



FINAL REPORT

(due on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: 1.03.29

Project Title: Improving Cotton Nutrition diagnosis and N fertilizer Use-Efficiency

Project Commencement Date: 1/7/2007 **Project Completion Date:** 30/6/2010

Cotton CRC Program: The Farm

Part 2 – Contact Details

Administrator: Ms Jo Cain

Organisation: CSIRO

Postal Address: LB 59 Narrabri 2390

Ph: 67991513

Fax: 67931186

E-mail: jo.cain@csiro.au

Principal Researcher: Dr Ian Rochester

Organisation: CSIRO

Postal Address: LB 59 Narrabri 2390

Ph: 67991520

Fax: 67931186

E-mail: ian.rochester@csiro.au

Supervisor: Dr Michael Bange

Organisation: CSIRO

Postal Address: LB 59 Narrabri 2390

Ph: 67991540

Fax: 67931186

E-mail: michael.bange@csiro.au

Signature of Research Provider Representative: _____

Part 3 – Final Report Guide (due within 3 months on completion of project)

Background

This project continues research aimed at improving soil fertility and ensuring cotton crops are supplied with sufficient nutrients to attain maximum yields. Three streams of research were undertaken:

Nutrient Management:

Growers commonly monitor soil fertility and crop nutrient levels to avoid nutritional stresses that may affect yield potential. Environmental concerns of excessive fertiliser use are also relevant so nutrition advice should be based on crop needs and the economics of fertiliser responses. The recently-revised NutriLOGIC DSS determines the appropriate rates for fertiliser application based on soil and tissue analyses. It provides information on all nutrients and commonly-measured soil parameters and links to NUTRIpak where concepts and further explanation are required. Most of this information was collected within the previous project CRC52C. This new project will help refine nutrient management, especially for high-yielding cotton.

Soil health - Cropping systems:

An experiment that was initiated in 1995 has shown the benefits of rotating cotton with cereal and legume crops in preference to continuous cotton or fallowing. Those benefits include higher yield potential, improved soil structure, reduced N fertiliser requirement and improved P and K nutrition. This experiment produces a wide range of fertility conditions and provides valuable comparative information on crop nutrition and nutrient removal.

Efficient use of fertilisers:

While cotton yields have increased steadily over the past decade, so have N, P and K fertiliser applications. The cotton industry promotes effective use of fertilisers in the BMP program, largely to reduce the risk of environmental damage from leaching and greenhouse gas emissions. Improved use-efficiency of fertilisers will also improve profitability. N use-efficiency can be substantially improved in some situations.

Objectives

- Determine optimum nutrient levels in soil and plant samples gathered from many commercial and experimental cotton crops within several valleys and relate these values to crop productivity and yield. Low and high-yielding fields as well as high and low input systems were surveyed. This information will fine-tune the existing critical levels of each nutrient. This will allow growers and consultants to identify soil fertility and cotton nutrition problems in their crops and soils. Accurate estimates of the quantities of nutrients removed from cotton crops, based on the yield level, to guide those growers who wish to replace those

nutrients. This will be extended to the cotton industry through the NutriLOGIC DSS (50% time)

- Further investigate soil health changes associated with varied cropping systems. Assess differences in water and fertiliser use-efficiencies within these systems, as well as soil structure, chemical fertility and soil biology and relate this to the productivity of each system (25% time)
- Assess Nitrogen Use-Efficiency (NUE) by sampling fields throughout the cotton-growing areas in collaboration with the Cotton Nutrition Group and the Cotton Extension Team. Identify the circumstances where N is used efficiently or inefficiently and use this information to promote and extend BMP for N fertiliser use. Relate NUE to cotton gross margins. Establish an industry benchmark for this important input. Devise a simpler method for measuring NUE (25% time)

Methods

Soil and plant materials were sampled from 82 commercial cotton crops within 7 valleys to determine nutrient levels and then related to crop productivity, yields and nutrient use-efficiency. High and low yielding sites were included in this monitoring, in close collaboration with the Cotton Extension Team.

Soil health was monitored in the long-established cropping systems experiment that compares several rotation crops, including faba beans, wheat and vetch. Soil structure, chemical fertility and biological activity were monitored in this experiment, as well as crop nutrition.

