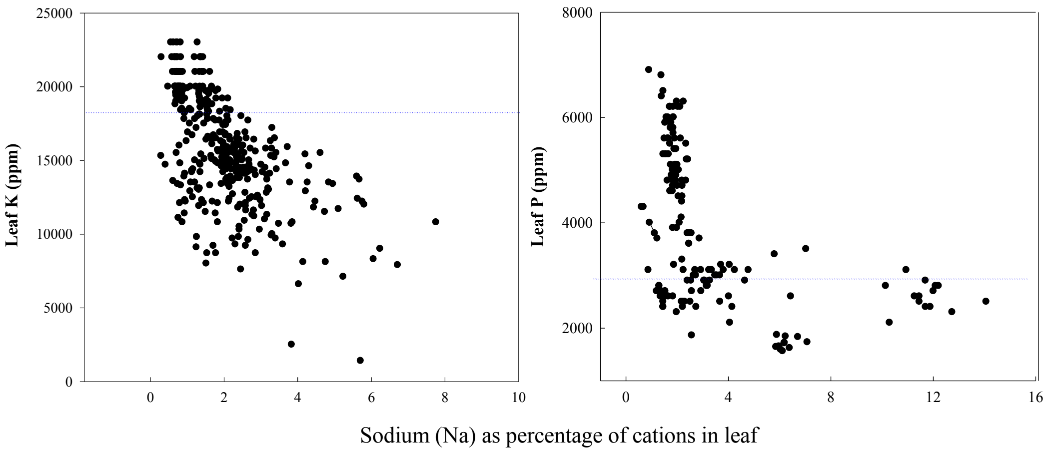
In many samples, P and K nutrition appeared to be limiting, with both nutrients being below the accepted critical limits in many sites. Interestingly, high levels of sodium often concurred with low concentrations of both P and K. At high levels, sodium appears to inhibit P uptake and to a lesser extent, K uptake.

Phosphorus: The critical limit for leaf P is around 0.3% P (3,000 ppm). A high proportion of the samples collected were below this limit, especially those collected post flowering where P was translocated from leaves to developing bolls. In fertile soils, leaf P concentrations did not decline at this time.

Potassium: Leaf K concentration is known to decline through the season as described in the figure below (data from 2001/2002 season). As a first approximation, data points falling below the fitted line could be considered low or deficient in terms of K content of their leaves and those above could be considered to be adequately nourished in terms of potassium. K deficiency symptoms were observed in all valleys in many crops, particularly during boll filling and often coincided with high levels of sodium in the leaf. Further research is required to determine how to remediate these soils and crops.



Sodium: Leaf sodium concentrations were closely related to soil sodicity. ACRI soils, being particularly low in sodium, grew cotton that took up very small amounts of sodium. Relationships were derived with P and K and sodium using the data collected from a large range of sites.



In field experiments, there appeared little responses to applied potassium fertilisers in levels of K in the leaves or in lint yield, even on sites of relatively low sodicity.

While salinity is thought not to substantially affect cotton production, the associated problem of soil sodicity (high sodium content) is of concern in many cotton soils. Very little soil sodicity research has been undertaken, although it is believed that species differ markedly in their tolerance of sodicity. Legumes are thought more sensitive to sodicity than cotton or wheat. Many productive cotton fields show poor growth and N fixation by legume crops (eg CRC Farming Systems Expt site at Wee Waa).

Glasshouse experiments were initiated to investigate these phenomena more closely. In the first experiment, high soil sodium levels significantly reduced cotton as well as legume growth. In the second experiment, nutrient concentrations in cotton leaves were reduced as soil sodicity increased – nutrients most severely affected were iron, zinc, phosphorus and potassium. This validates what has been observed in the field.

Cotton cultivars have been assessed in their capacity to take up or exclude P, K and Na and other nutrients. Considerable variation exists and will be employed to aid future varietal selection by CSIRO breeders.

An associated three-year project was proposed to CRDC to further research P and K nutrition of cotton. This project did not go ahead as no suitably qualified scientist was recruited.

A post-graduate student (Kylie Dodd, UNE) has commenced a research project to investigate the importance of elevated soil sodicity levels to cotton production.

