Australian Government
Cotton Research and Development Corporation

FINAL REPORT 2013

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: CRC1115

Project Title: Developing N-efficient cotton systems that produce low GHG emissions and promote healthy soil

Project Commencement Date: 1/07/2010 **Project Completion Date:** 30/06/2013

CRDC Program: 4 Farming Systems

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Signature of Research Provider Representative: ______________________________

Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

Soil Carbon status and stubble management
Soil organic C has increased substantially within the cropping systems experiment at Narrabri, but moreso in the legume-based systems. These increases are sufficient to offset the C emissions associated with cotton production within the field, especially where soil C levels have substantially increased in the subsoil. Soil C status is strongly related to how crop stubble is managed; retaining stubble at the surface limits C entering the soil system, compared with incorporating stubble where it is assimilated by the soil microbial biomass.

Efficient use of Nitrogen fertilisers
Cotton NUE has declined across the industry over the past 3 years due to excessive N fertiliser use. It will be possible to measure crop NUE industry-wide by analysing fuzzy seed for its N content. Higher-yielding cultivars that take up more nutrients as well as improved soil fertility have resulted in changed nutrient use-efficiency over time.

Greenhouse gas emissions (GHG)
Previous studies have shown substantial emissions of GHG's, especially where high rates of N fertilisers are used and in irrigated systems which exacerbate the problem. This project will provide insight into better management practices that will minimise GHG emissions. Nitrous oxide (N_2O) and carbon dioxide (CO_2) will be measured in an associated project that will be supervised by Dr Rochester with technical and scientific expertise provided within it to directly measure GHG emissions from cotton cropping systems.

Benefits of legume cropping on soil health
Apart from improved soil N status, legume cropping improves soil structure, increases soil organic C status and promotes a more active and dynamic soil microbial biomass and enhances nutrient availability. The cropping systems experiment at Narrabri has enabled changes in soil health parameters to be measured, which are becoming more noticeable in the subsoil over time.

Nutrient Management
The NutriLOGIC DSS helps managers determine appropriate fertiliser management strategies based on soil and crop tissue analyses. It provides information on all nutrients and links to NUTRIpak. NutriLOGIC is regularly updated. An independent study has shown the critical nutrient levels embedded in NutriLOGIC are appropriate for very high-yielding cotton.

Objectives

This project will assist the cotton industry to reduce its impact upon the environment and improve the health of its soil resource and achieve its aims to use fertiliser inputs more efficiently.

Soil health benefits will be measured within the cropping systems experiment. A greater emphasis will be placed on biological aspects than in the past, especially in regard to remediating the subsoil. Soil physical and chemical fertility will continue to be monitored.

Changes in Soil C will be measured regularly in the cropping systems experiment to identify best management practices. This will include identifying better stubble management practices. The project aims to demonstrate that simple changes in management can improve soil C status that can balance eCO_2 emissions from cotton production.

N use-efficiency will be further calibrated in N fertiliser rate experiments annually. With assistance from CRC adoption program, this project will extend the use cottonseed N analysis to assess NUE industry-wide that will provide feedback to growers about their use of N fertiliser in a field basis. This will help minimise fertiliser-derived nitrous oxide emissions from cotton crops. Better management practices will be developed to ensure GHG emissions are reduced by using data derived in the associated GHG project that will measure emissions of N_2O and CO_2.

Other nutrients: The NutriLOGIC program will be upgraded with more definitive guidelines for all nutrients including N. This will provide more effective guidelines to restore / maintain soil chemical fertility and avoid crop nutrient deficiencies. The use-efficiency of other nutrients (especially P and K) will also be assessed.

Methods

2. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

- Continue the cropping systems experiment allows comparison of legume and non-legume rotation crops and quantifies N fertiliser response in cotton
- Soil organic carbon analyses done using dichromate oxidation
- Soil biological activity assessed by measuring soil microbial biomass
- Soil structure compared using a cone penetrometer
- Soil chemical fertility assessed through commercial soil analyses
- Stubble management options assessed by observing changes in soil carbon levels, soil microbial biomass and water holding capacity under controlled laboratory conditions
- Cottonseed N analyses done using both NIR technology and Kjeldahl analyses
- Plant N analyses done using Kjeldahl analysis – other nutrients by ICP analysis
- Experiments to assess changes in nutrient use efficiency done by comparing current and redundant cotton cultivars
- Remote sensing data compared with crop and soil nutrient data using statistical programs

Results

3. Detail and discuss the results for each objective including the statistical analysis of results.

Soil carbon and stubble management

The results of 15 years monitoring of soil organic carbon (SOC) in the larger of the two cropping systems experiment in field 6west at ACRI was published in 2010 and is updated in the following figure 1. Also, soil collected from the smaller experiment (field 6east) has been analysed for SOC and is presented in figure 2. Both experiments show a similar increase in SOC. When the deeper soil profile (30-50 cm) is examined, the rate of SOC accumulation is greater, compared with the surface soil (0-30 cm). The rate of SOC increase over the period of sampling was 0.23 t SOC/ha/yr in the surface soil and 1.06 t SOC/ha/yr for the 30-60 cm layer. Combining the data for 0-60 cm, the SOC increased by 1.29 t SOC /ha/yr. This increase in SOC is equivalent to 4.7 t eCO_2 that would more than compensate for the estimated average 1 to 1.5 t eCO_2/ha produced during a cotton crop. There is no strong evidence for SOC increasing below 60 cm. Figure 3 shows the significant increase in SOC over time for the soil profile to 90 cm that has averaged 1.04 t C/ha/yr (or 3.8 t eCO_2/ha/yr) over the monitoring period.