A means of estimating N fertiliser use-efficiency that was previously identified for use in cotton cropping recently was used to measure N use-efficiency in commercial cotton crops throughout the major cotton-growing areas, in cooperation with the cotton extension team. By studying N fertiliser responses within various cropping systems, N use-efficiency can be related to the amount of N fertiliser needed by a cotton crop. N fertiliser use-efficiency relies on measuring crop N uptake at maturity, a laborious procedure. This project attempted to simplify this task to make NUE measurement more accessible to the entire industry by measuring seed N concentration. A component of the project was to develop a protocol with extension officers that can be used in on-farm experiments with interested growers to assess the effect of N rates on growth, yield, profitability, efficiency of use and greenhouse emissions. This helped provide experience to the extension officers, valuable objective local data and a focus for field days and extension.

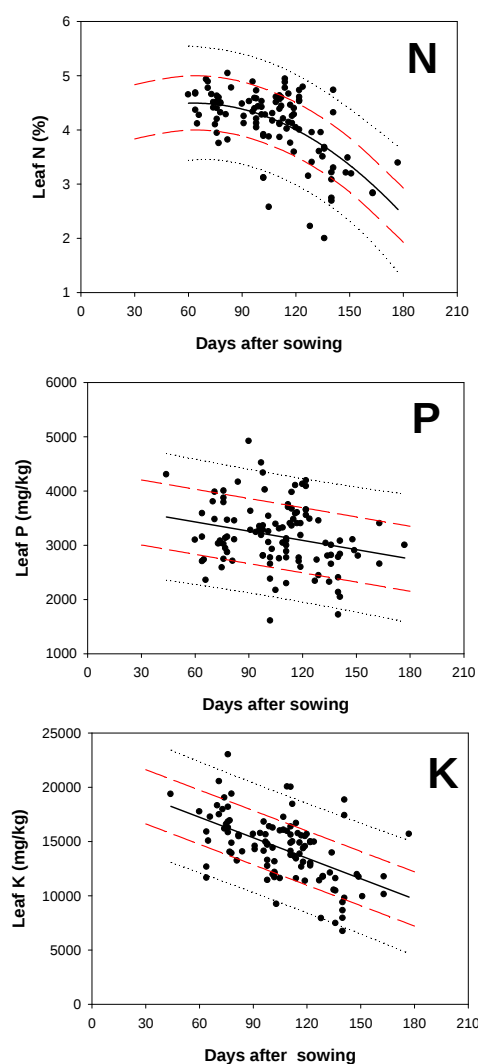
The use-efficiency of other nutrients was assessed in a range of cotton cultivars. This has shown little change in use-efficiency in those nutrients – the major change was in N use-efficiency. The NutriLOGIC DSS has been modified to fine-tune the critical levels of each nutrient using this and other data collected within the field experiments.

This project has had strong linkages with two CRC-funded Post graduate projects of Meredith Errington investigating redistribution of nutrients in high yielding plants and Tim McLaren's project that investigates soil phosphorus cycling in cotton-growing soils.

Results

Soil and cotton plant nutrient levels

The leaf nutrient concentration data base has been substantially increased and the NutriLOGIC DSS revised accordingly. However, little has needed to be revised with respect to soil and plant nutrient levels and chemical fertility, as evaluations of leaf and soil nutrient analyses demonstrated that the critical values suggested by NutriLOGIC were sufficient to achieve maximum lint yield in the three most recent seasons. The figure below indicates the trends in leaf N, P and K concentrations during a growing season; the area between the red dashed lines indicate sufficiency, the area below deficiency and above indicates excess, to provide adequate levels of nutrients to achieve maximum lint yield.



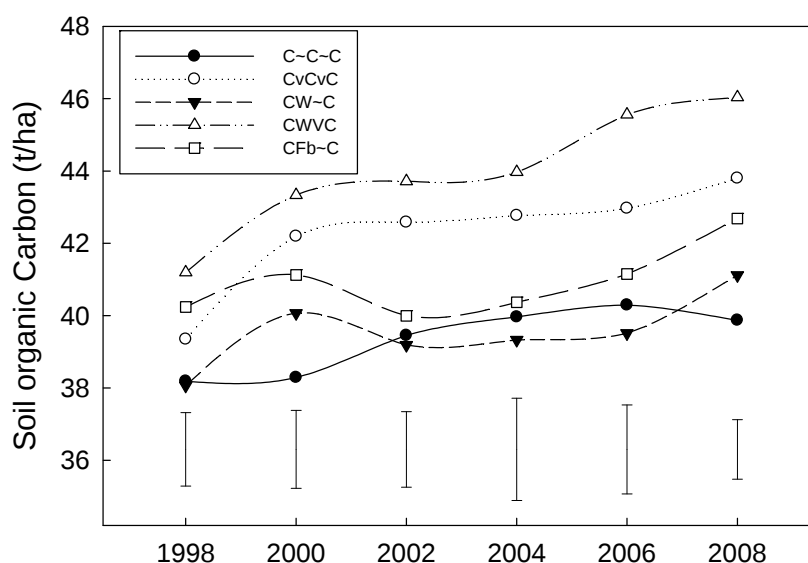
Similarly, the module within the NutriLOGIC DSS that interprets petiole nitrate data has been refined to more accurately predict cotton N fertiliser requirement from