Rapid assessment:

Calibration of the SPAD chlorophyll meter has been progressed and this has been made available to those consultants and growers who have purchased these meters. While the variation between cultivars can be accounted for satisfactorily, between seasonal variation still poses some problems and requires further research. Large differences have been identified between cultivars and allowance can now be made for this. Further validation of revised calibrations is required. However, substantial variation between years is the constraint that will limit the usefulness of this technology for the cotton industry at large. Further investigation into means of accounting for the between year variation is necessary.

The use of NIR (Near-Infra-Red) techniques to determine the nutrient content of cotton leaf samples is still being assessed. Many samples were scanned in November 2002 with one machine that is no longer available, although comparison of the results from chemical analyses produced reasonable correlations (see table below). More powerful scanning NIR equipment is now available to that previously used, and this is being used currently to produce more accurate calibrations. Samples not used to produce these calibrations will be used to assess these calibrations.

Nutrient	Range tested (ppm)	Calibration (r^2)

Fe	89 - 120	0.90
Mn	35 – 100	0.94
B	80 – 140	0.71
Cu	5.0 – 6.0	0.18
Zn	17 – 30	0.95
Ca	48500 – 57500	0.40
Mg	8000 – 13000	0.07
Na	1800 – 4000	0.69
K	1000 – 11000	0.76
P	1800 – 4600	0.90

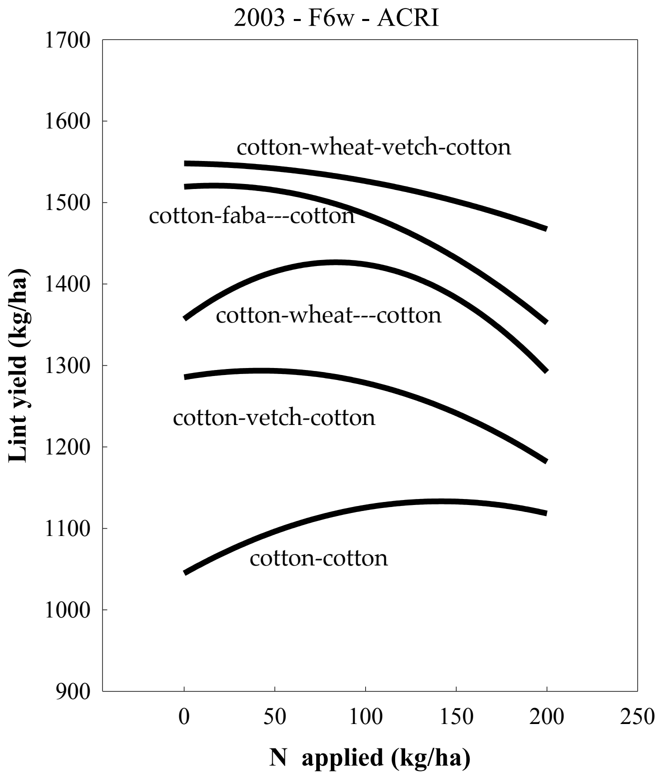
Legumes in the cropping system:

Comparison of legume species/cultivars:

Named commercial vetch cultivars have been assessed in terms of N_2 fixation in several field experiments. The most effective cultivar has been Namoi Woolly Pod vetch and Capello (a selection from Namoi woolly pod vetch) that out-produces other cultivars in DM production and N fixation. This cultivar has fixed up to 265 kg N/ha between continuous cotton crops and regularly fixes 200 kg N/ha. Other winter forage crops (including clovers and medics) have not been as productive as vetch. Faba beans can also fix large quantities of N (up to 190 kg N/ha) but add only 110 kg N/ha to the soil as much N is removed in the seed. Vetch crops have been monitored on commercial farms, with N inputs measured between 120 and 190 kg N/ha. At Emerald, vetch has put between 80 and 240 kg N/ha into the soil depending on the availability of water and growing time as many commercial crops are mulched prematurely.