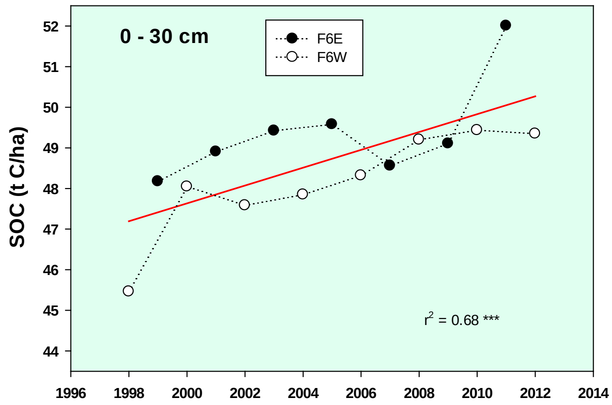


Figure 1.
Soil organic carbon (SOC) in the 0-30 cm layer of the two cropping systems experiments in field 6 at ACRI.

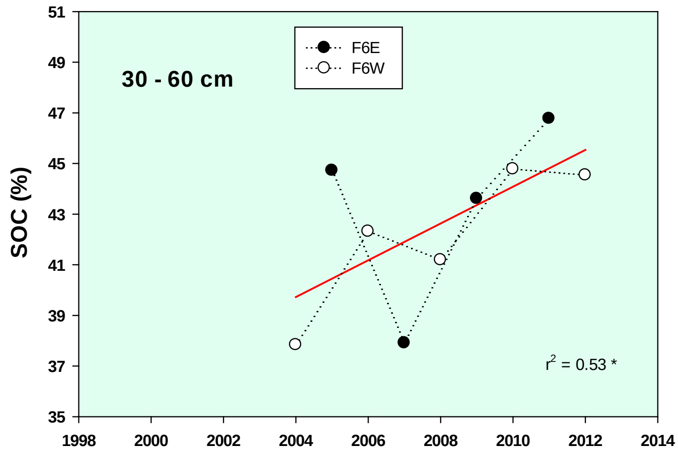


Figure 2.
Soil organic carbon (SOC) in the 30-60 cm layer of the two cropping systems experiments in field 6 at ACRI.

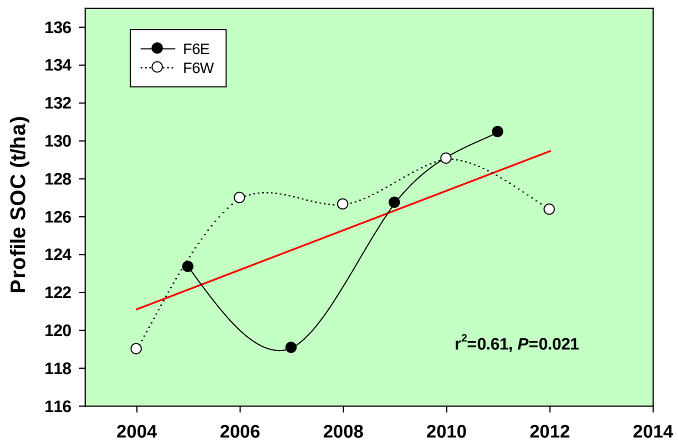


Figure 3.
Soil organic carbon (SOC) in the soil profile (0-90 cm) of the two cropping systems experiments in field 6 at ACRI.

Two experiments were conducted by incubating soil to which crop stubble has been applied and either left on the soil surface or incorporated into the surface soil to 10 cm depth. These incubation experiments were done over several months at either 15^{0}C (in a shed over winter) or 32^{0}C (in a glasshouse during summer). Soil was kept moist with weekly irrigation to field capacity. There was no effect of stubble type added (either vetch or cotton), but a highly significant effect of stubble placement (surface or incorporated). These effects were similar at both incubation temperatures.

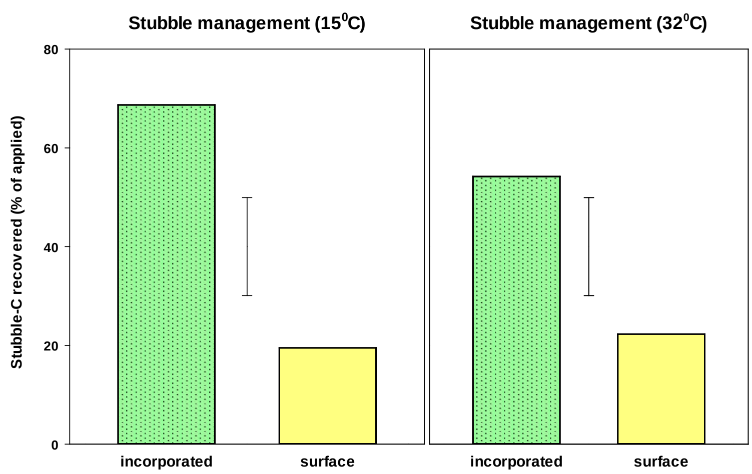
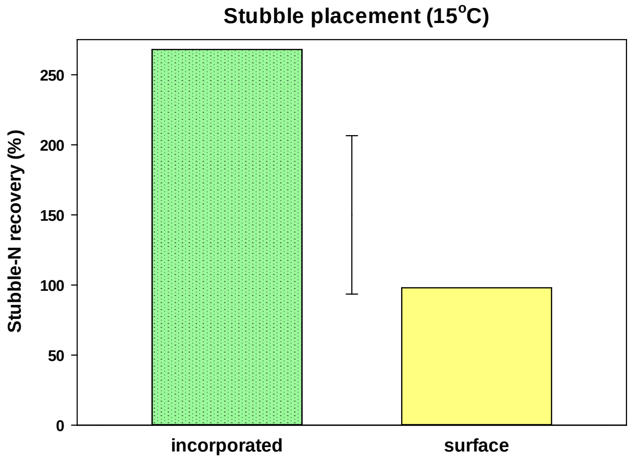


Figure 4.
The recovery of stubble-C in pots of soil to which stubble was applied either to the surface or incorporated into the soil and incubated at either 15 or 32^{o}C. Error bars are the lsd (P=0.05).