early-season petiole analyses. The substantial changes to the algorithm allow the program to produce realistic estimates for N fertiliser application where petiole nitrate levels are increasing in the early pre-flowering period. However, petiole testing has not been very successful in recent years because of the variable weather conditions (cloudy, inclement and cold shock days) in most valleys during the pre-flowering period. Hence, leaf analyses are now recommended, as this testing is more robust, particularly under adverse weather condition when petiole analysis should not be used.

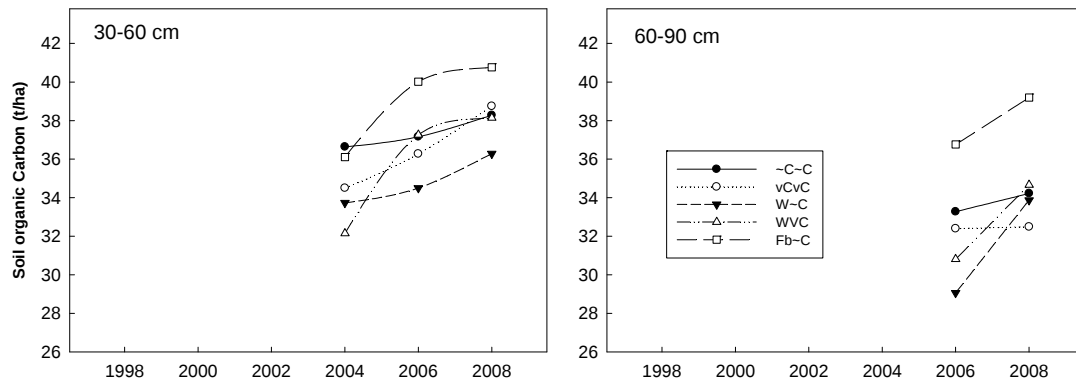
Soil health

Soil carbon sequestration

Soil organic carbon (SOC) has increased throughout a 10-year monitoring period (1998-2008) in an experiment that compared five cotton-based cropping systems. These systems included faba bean, vetch and wheat crops, as well as fallows of up to 10 months. All crops were grown on permanent ridges using minimum tillage. Topsoil (0-30 cm) contained between 40 and 42 t SOC ha⁻¹ in 1998 and increased by 0.28 t C/ha/yr (or 0.51 to 1.69 t CO₂e/ha/yr) across the five cropping systems. CO₂e are the units used to define total greenhouse gas emissions – 1 t C is equivalent to 3.66 t CO₂e.



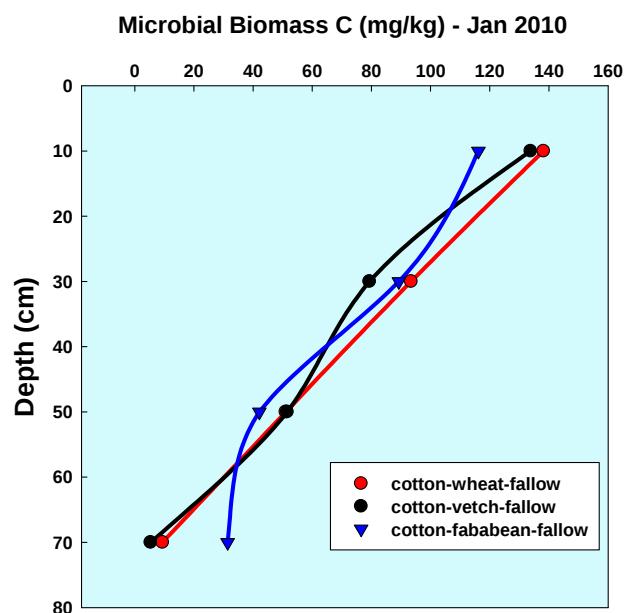
Between 2006 and 2008, SOC was measured to 90 cm depth; this indicated that on average 2.2 t C ha/yr were sequestered (equivalent to 8.1 t CO₂e/ha/yr). The greatest accretions of C occurred in the subsoil: 13%, 38% and 49% of the sequestered-C was found in the 0-30, 30-60 and 60-90 cm depth intervals, respectively.