N fertilizer response following legumes:

A cropping systems experiment has been maintained at ACRI since 1994 and includes the common rotation systems used within the cotton industry. Because of the large quantities of N being added to the soil via legume crops, the requirement for fertilizer N is greatly reduced. In the past few seasons, cotton following faba bean has required no fertilizer N, nor has the system where cotton follows wheat and vetch. In comparison, Cotton following wheat required about 80 kg N/ha. In continuous cotton systems, cotton required 140 kg N/ha, which was reduced to 60 kg N/ha where vetch was grown between annual cotton crops. In the 2002/03 season, including vetch increased gross margins by ~$400, largely through increased lint yield by between 13-25%. These effects are becoming more significant with each cycle of the experiment. The best yielding system involves cotton, followed by wheat then vetch prior to the next cotton crop. This system requires no input of N fertilizer, nor does the cotton-faba bean-fallow-cotton system that yields slightly less than the wheat-vetch system.



Soil quality assessment:

Soil strength data was collected through the 2000/2001 and 2001/2002 growing seasons in the cropping systems field experiments. Soil strength was reduced by 10% following vetch cropping as assessed during the growth of the cotton crop, indicating that vetch crops can improve soil condition.

Glasshouse experiments have indicated that legume crops exude acids from their roots, thereby modifying their rhizospheres. Cowpea and lablab reduce soil pH more so than soybean. Vetch also reduces the pH of its rhizosphere, an effect that can be measured in soil collected from the field. This effect is beneficial in terms of improving the availability of micronutrients in the soil and may be in part related to improved soil condition (tilth).

A glasshouse experiment was initiated in October 2001 to assess legume crop root exudation indicated that some legume crops (notably soybeans and cowpeas) can acidify their root environment and may thereby alter nutrient availability more than non-legume crops. These changes in soil pH were also observed to a lesser degree in soil sampled from the field experiments.

A further laboratory study demonstrated that some legume species exude greater quantities of organic acid than others. Plant and soil samples have been forwarded to colleagues in CSIRO PI Canberra for further analyses in order to estimate acid exudation from legume roots.

Other issues investigated:

Other experiments conducted during past season included assessment of “Bio-N”, a commercial preparation of free-living N fixing micro-organisms and “Nutri-smart”, a coal-based product also containing beneficial soil-borne micro-organisms. Neither product showed any response in either of the field experiments.

Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?

Conclusions

- Cotton leaves should a wide range of nutrient concentrations. In many instances of leaves sampled through several valleys, low levels of phosphorus, potassium and zinc have been observed. High levels of sodium are most often associated with poor phosphorus and potassium nutrition. High levels of exchangeable sodium in the soil affect P and K nutrition. Sodic soils occur throughout the cotton belt.
- The SPAD meter requires further research to overcome between year variations. However, it has shown promise as a means of indicating the N status of cotton crops at an early stage of crop development.
- Assessment of crop nutrient status by more rapid techniques (NIR) should be possible in the near future with calibration of a promising technique. Availability of NIR equipment has hindered the progress of this project.
- Cotton requires significantly less N fertilizer following legume crops.
- Legume cropping between cotton crops can elevate yield potential of cotton.
- Vetch and some other legume crops can substantially improve soil condition, reduce soil strength and possibly improve water-holding capacity through enhanced soil structural condition.

Further cooperative research

- Efforts are being continued to ascertain by what mechanisms cotton yield potential is enhanced following some legume crops. There has been some indication in past years that soil water-holding capacity is improved following legume crops – this will be investigated in the 2003/04 season. Other researchers are making use of the legume cropping systems experiments by including these crops in their research.
- Another facet of this research will be to investigate acid evolution from legume crop root systems and how this may manifest itself in terms of improved soil condition.
- The availability of NIR equipment and software to facilitate the calibration of the leaf samples for nutrient content is now progressing.
- A means of interpreting crop nutrient analyses from these analyses and commercial laboratories will be incorporated into the NutriLOGIC program.

Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?

Economic: Cotton growers are now more aware of losses of nutrients from their land. Applying the optimum amount of those nutrients that are deficient will improve the productivity of their farms whilst minimising polluting of groundwater and the atmosphere and wasting fertiliser inputs has been shown to increase gross margins through higher productivity per unit of land.

Environmental: Applying the optimum amount of those nutrients that are deficient will improve the productivity of crops whilst minimising pollution of groundwater and the atmosphere and avoidance of wasting fertiliser inputs. Managing more N-efficient cropping systems requires less energy and less fertilizer input

Social: Growing crops on a more sustainable system where fewer inputs are used and the environment is enhanced rather than degraded is much more socially acceptable to the community in general.