Importantly, the incorporation of stubble also provided an energy source for the free-living (non-symbiotic) N-fixing bacteria in the soil. At completion of the incubations at both temperatures, appreciable quantities of N had been fixed in the soil due to this process. The process is probably limited in the field when the soil dries and the same level of N input may not occur unless the soil is maintained in a moist condition. In the 32^{o}C experiment, fixation of more than 100 kg N/ha was calculated where vetch stubble was added and 40 kg N/ha where cotton stubble was added. In the 15^{o}C experiment, fixation of more than 160 kg N/ha was calculated where vetch stubble was added and 80 kg N/ha where cotton stubble was added. No N fixation was apparent where the stubble was surface applied, and little N was lost, in contrast to C.



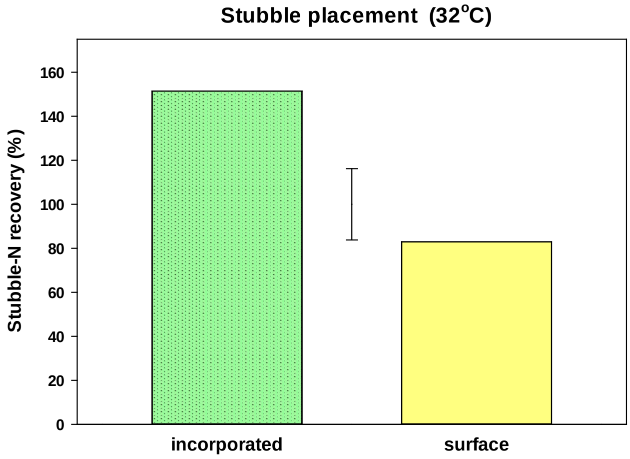


Figure 5.
The recovery of stubble-N in pots of soil to which stubble was applied either to the surface or incorporated into the soil and incubated at either 32 or 15^{o}C. Errors bars are the lsd (P=0.05).

<u>Nitrogen fertiliser response and use-efficiency</u>

The response to applied N fertiliser with respect to cotton yield has been studied within two cropping systems experiments. Although legume crops have been grown in some systems, there is usually a need to apply N fertiliser to maximise profit and yield. Lint yield data for the past three seasons presented in Figure 5 below are representative of high-yielding commercial cotton crops.

In 2011, the cotton crop did not establish well in the continuous cotton systems, but the slightly decreased plant population could not account for the poorer lint yield – this may have been due to increased seedling disease in these treatments. This effect was not as significant in 2013.

Wheat and faba bean rotations consistently produce the highest cotton lint yields, and have recently out-performed the vetch-fallow system. Reasonably high lint yields were attained without N fertiliser, but applying N fertiliser increased yield by about 30%. All systems, even the legume systems required some N fertiliser.

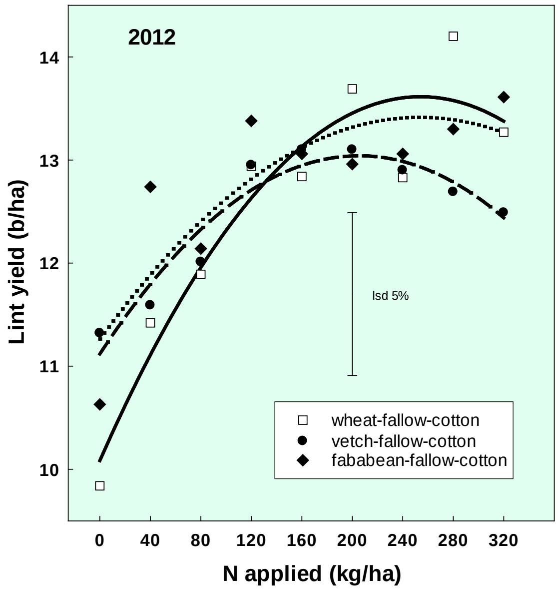
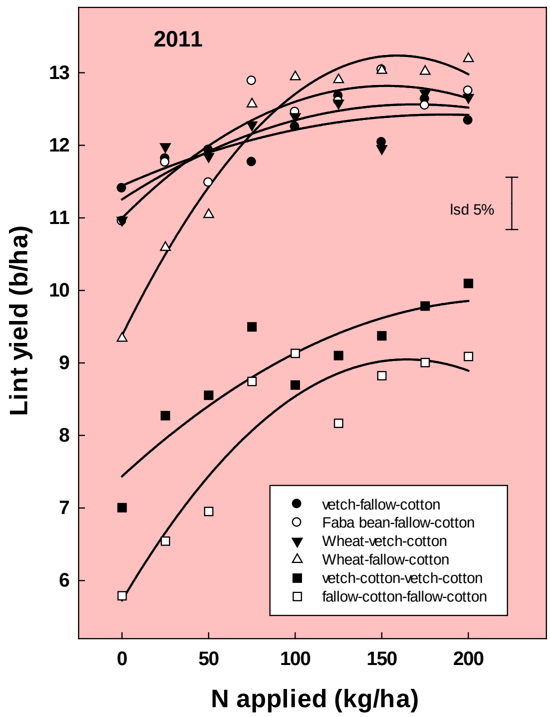
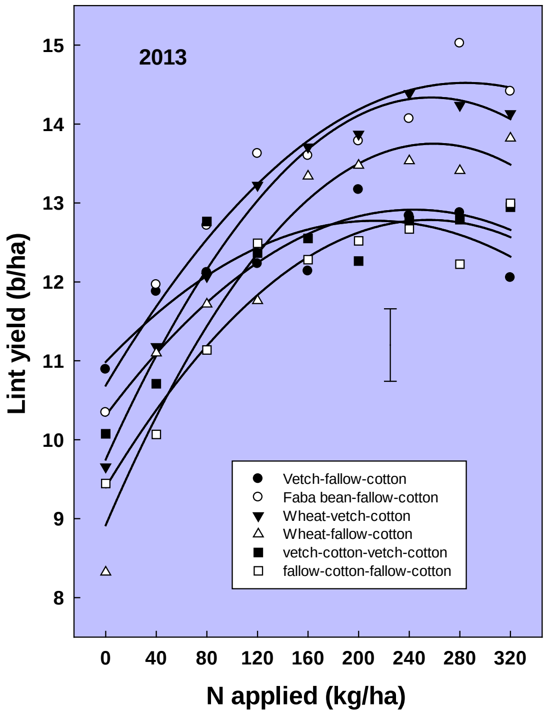


Figure 6.
The response in lint yield to applied N fertiliser in two cropping systems experiments from the 2011, 2012 and 2013 picking years. Errors bars represent the lsd (*P*=0.05) for the cropping system x N fertiliser interaction.