SOC was 7% higher in the cropping systems that received legume stubble. Faba bean and vetch stubbles averaged 2.89 and 3.89% N, whereas wheat and cotton stubbles averaged 0.78 and 1.56% N, respectively. Carbon (C) inputs from crop stubble (excluding roots) ranged from 11.8 to 29.6 t C/ha over the 10-year period. Sequestered C vastly exceeded the estimated CO₂e emissions (~1 t CO₂e/ha/yr) typical of irrigated cotton cropping systems, according to the cotton greenhouse gas calculator derived by Prof. peter Grace (QUT).

Soil microbial biomass

Improved soil health can also be demonstrated by measuring soil microbial biomass. While there were no statistically significant differences among the cropping systems tested, the levels of microbial activity in the lower levels of the soil profiles are extremely important in recycling nutrients, enhancing soil water storage and improving soil structure. Earlier soil samplings indicated that there was substantial microbial activity within the soil profile below the surface 30 cm of soil. This was confirmed in 2010, as shown in the figure below.



Rotation crops

Wheat

Durum wheat crops have been grown in the past 3 winters successfully. They have required up to 3 irrigations and up to 200 kg N/ha was applied. These crops have yielded 5-6 t/ha with high protein content (15 to 20%). Cotton response to applied N following these crops was reduced, compared with less-intensively managed wheat crops grown in the past.

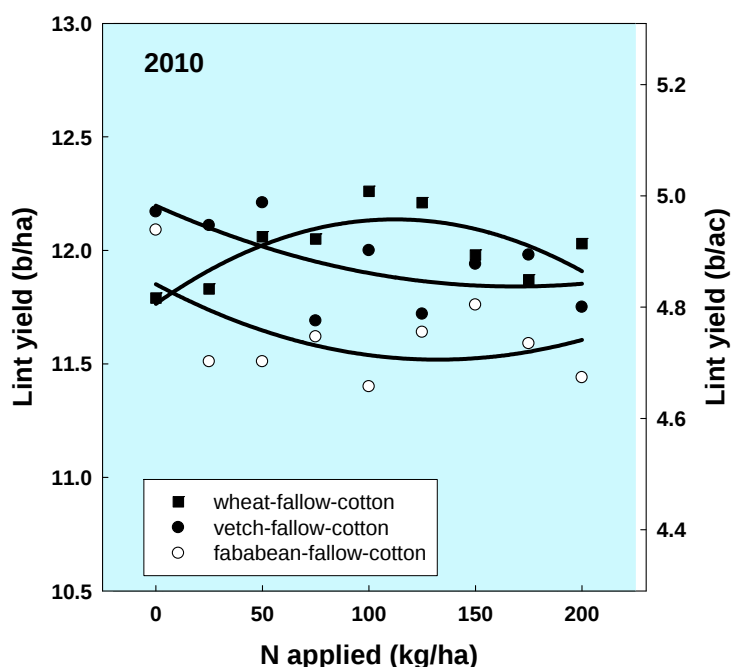
Faba bean

Faba bean crops sown in 2007, 2008, and 2009 fixed 75, 340, 210 kg N/ha, most were sown later than ideal due to delays with picking the preceding cotton crop. Faba beans yielded 1.4, 1.8, 2.2 t grain/ha and removed 60, 90, 90 kg N/ha, returning 15, 250, 210 kg N/ha to the soil.

Vetch

Vetch crops fixed 30, 70, 190 kg N/ha, were also sown relatively later than ideal and were not irrigated through the dry winters. All vetch crops were green-manured in September if the land was to be planted with cotton, else green-manured in October where the land was fallowed prior to sowing cotton the following year.

The typical yield response of cotton to N fertiliser following these crops is shown in the figure below. Cotton following legume crops required no N fertiliser, whereas the wheat system required 50 kg N/ha to optimise lint yield in 2009/2010.