Provide a summary of the project ensuring the following areas are addressed:

technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)

- Deficiencies of P, K are primarily related to soil sodicity.

- Vetch is a highly effective N fixing rotation crop: the area sown to vetch in most cotton-growing regions is expanding
- Legumes crops can enhance soil quality to boost the yield potential of following cotton crops.
- N fertilizer rates are substantially reduced for cotton following legume crops

other information developed from research (eg discoveries in methodology, equipment design, etc.)

- Further SPAD meter data calibration is required to take account of significant between season variation.
- Use of NIR technology is showing very encouraging results and could be operational within 2004.

are changes to the Intellectual Property register required?

NO.

Detail a plan for the activities or other steps that may be taken:

- **to further develop or to exploit the project technology.**

  Extension activities need to be directed towards soil and plant tissue sampling to determine nutritional requirements of cotton. Also, extension of the legume (especially vetch) inclusion in the cropping system is essential.

- **for the future presentation and dissemination of the project outcomes.**

  Two papers are in an advanced stage to be published for scientific review on the benefits of cropping vetch and the effect of sodium on crop nutrition. Articles for the agricultural press (eg Australian Cottongrower) will be published.

- **for future research.**

  The legume-based cropping systems experiments in Field 6 at ACRI will continue indefinitely as they have been yielding very important information as they approach eight years since establishment. The visit from Assoc/Prof Glen Harris, University of Georgia, Tiffton, USA during 2003 (20/1/03 – 17/3/03) helped to formulate some ideas for future research with respect to P and K and sodicity research – those conclusions are discussed in the report for Project CSP 142C.

List the publications arising from the research project and/or a publication plan.

Refereed Journals:

Rochester IJ and Constable GA. (2000). Denitrification and immobilization in flood-irrigated alkaline grey clays as affected by nitrification inhibitors, wheat straw and soil texture. *Aust J. Soil Research* 38, 633-42.

Rochester IJ, Peoples MB, Hulugalle NR, Gault RR and Constable GA (2001). Using legumes to enhance nitrogen fertility and soil condition in cotton cropping systems. *Field Crops Research* **70**: 27-41.

Rochester IJ, Peoples MB and Constable GA (2001). Estimation of the N fertilizer requirement of cotton grown after legume crops. *Field Crops Research* **70**: 43-53.

Peoples M, Bowman A, Gault R, Herridge D, McCallum M, McCormick K, Norton R, Rochester I, Scammell G, Schwenke G. (2001). Factors regulating the contribution of fixed nitrogen by pasture and crop legumes to different farming systems of eastern Australia. *Plant and Soil* **228**, 29-41.

Rochester IJ (2003). Estimating nitrous oxide emissions from flood-irrigated alkaline grey clays. *Australian Journal of Soil Research* **41**: 197-206.

Rochester IJ, Gault RR, Peoples MB (2004). Vetch (Vicia villosa) and other rotation crops improve productivity of irrigated cotton. *Field Crops Research*

Conference papers:

Rochester IJ, Constable GA, Peoples MB. (2000) 'Monitoring cotton nutrition'. 10th Australian Cotton Conference. (Brisbane, 2000) pp 283-287.

Rochester IJ and Constable GA. (2003) Variation in cotton cultivars to take up nutrients and tolerate soil sodicity. World Cotton Research Conference -3 (Cape town, 2003).

Rochester IJ, Roberts G, Peoples M, Kelly D, and Nehl, D (2001). The benefits of vetch cropping in cotton systems. Australian Cottongrower 22(6), 22-27.

Rochester IJ. (2002). Managing cotton nutrition. In ACGRA conference Proc. Brisbane. August 2002.

Reviews and Book Chapters:

Rochester IJ, Rea M, Dorahy C, Constable GA, Wright P, Deutscher S, Thongbai P and Larsen D (2001). NUTRIpak – a practical guide to cotton nutrition. Australian Cotton CRC. CSIRO Publishing.

McKenzie D, Shaw A, Rochester I, Hulugalle N and Wright P (2003). Soil and nutrient management for irrigated cotton. P 5.3.6. NSW Agriculture.