The published value for optimum Crop N use-efficiency (12.5 kg lint / kg crop N uptake) did not deviate substantially in the 3 years of these experiments. Table 1 below indicates the lint yield, economic optimum N fertiliser rate, crop NUE and N fertiliser use-efficiency (NFUE) in these experiments meaned over the cropping systems, for the past three seasons. The flooding that occurred in 2011/2012 reduced NFUE and increased Crop NUE relative to the other years.

Table 1. Lint yield at the economic optimum fertiliser rate, and associated measures of N use-efficiency. Within crop sequence, V refers to vetch, W to wheat, Faba to faba beans and C to cotton and ~ to fallow.

Season	Crop sequence	Lint yield (b/ha)	Optimum N fertiliser (kg/ha)	Crop NUE (kg/kg)	NFUE (kg/kg)
2010-11	~C~C	12.3	124	9.58	22.5
	vCvC	12.8	131	11.0	22.1
	W~C	12.5	131	11.6	21.7

	WvC	13.2	148	10.6	20.3
	Faba~C	9.82	188	9.65	11.9
	V~C	9.02	150	10.0	13.7
2011-12	W~C	13.5	223	14.6	13.8
	WvC	13.0	168	13.8	17.5
	Faba~C	13.3	201	13.0	15.1
2012-13	~C~C	12.7	222	12.8	12.9
	vCvC	12.9	204	11.7	14.3
	W~C	13.8	235	11.8	13.3
	WvC	14.3	232	12.2	14.0
	Faba~C	14.5	248	12.2	13.3
	V~C	12.7	169	13.5	17.1

When the data from the last three years from all the N fertiliser rates and cropping systems are considered (Figure 7), there is no discernible change in the relationship between crop NUE and excess N fertiliser application.

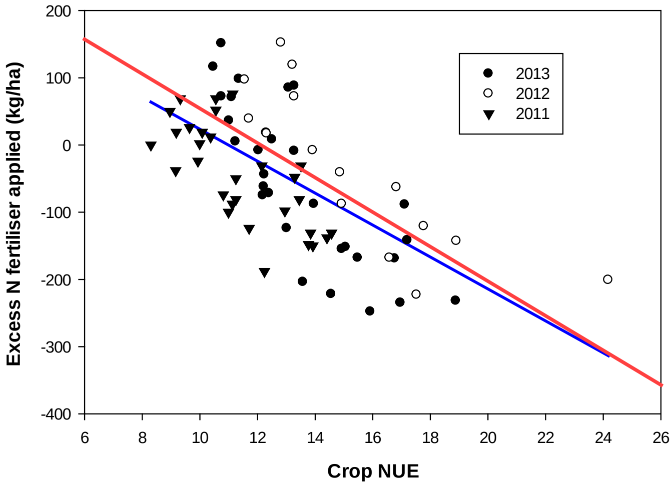


Figure 7.
The relationship between Crop NUE and excess N fertiliser application in two cropping systems experiments from the 2011, 2012 and 2013 picking years. The red line is the established relationship, the blue line the linear regression line for the three years.

An alternative measure of N fertiliser use-efficiency (NFUE) uses lint yield / kg N fertiliser applied (Figure 8). This measure takes no account of background soil N and therefore, the two measures of NUE are poorly correlated. However, NFUE can indicate where N fertiliser is used inefficiently. A value of between 12.5 and 16 indicates sufficient N was applied (ie where excess N fertiliser equals 0±25 kg N/ha – Figure 8) and where N fertiliser is used efficiently (Table 1).

The third means of assessing NUE in cotton is with fuzzy seed N analysis. This procedure has been used in surveys of the cotton industry and the research has been published in a peer-reviewed journal (Figure 9). All three methods indicate where excess or inadequate N fertiliser has been applied.

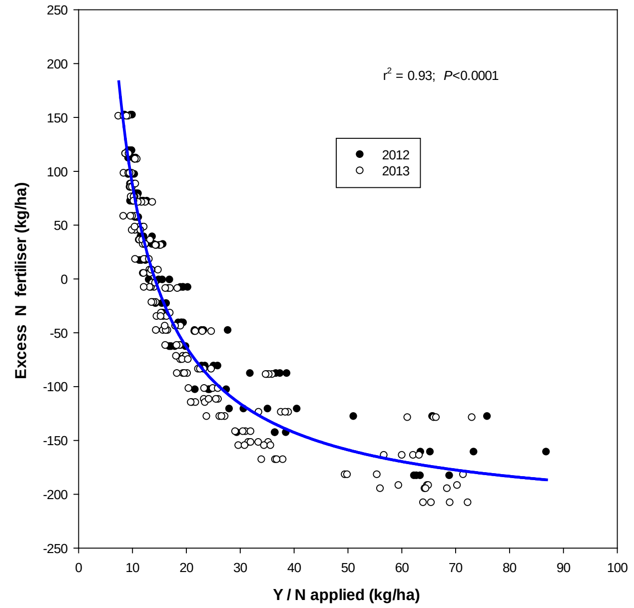


Figure 8.
The relationship between N fertiliser use-efficiency (NFUE) and the excess or inadequate application of N fertiliser in two cropping systems experiments from the 2012 and 2013 picking seasons.