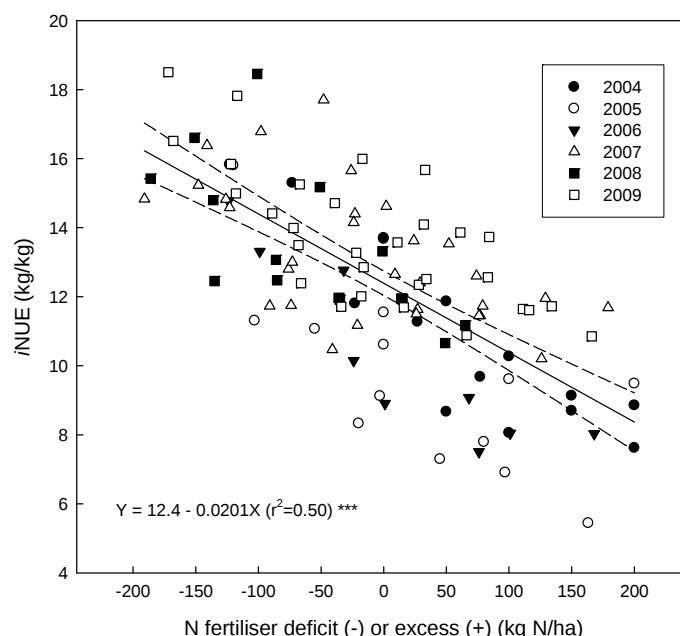


Nutrient use-efficiency

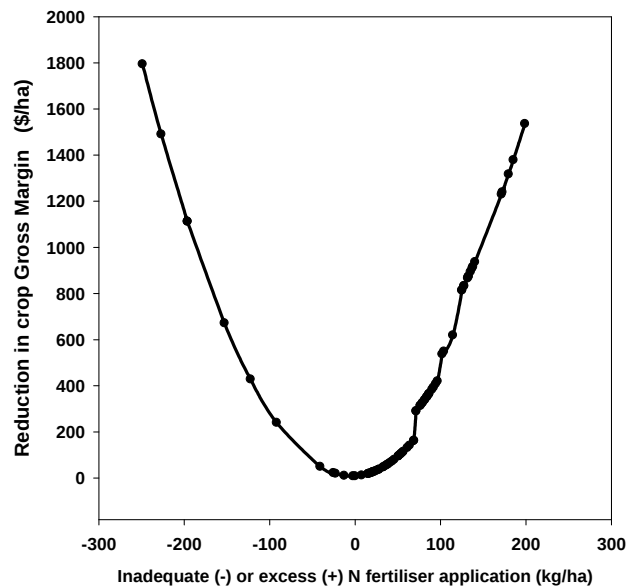
N use efficiency

Crop NUE was determined by dividing lint yield by crop N uptake. The optimal N fertiliser rates were determined from fitted quadratic functions that related

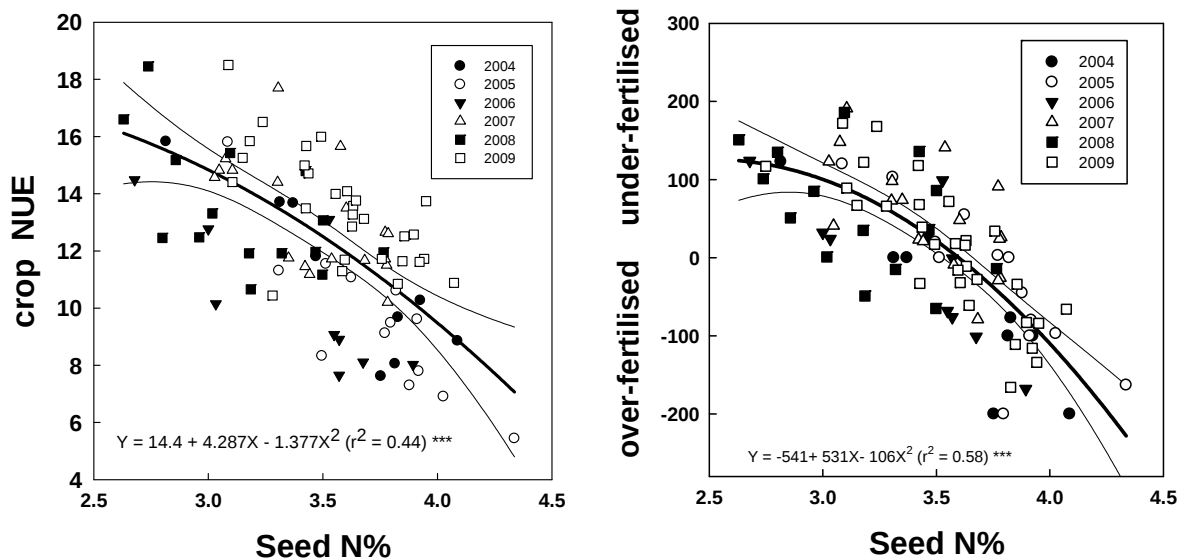
lint yields with N fertiliser rates for each cropping system in each year. When the optimal N fertiliser rate was applied, crop NUE averaged 12.5 ± 0.2 kg lint/kg crop N uptake. The crop NUE was then used to determine the degree to which N fertiliser was under or over-applied, with respect to the economic optimum N fertiliser rate. Low NUE values were associated with excessive N fertiliser application.