Seminars/Workshops:

Presentation at CSD/CSIRO Research Review (1/6/00)
Presentation at Australian Cotton CRC Review (21/6/00)
Presentation at Grower meeting (Wee Waa – 9/8/00)
Presentation to Mallawa cotton growers (Field Day – 28/8/00)
Presentation at Cropping Systems Forum (Dalby - 7/12/00)
Presentations to Macintyre growers (Field Day - 28/2/01)
Presentation to UNR cotton growers at Griffith UNR conference (6/3/01)
Presentation to Namoi cotton growers (Field Day - 16/3/01)
Presentation at Twynam Cotton meeting (Narrabri – 27/6/01)
Presentation at Potassium Workshop (Armidale – 3/7/01)
Presentation at Australian Cotton CRC Review (11/7/01)
Presentations to organic Cottongrowers (Narrabri – 31/7/01, Warren – 1/8/01)
Presentations to CQ Cottongrowers (Emerald – 8/8/01, Theodore – 9/8/01)
Presentation at Cotton/Greenhouse workshop (Narrabri – 16/8/01)
Presentation to Lower Namoi cotton consultants (Wee Waa - 7/11/01)
Presentation at Farming systems workshop (Narrabri – 6/12/01)
Presentation to Walgett cotton growers (Field Day - 14/12/01)
Presentation to Cotton Industry Development Officers (Narrabri – 12/1/02)
Presentations to Namoi cotton growers (Field Day - 6/3/02)
Presentations to Namoi cotton growers (Field Day - 7/3/02)
Presentation to Bourke growers (Bourke – 2/7/02)
Presentation to Auscott agronomists (Narrabri - 11/7/02)
Presentation to potassium researchers (Toowoomba - 24/7/02)
Presentation to Bourke growers (Narrabri – 30/1/03)
Presentations to Namoi cotton growers (Field Day - 20/2/03)
Lectures to CRC Cotton Production Course students on cotton nutrition (1 each year)

Media interviews:

Land newspaper article on Vetch cropping (13/9/01)
NW magazine newspaper article on Vetch cropping (31/10/01)
Audio interview for CSD clients on monitoring crop N (8/11/01)
Video interview for CSD clients on monitoring crop nutrition, winter crop options
Several website video interviews on nutrition issues (CSD - web on Wednesday)

AWARDS:

Achievement Award from Cotton CRC re "outstanding collaboration in the development of NUTRIpak" (10/7/01).

Supervision of Ph.D. Student (Sevag Bedrossian – Potassium nutrition of cotton)
Supervision of Ph.D. Student (Chris Dorahy – Phosphorus nutrition of cotton)

Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.

Cotton growers can now have a better understanding of their crops' nutritional requirements by soil and tissue testing. This is one area where our extension team can participate. Testing will indicate where nutrition problems lie and allow for some interpretation of means to address those problems with remedial action. It is important that rapid and accurate testing is available. The SPAD meter will allow in field measurements of crop N nutrition to be made and adoption of NIR technology by labs will enable multi-nutrient testing to occur quickly and cheaply.

Growers who choose to include legume crops in their cropping system will benefit financially from reduced N fertilizer addition and improved soil quality. Cotton yield potential is improved, allowing for greater gross margins from cotton production.

Summary

This project has identified several major nutritional disorders of cotton that commonly occur throughout Australian cotton crops. This was achieved by surveying many crops in several valleys through three growing seasons. The range of nutrient concentrations observed has enabled a more precise identification of the critical nutrient concentrations required in cotton leaves during the development of a crop.

There remains more research to be done on improving the techniques for more rapid detection of nutrient stress. Currently, Near-Infra-Red (NIR) analysis has been used to assess N content of cotton, and this technology is being extended to analyse cotton plant tissues for all essential plant nutrients. The further development of the SPAD chlorophyll meter requires continued research, although commercial interests within the cotton industry are using the existing calibrations.

The development of N-efficient cropping systems using legumes has progressed through the use value of green-manuring vetch crop (and other forage legumes) grown between back-to-back cotton crops as well as following wheat. N fertilizer application rates can be substantially reduced if not eliminated and the uptake of other nutrients to cotton is often improved. Many cotton growers are now growing vetch in their cropping system. This has the potential to increase cotton yields and gross margins substantially.

This project has shown that legume cropping is associated with a measurable improvement in soil quality. This is possibly related to the exudation of organic acids from legume root systems that may solubilise minerals within the soil, thus conferring a better environment in which roots may grow. This requires further research.