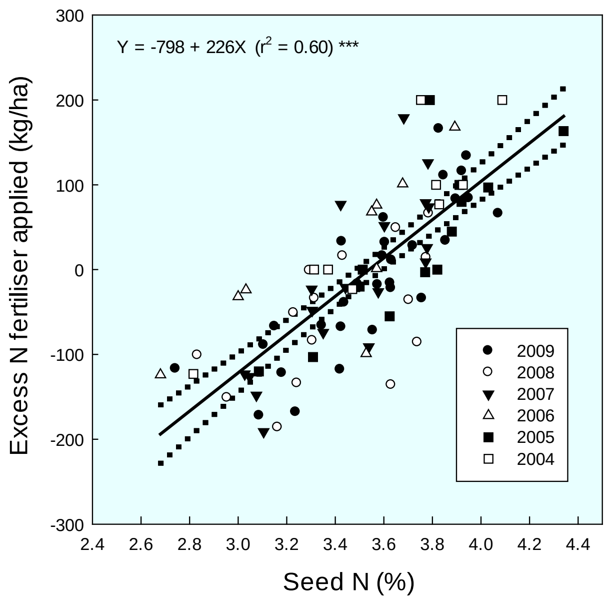


Figure 9.
The relationship between the N concentration in fuzzy cotton seed and the excess or inadequate application of N fertiliser in two cropping systems experiments between 2004 and 2009 picking seasons.

Greenhouse gas (GHG) emissions

A separate GHG project is being conducted in the ACRI Field 6 cropping systems experiment with N fertiliser rates being the main treatment; the results are reported in a separate final report. In addition to this, CSIRO PI appointed a summer student (Crystal Wood) to study the emission of nitrous oxide (N_20) from crop foliage during the summer of 2012-13. This project confirmed that about 10% of the N_2O emitted from the system was evolved through the crop foliage and the rest directly from the soil. There was no indication that N_2O was formed within the plant, but was transpired as water moved through the plant. The release of N_2O was linked to time after irrigation, the time of day, but importantly, not to the rate of N fertiliser applied. There is a plan to publish this study in 2013.

Benefits of legume cropping on soil health

Legume crops provided some organic N to later crops. Over the past 3 years, faba bean crops have fixed up to 400 kg N/ha, but averaged an input of 220 kg N/ha after seed was harvested. Vetch crops have averaged inputs of 110 kg N/ha, largely due to dry winters. However, their effect on soil health is noticeable beyond the N effect, by providing small improvements in soil water holding capacity, encouraging soil organic matter accumulation and reducing cone penetrometer resistance, thereby facilitating root exploration by cotton crops.

Figure 10 below demonstrates a small but statistically significant decrease in the force needed to move through the soil profile in the systems that included a legume. This is measured using a cone penetrometer that records the force required to insert a small metal cone into the soil profile.

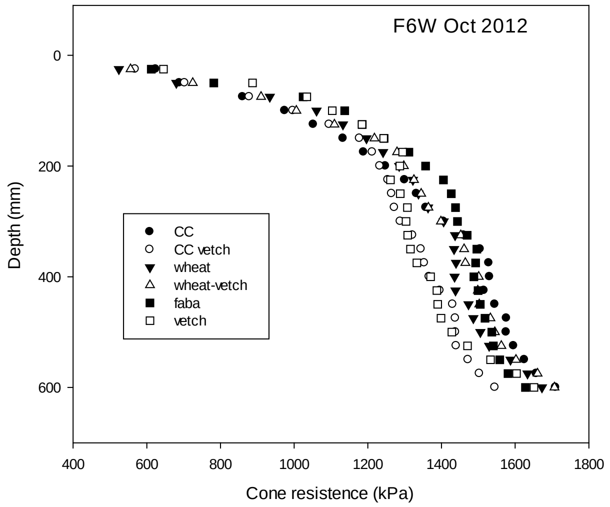


Figure 10.
The pattern observed in soil strength at increasing depth in the profile in six cropping systems measured after sowing in 2012.

Soil water was also monitored using Odyssey capacitance probes that record soil moisture to 1 m depth. The difference in soil water between refill and depletion before and after irrigation indicates crop water extraction. In 2012-2013, the crop water use was calculated for the six cropping systems examined. Figure 11 below indicates the relationship between irrigation water use by the crop and lint yield. The experiment was irrigated six times, and five in-crop. The highest yields were in the wheat-fallow, wheat-vetch and faba bean-fallow systems, while the continuous cotton and vetch fallow systems yielded the least and extracted less soil water.

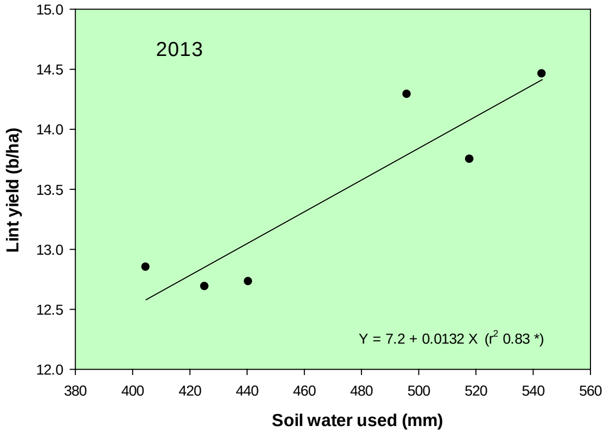


Figure 11.
The relationship between lint yield and soil water used by cotton in six cropping systems in2013.

Comparing the continuous cotton (CC) and faba bean (CFb~) rotation systems (see Figure 12 below) indicated that cotton following faba beans extracted 565 mm compared with 440 mm in the continuous cotton system (28% more water extracted – $P<0.01$) that possibly reduced water stress in the cotton that followed faba beans and enabled that crop to produce a greater lint yield. It is also acknowledged that other factor may have contributed to improved growth that led to more water use. Importantly, the legume system showed the highest and lowest refill points at each irrigation (Figure 12).