Crop NUE was determined in 82 commercial cotton crops in five valleys over the final 4 years of this study. The crop NUE value was high in 8 fields (10%), optimal in 9 fields (11%) and low in 65 fields (79%). Crop N uptake averaged 247 kg N/ha, yield 2273 kg lint/ha and crop NUE 10.1 kg lint/kg crop N uptake for these sites. Averaged over all sites and years, about 49 kg N/ha too much N fertiliser was applied. An economic appraisal of these sites by Janine Powell indicated how the crop gross margin was affected by inadequate or excessive N fertiliser application.



Importantly, crop NUE can be estimated from the N concentration determined in the cotton seed. Where crop N use-efficiency is optimised cotton seed N% is around 3.5%, as shown below.



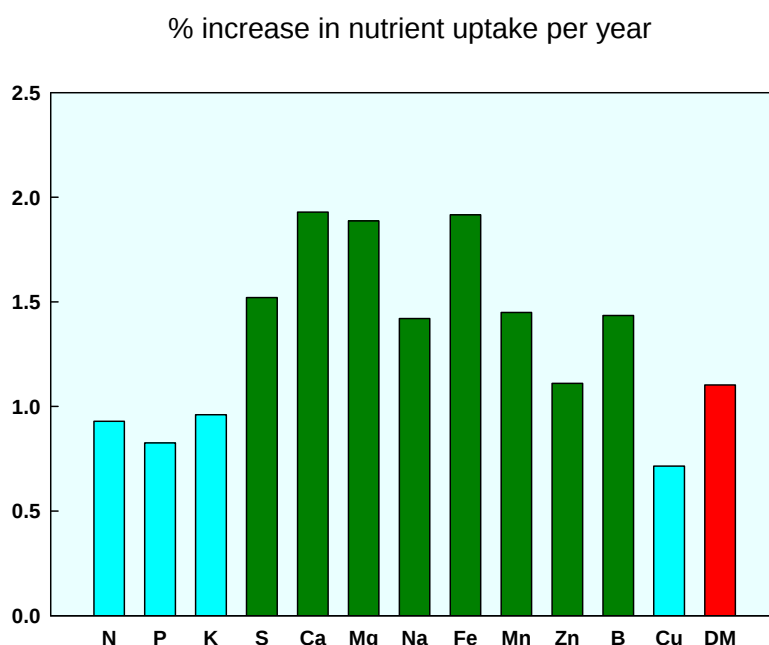
N fertiliser recovery by cotton ranged from <20% in N-fertile fields where legume crops had been grown, to more than 60% following winter cereal crops. Information on crop NUE will enable cotton producers to assess their N fertiliser management and adjust N fertiliser rates for future crops. This study demonstrated that there is scope to substantially reduce N fertiliser inputs to Australian cotton fields without reducing yields.

Commercialisation of this research has commenced, by investigating means of assessing fuzzy cotton seed at the ginning stage, using NIR (near-infra-red)

technology, which allows for quick non-destructive analysis of fuzzy seed. This would allow reporting of crop NUE and potential crop N management problems to the grower along with their fibre quality and gin out-turn data. Calibration of the NIR equipment has been slow, possibly because of interference from the lint, but this work is continuing.

Other nutrients

A selection of cotton cultivars was chosen that had been commercially grown in Australia since 1973 and included currently-grown cultivars. We were able to compare nutrient uptake, yield and nutrient use-efficiency among the cultivars and assess whether these parameters had changed over time in using modern agronomy. Data from the first year of the experiment is shown below. Cotton cultivars have consistently grown larger during this period and take up more nutrients, especially micronutrients, as shown below.



Changes in the use-efficiency of all nutrients have been investigated using this and other data collected over the past 30 years. Relatively small changes have been identified, but this research is continuing. Data is being collated to identify the use-efficiency of other nutrients in a similar manner to that described above for N. That information will be published when sufficient data has been collected from a number of experiments sampled over several years.

Outcomes

This research project has provided the basis for substantial economic, environmental and social benefits. It has promoted more economical use of N fertiliser inputs to produce a better cost/benefit ratio from fertiliser inputs. Reduced impact of fertiliser overuse (particularly nitrogen) on atmospheric greenhouse gas emissions will reduce off-target consequences of cotton production. Improved soil quality (health)

resulting from rotation crops (especially legume crops) will ensure this natural resource sustains cotton production into the future. More responsible use of fertiliser inputs will result in a reduced impact of cotton farming on the environment, and make cotton-growing regions better communities in which to live. This project has helped the cotton industry advance its objective to remain highly sustainable into the future, which is important in the survival of rural communities. Especially importantly, the project has shown that irrigated cotton cropping systems can be highly carbon positive where soil and crop stubbles are managed sustainably and in an environmentally friendly manner. It also challenges the Cotton Extension Team to deliver these outcomes through adoption of improved management practices throughout the cotton industry.

- a) *Technical advances achieved* - Provisional patent – Nitrogen Fertiliser Use Efficiency
- b) *Other information developed from research* – Major carbon sequestration can occur at depth in irrigated soils, beyond the depths normally examined in research studies
- c) *Changes required to the Intellectual Property register* - None

Conclusion

- The NutriLOGIC DSS provides an updated resource for cotton growers to manage soil fertility and cotton nutrition. This program provides recommendations to optimise crop nutrition through interpreting soil and plant analyses.
- N use-efficiency has been benchmarked and indicates the cotton industry substantially over-uses N fertiliser. The industry can safely reduce N fertiliser inputs by about 25% without reducing yield.
- The cotton industry can become Carbon positive by adopting minimum tillage practices, incorporating all crop stubble, including legume crops in the rotation and reducing fallow times. This would be a highly advantageous position to assist marketing cotton products.
- Soil health can be improved dramatically with legume cropping. Marked improvements can be seen in terms of soil physical environment, chemical fertility and biological activity in those cropping systems that include legume crops. This has impacted on cotton yield. For example, the cotton-vetch-fallow-cotton rotation remains the highest-yielding and requires very little N fertiliser to be applied.

Extension Opportunities

1. Detail a plan for the activities or other steps that may be taken:
 - (a) A soil fertility/crop nutrition extension group has been formed (Duncan Weir to co-ordinate)
 - (b) The project outcomes have largely been incorporated in the myBMP program.

- (c) This research is continuing and requires further input from extension staff to communicate N use-efficiency procedures, stubble management practices to optimise sequestering of carbon into cotton-growing soils to build soil health.

Publications

Journal articles

- Rochester IJ (2007). Nutrient uptake and export from an Australian cotton field. *Nutrient Cycling in Agroecosystems* **77**: 213-223.
- Dorahy CG, Blair GJ, Rochester IJ and Till AR (2007). Availability of P from ³²P-labelled endogenous soil P and ³³P-labelled fertilizer in an alkaline soil producing cotton in Australia *Soil Use and Management* **23**, 192-199.
- Chen D, Freney JR, Rochester I, Constable GA, Mosier AR and PM Chalk (2007). Evaluation of a polyolefin coated urea (Meister) as a fertilizer for irrigated cotton. *Nutrient Cycling in Agroecosystems* **81**, 245-254.
- Dorahy, C.G., Rochester, I.J., Blair, G.J. and Till, A.R. (2008) Phosphorus use-efficiency by cotton grown in an alkaline soil as determined using ³²phosphorus and ³³phosphorus radio-isotopes. *Journal of Plant Nutrition* **31**: 1877-1888
- Peoples M.B., J. Brockwell, D.F. Herridge, I.J. Rochester, B.J.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khan, H. Hauggaard-Nielsen, and E.S. Jensen (2009). Review article: The contributions of nitrogen fixing crop legumes to the productivity of agricultural systems. *Symbiosis J.* **48**, 1-17.
- Dodd K, Guppy C, Lockwood P, Rochester I (2009). The effect of sodicity on cotton: Plant response to solutions containing high sodium concentrations. *Plant and Soil* **330**, 239–249 10.1007/s11104-009-0196-6
- Rochester IJ (2010). Phosphorus and potassium nutrition of cotton: interaction with sodium. *Crop and Pasture Science*. (in press)
- Rochester IJ (2010). Sequestering carbon in minimum-tilled clay soils used for irrigated cotton and grain production. *Soil and Tillage Research* (in review),
- Rochester IJ (2010). Assessing internal crop Nitrogen use efficiency in high-yielding irrigated cotton. *Nutrient Cycling in Agroecosystems* (in review),