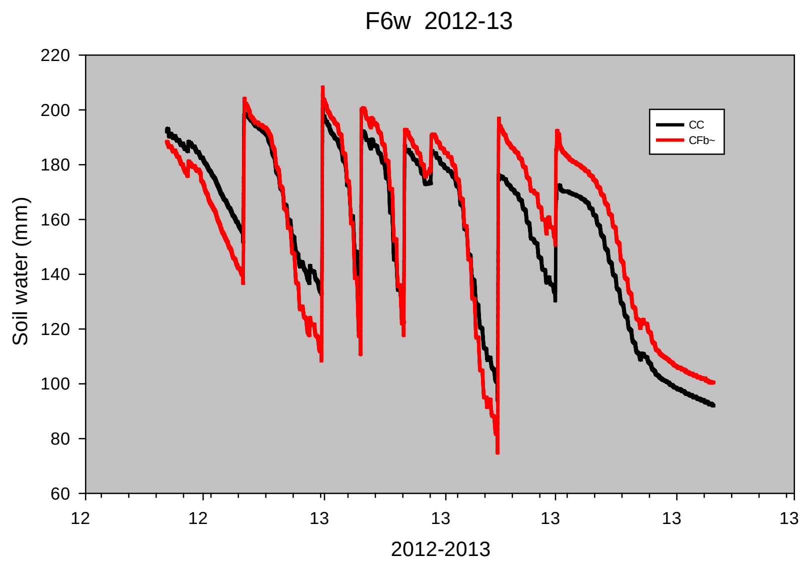


Figure 12.
Soil water measured in the highest and lowest yielding cropping systems during the 2012-13 cotton season.

Water used per bale of lint produced did not differ significantly among the cropping systems. use Water use-efficiency values averaged 2.9 bales/ML applied irrigation water and 1.7 bales/ML total water used by the crop (includes rainfall).

<u>Nutrient Management and NutriLOGIC upgrade</u>

There appears no evidence for any nutrient other than N being deficient in the soil or limiting crop growth in these field experiments. Zinc and boron have been applied previously, but the field remains highly fertile despite the continued high yield afforded by the cotton crops. The N fixed by the legumes largely remains in an organic form until decomposed; this input of N may be sufficient for all but the highest yielding cotton crops.

The soil N section of the NutriLOGIC program is being revised, to provide more precise and accurate recommendations to apply N fertiliser at the economic optimal rate and to use N fertilisers efficiently. The current version relies on inputs of soil nitrate-N, the rotation crop to indicate the level of N fertiliser required to optimise lint yield. This revision is based on data collected over the past eight years (2006 to 2013). The new data presented below will be incorporated into a revised NutriLOGIC in 2013. This data includes much higher yields than were used for the current version and the fertility of cotton soils generally has improved with time. The difference between yield at optimum N fertiliser application and the maximum yield is small, normally less than 20 kg lint/ha.

The inherent N fertility of the systems in these experiments is shown below by the amount of N taken up by the crop without added N fertiliser (Figure 13). The rotation crops chosen (and particularly the legume input), has a greater influence on crop N uptake than the pre-sowing soil nitrate level. However, soil nitrate-N still has a highly significant relationship with crop N uptake (r^2=0.30, P<0.001). In the current version of NutriLOGIC, soil nitrate-N is more influential than the cropping system in determining the N fertiliser recommendation, so the emphasis soil nitrate-N has changed somewhat with the revision.

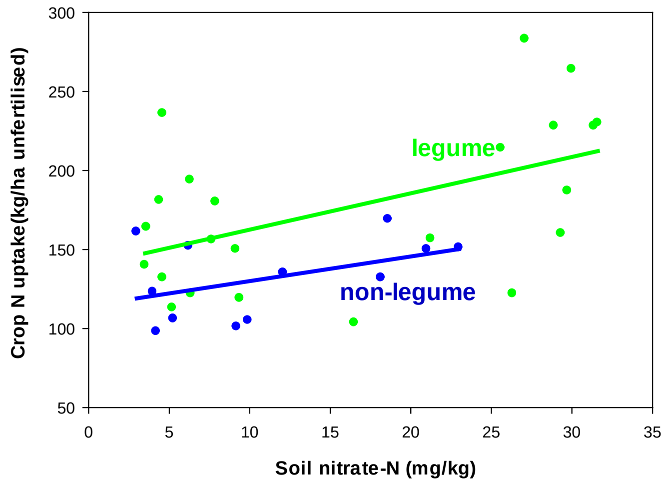


Figure 13.
The relationships observed between pre-sowing soil nitrate-N and crop N uptake at cut-out, meaned over cropping systems that included or excluded legume crops.

The amount of crop N needed to produce crops of a certain lint yield is shown in Figure 14. The difference between the crop N uptake produced without N fertiliser (Figure 13) and the amount of crop N uptake required to produce a specific yield (Figure 14), is the basis for the N fertiliser recommendation.

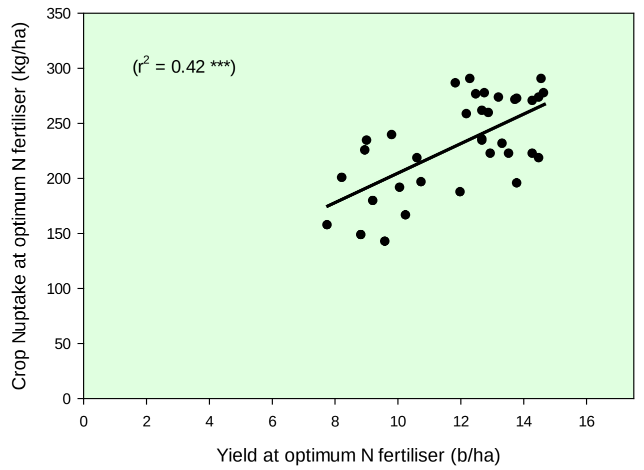


Figure 14.
The relationships observed between the economic optimum lint yield and crop N uptake required to achieve that yield over the past eight years.

Figure 15 below demonstrates the importance on soil-derived N which supplies between 68 to 75% of the crop's N requirement. Yield may be limited by the soils inability to supply nutrients, including N, in the quantities required by the crop, irrespective of fertiliser application.