Websites

NutriLOGIC has been updated regularly:

<http://cottassist.cottoncrc.org.au/NutriLOGIC/Default.aspx>

Conference papers

- Peoples M.B., J. Brockwell, D.F. Herridge, I.J. Rochester, B.J.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khan, H. Hauggaard-Nielsen, and E.S. Jensen (2007). Review article: The contributions of nitrogen fixing crop legumes to the productivity of agricultural systems. The 15th International Congress on Nitrogen Fixation, January 21–26, 2007, Cape Town, South Africa.
- Peoples, M.B., Rochester, I.J. and Layzell, D.B. (2007). Environmental impact of legumes and their role in cropping systems to meet future demands for food, fibre and

- bioenergy. Proceedings 6th European Conference on Grain Legumes (Lisbon, 12-16 November, 2007) Abstract (http://www.grainlegumes.com/aep/events/lisbon_2007/)
- Errington M, Campbell L, Rochester I, Tan D (2007). Efficacy of foliar fertilization in cotton Proceedings 4th World Cotton Research Conference (Lubbock, Texas, 10-14 September, 2007) (<http://wcrc.confex.com/wcrc/2007/>)
- Rochester IJ (2008). Optimizing N fertiliser use and N fertiliser use-efficiency. In: Cotton in a Climate of Change, proceedings 14th Australian Cotton Conference (Broadbeach, 12-14 August, 2008) 6pp (www.australiancottonconference.com.au) 14th Australian Cotton Conference. Broadbeach, Queensland.
- Rochester IJ (2010). Sequestering Carbon in Irrigated Cotton Soils. In: fashioning the Future, proceedings 15th Australian Cotton Conference (Broadbeach, 10-12 August, 2010) 6pp (www.australiancottonconference.com.au) <http://www.australiancottonconference.com.au/resources.php?ContentID=3&PresenterID=35>

Extension articles

- Rochester I, O'Halloran J, Maas S, Sands D, Brotherton E (2007) Monitoring nitrogen use efficiency in your region. Australian Cottongrower magazine. (Aug 2007 p22).
- Rochester I, Filmer M (2007). Benchmarks identified for nitrogen efficiencies. Farming Ahead. No. 190. (November 2007 p 52-55). www.kondinin.com.au
- Rochester I, Ceeney S, Maas S, Gordon R, Hanna L, Hill J (2009) Monitoring nitrogen use efficiency in cotton crops. Australian Cottongrower magazine. (May 2009 p42).

Part 4 – Final Report Executive Summary

This project aimed to identify means to improve nutrient use-efficiency in Australian cotton production systems and to improve soil health/fertility. The NutriLOGIC DSS provides an updated resource for cotton growers to manage soil fertility and cotton nutrition. This program provides recommendations to optimise crop nutrition through interpreting soil and plant analyses.

N use-efficiency has been benchmarked and indicates the cotton industry substantially over-uses N fertiliser. The industry can safely reduce N fertiliser inputs by about 25% without reducing yield.

The cotton industry can become carbon positive by adopting minimum tillage practices, by incorporating all crop stubble, by including legume crops in the rotation and reducing fallow times. Producing cotton using sustainable soil and crop management and reducing our net CO_{2e} emissions will greatly assist marketing Australian cotton.

Soil health can be improved dramatically with legume cropping. Marked improvements can be seen in the soil physical environment, chemical fertility and biological activity in those cropping systems that include legumes. For example, the cotton-vetch-fallow-cotton rotation remains the highest-yielding system and requires very little N fertiliser and therefore produces low carbon emissions.