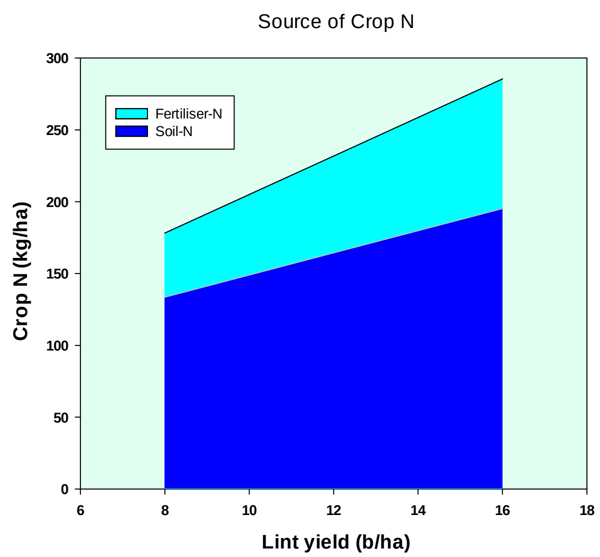


Figure 15.
Schematic representation of the soil-derived crop N and that derived from applied N fertiliser

The changes to the soil N section of the NutriLOGIC program will be implemented in 2013. The program will require an input of the expected yield level based on recent crop production from the specific field in question.

Outcomes

4. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

Soil carbon

Results of both experiments indicate clearly that management can play an important part in enabling soil carbon levels to increase substantially over time. This has beneficial impacts on soil health parameters including soil water holding capacity, improved soil structure, increasing the abundance of microbial populations to enable improved nutrient cycling.

Legume cropping

Legume crops continue to input substantial quantities of N fixed from atmospheric N_2. However, the soil incubation studies have demonstrated the importance of incorporating crop stubble to provide an energy source for free-ling N-fixing bacteria in the soil which can also import a significant quantity of N to the system. Legume impacts were not only on N inputs but also on soil structure (though increased SOC) and thereby allowing remediation of sub-soil limitations such as sodicity.

Crop nutrient use-efficiency

NUE has been precisely defined fro irrigated cotton production and data will soon be published for all other nutrients

Soil health

Soil health directly impacts on crop production by providing a better environment for root exploration, nutrient uptake, water storage and extraction. No one soil parameter appears to show any substantial improvement due to changes in soil or crop management, but the small effects are additive and can improve crop yields. Differences between cotton crops that follow rotation crops or cotton (ie back-to-back cotton) are more substantial and are a good indication of where advances in soil health can be more effective.

Improved NutriLOGIC

The data collected over the past several years has been collated to revise the soil N calibrations to more precisely indicate response to N fertiliser applications and indicate the quantities of n fertiliser required, after taking into account the rotation system, climate of the region, soil analysis value and the expected yield for the cotton crop, based on yields realised from previous crops.

Links to GHG project

The measurement of GHG's has been linked to the NUE research undertaken in the long-term N rate experiments at ACRI. The GHG project uses one of the four blocks of the experiment at ACRI. Four N fertiliser rates are compared within one cropping system, starting with the cotton phase, and continued through the faba bean crop and then fallow for several months. This has enabled the losses of N fertiliser to be quantified as gaseous N losses, whereas previously, these losses were assumed as combined leaching and denitrification losses.

Industry Engagement

Information relating to soil fertility and cotton nutrition has been freely given to cotton growers and their consultants regularly through phone conversations, field days, CRC cotton course and industry press etc. This project has assisted in two summer undergraduate projects (CSIRO-funded) and two post-graduate projects (Tim McLaren and Merry Conaty).

5. Please describe any:-

a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.); None
b) other information developed from research (eg discoveries in methodology, equipment design, etc.); and None
c) required changes to the Intellectual Property register. None

Conclusion

6. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

This research has shown how cotton cropping systems can use N fertiliser inputs more efficiently. This reduces the cost of fertiliser inputs on most cotton farms while reducing the emissions of GHG's such as N_2O. As well, changes to the management of the soil and crops has enabled soil carbon to be conserved, through the reduction of tillage operations (i.e. using permanent beds) and the incorporation of crop stubble (compared with leaving it on the soil surface). The health of the soil in these systems continues to improve in chemical fertility, better soil structure and a viable, diverse soil biota. Healthier soils will enable future increases in crop productivity. The changes that have occurred in these systems have helped them to remain highly productive and profitable.

Extension Opportunities

7. Detail a plan for the activities or other steps that may be taken:
   (a) to further develop or to exploit the project technology.
   In 2013, a national nutrient management program was initiated with the industries D&D team with each member conducting a crop nutrition/soil fertility experiment in their area in collaboration with a grower. This will provide a platform to demonstrate research outcome for nutrient management to ensure growers are optimising fertiliser inputs and measuring soil fertility and crop performance to optimise lint yield.
   (b) for the future presentation and dissemination of the project outcomes.
   The revision of soil N module of the NutriLOGIC program will provide a more precise estimate of N fertiliser needed to optimise cotton production than the current version.
   (c) for future research.
   There is a paucity of research involving crop stubble management and an opportunity is emerging for an in-depth study of the value of stubble to improve soil fertility.

8. A. List the publications arising from the research project and/or a publication plan.
   (NB: Where possible, please provide a copy of any publication/s)

<u>Refereed articles</u>

Dodd K, Guppy C, Lockwood P, Rochester I (2010). 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* 61: 1-10.

Sodium effect P and K

Rochester IJ (2011). Sequestering carbon in minimum-tilled clay soils used for irrigated cotton and grain production. *Soil and Tillage Research* 112, 1-7. DOI 10.1016/j.still.2010.10.012

Carbon - cotton soils

Rochester IJ (2011). Assessing internal crop Nitrogen use efficiency in high-yielding irrigated cotton. *Nutrient Cycling in Agroecosystems* 90, 147-156. DOI 10.1007/s10705-010-9418-9

Cotton - N use-efficiency

Rochester IJ (2012). Using seed nitrogen concentration to estimate crop N use efficiency in high-yielding irrigated cotton. *Field Crops Research* 127, 140-145. DOI 10.1016/j.fcr.2011.11.018

cotton Seed N% - NUE

Conferences

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

Grace, Peter; Barton, Louise; Chen, Deli; Eckard, Richard; Graham, John; Hely, Sara; Kelly, Kevin; Officer, Sally; Rochester, Ian; Rowlings, David; Scheer, Clemens; Schwenke, Graeme; and Wang, Weijin. (2010) The Australian nitrous oxide program. In: Gilkes, R.J, Prakongkep, N. (Eds.). Proceedings 19th World Congress of Soil Science; Published on DVD; http://www.iuss.org; Congress Symposium 4; Greenhouse gases from soils, IUSS, Brisbane, pp. 247-248.

Grace, Peter; Rowlings, David; Rochester, Ian; Kiese, Ralf; and Butterbach-Bahl, Klaus. (2010) Nitrous oxide emissions from irrigated cotton soils of northern Australia. In: Gilkes, R.J, Prakongkep, N. (Eds.). Proceedings 19th World Congress of Soil Science; Published on DVD; http://www.iuss.org; Congress Symposium 4; Greenhouse gases from soils, IUSS, Brisbane, pp. 179-182.

Rochester IJ and Constable GA. (2012) Nutrient use-efficiency in current and redundant cotton cultivars. Proceedings of the 16th ASA Conference UNE, Armidale. Capturing opportunities and overcoming obstacles in Australian Agronomy. http://www.regional.org.au/au/asa/2012/nutrition/7937_rochesteri.htm#TopOfPage

Unrefereed articles

Rochester IJ (2011). Sequestering carbon in irrigated cotton soils. Australian Cottongrower magazine, 2011

Rochester IJ (2011). Rotating towards carbon-neutral cotton crops. Australian Cottongrower magazine yearbook. 32 (5) p99.

Rochester IJ (2012). It pays to optimise N fertiliser inputs. Australian Cottongrower magazine, pp 40-42 April-May 2012

Rochester IJ (2012). Cotton seed N indicates fertiliser use efficiency. Australian Cottongrower magazine, pp 44-45 April-May 2012

Macdonald B, Nadelko, T, Rochester I (2012) Impact of nitrogen fertiliser losses from cotton. Australian Cottongrower magazine, pp 27-28 Aug-Sept 2012

Rochester IJ, Gordon K (2012). Increase soil carbon by managing stubble. Australian Cottongrower magazine, pp 31-33 Aug-Sept 2012

Book chapter

Rochester I, Constable G, Oosterhuis D (2012). Cotton nutrition during flowering and fruiting. *In* Flowering and Fruiting in Cotton. Eds DM Oosterhuis and JT Cothren. The Cotton Foundation Cordova, Tennessee USA.

B. Have you developed any online resources and what is the website address?

NutriLOGIC is regularly revised.
http://cottassist.cottoncrc.org.au/NutriLOGIC/About.aspx

Part 4 – Final Report Executive Summary

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Soil Carbon status and stubble management

Soil organic C (SOC) is reportedly declining in most cropping soils. Within the cotton cropping systems experiment at Narrabri, SOC has increased substantially, especially in the legume-based systems, and particularly in the subsoil. SOC increases of this magnitude are sufficient to offset the C emissions associated with cotton production. Soil C content is strongly related to how crop stubble is managed; incorporating stubble enables stubble-C to be assimilated within the soil microbial biomass compared with retaining stubble at the surface as most stubble-C is lost to the atmosphere. Increasing soil C is highly beneficial to crop production, soil health and the environment and is essential for consistently producing high-yielding cotton.

Efficient use of Nitrogen fertilisers

Cotton NUE has declined across the industry in recent years due to excessive N fertiliser use. Several measures of NUE have been defined and correlated with the economic optimum rates of N fertiliser application derived from N fertiliser rate experiments at ACRI. One new measure of NUE analyses fuzzy seed for its N content at the gin, another assesses NUE using lint yield and N fertiliser application rate. All are capable of identifying where excessive amounts of N fertiliser have been used. Adopting these tools will help the industry use N fertiliser more effectively and reduce GHG emissions.

Greenhouse gas emissions (GHG)

Previous studies have shown substantial emissions of GHG's, especially where high rates of N fertilisers are used and in irrigated systems which exacerbate the problem. Nitrous oxide (N_2O) and carbon dioxide (CO_2) are being measured in the cotton-based cropping systems experiment. This is providing insight into better management practices (i.e. optimising N fertiliser inputs and managing stubble better) to minimise GHG emissions.

Benefits of legume cropping on soil health

Apart from improved soil N status, legume cropping improves soil structure, increases soil organic C status and promotes a more active and dynamic soil microbial biomass and enhances nutrient availability. Importantly, the amounts of water extracted from the legume-based systems has increased, which is closely correlated with higher-yielding systems. The cropping systems experiments at ACRI have shown changes in soil health parameters, particularly in the subsoil. Including legume crops in the systems benefits soil health in several ways, not just with N inputs, but by also improving soil water storage and extraction, soil structural improvement, and builds resilience into the soil system to provide for better crops.

Nutrient Management

The NutriLOGIC DSS helps managers determine appropriate fertiliser management strategies based on soil and crop tissue analyses. It provides information on all nutrients and links to NUTRIpak. NutriLOGIC is regularly updated to ensure that the critical nutrient levels embedded in NutriLOGIC are appropriate for high-yielding cotton. The soil N section of NutriLOGIC is currently being revised in a way that will facilitate future revisions. This ensures the most recent high-yielding crops are included in the nutrient recommendation calibrations. It is important that cotton growers and consultants have access to a facility that interprets soil and crop tissue nutrient analyses and recommends fertiliser applications independently of fertiliser resellers and manufacturers.

Cropping systems

This research project has identified cotton cropping systems that use inputs of fertiliser resources and energy efficiently, conserve soil carbon, produce low GHG emissions, and yet are highly productive and profitable. The health of these soils will continue to improve with the management systems employed and this will enable cotton productivity to increase in the future.