FINAL REPORT

(due on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: **1.04.10**

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Cotton CRC Program: The Farm

Part 2 – Contact Details

Administrator: Jo Cain (Administration Manager)
Organisation: CSIRO
Postal Address: Locked Bag 59, Narrabri, NSW 2390
Ph: 02 67991513 **Fax:** 02 6793 1186 **E-mail:** jo.cain@csiro.au

Principal Researcher: Dr Michael Braunack (Research Scientist)
Organisation: CSIRO
Postal Address: Locked Bag 59, Narrabri, NSW 2390
Ph: 02 6799 2416 **Fax:** 02 6793 1186 **E-mail:** michael.braunack@csiro.au

Supervisor: Dr Michael Bange (Principal Research Scientist)
Organisation: CSIRO
Postal Address: Locked Bag 59, Narrabri, NSW, 2390
Ph: 02 6799 15 **Fax:** 02 6793 1186 **E-mail:** michael.bange@csiro.au

Signature of Research Provider Representative: ______________________________

Part 4 – Final Report Guide (due at end date of project or 31st May 2012)

Background

The Cotton CRC and CRDC have, over the years, invested heavily in production related research to address the many challenges for sustainable, profitable and competitive cotton production in Australia. Although much of this research has been excellent, the challenge is to integrate research findings across a range of areas (e.g. pests, nutrition, agronomy, diseases, traits), when the recommendations maybe contradictory and the interactions are poorly understood and against a background of variable climate. Growers and agronomists are tackling these issues on farm though this information is not being effectively used – there is a great opportunity to harness and extend on these results.

There remains a strong need for leadership in integration and evaluation of research. This need is identified clearly in the Cotton CRC strategic plan and in the outputs for Sub-program 1.3 'Plants and soils'. Investment in this area is a priority that has been identified by both CRDC and the Cotton CRC, and was strongly endorsed by the ACGRA. This project will address the issues raised by ACGRA by undertaking experiments targeting the high yield and fibre quality issues, some in conjunction with growers. The research will also undertake components of helping to assemble current knowledge and co-ordination with other researchers especially those involved in farming systems related research.

Objectives

i. To assemble and critically analyses data from high yielding fields and current research to understand the essential factors in farming systems achieving high yield, and identify non-essential or marginal issues. Achieved

ii. From this analysis design and conduct targeted farming systems experiments to explore the contribution of different practices and input levels to yield and quality as well as their interactions and efficiency of use. Achieved

iii. New initiatives for cotton farming systems. Achieved

Methods

Objective (i). Assemble and critically analyse data from high yielding fields.

Several potential sources of data were investigated to determine their suitability to identify the most and least important factors in farming systems contributing to high yields and quality cotton. These included the Crop Consultants of Australia Surveys (CCA), proceedings of the Australian Cotton conferences, published research trial results, and the Cotton Seed Distributors (CSD) and Deltapine Company variety trial results.

The CCA surveys were not appropriate in that the results mainly present chemical use by the cotton industry and do not specifically report management inputs, cotton yield or quality parameters. Also, the survey data are expressed as percentages of respondents which often did not provide an industry wide perspective since only a small number of surveys were returned compared with the number distributed. Similarly the cotton conference proceedings, while providing some insight to agronomic input, crop rotation and yield were not useful as no quality parameters were reported. Research papers were not a good source of information as most experiments were conducted to investigate a particular issue and do not necessarily present agronomic inputs and quality parameters. The CSD and Deltapine variety trial results and a long-term rotation trial (Hulugalle et al. 2006, 2009) were the only sources of data reporting agronomic inputs and cotton yield and quality. The data also covered both irrigated and dryland systems and a selection of cultivars grown across a range of environments and thus represented an industry wide picture.

The analysis of data was limited from 2003/2004 to the 2009/2010 season. This corresponds to the wide adoption of Bollgard II® (genetically modified to provide resistance to the cotton pest *Helicoverpa armigera*) and Roundup Ready® cultivars by the Australian cotton industry.

Using the statistical package Genstat13 (VSN International, 2010) correlation analysis was used to identify inputs that had a significant effect on yield and fibre quality in irrigated and dryland farming systems. The correlation coefficient was used to assess the relative importance of each factor on lint yield with the closer the correlation to +1 indicating both factors moving in the same positive direction and vice versa with correlations closer to -1 showing a negative relationship. Also, multiple linear regression was undertaken to identify inputs significantly affecting lint yield across the Australian cotton industry and included both irrigated and dryland systems. The equation was of the form indicated below;

$$LY = C + a\,(Irrn) + b\,(N) + c\,(P) + d\,(PS) + e\,(K) + f\,(PrevC) + g\,(Rain) + h\,(SL) + i\,(CDD) \quad (1)$$

where LY = lint yield (kg/ha), C a constant, Irrn = number of in-crop irrigations, N = nitrogen application (kg N/ha), P = phosphorus application (kg P/ha), PS = plant stand (plants/m), K = potassium application (kg K/ha), PrevC = previous crop, Rain = in-crop rainfall (mm), SL = season length (days), CDD = cumulative day degrees and a, b, c, d, e, f, g, h and i are estimated coefficients. No interactions between inputs have been considered in the regression.

Since the data set contains both current commercial and breeding lines the most popular commercial cultivar (Sicot 71 family) over the period is used as a standard in providing an industry perspective in changes in lint yield and fibre quality parameters.

Results

On an industry basis the factors significantly influencing lint yield and fibre quality include; nitrogen, phosphorus, plant stand, previous crop, in-crop rainfall, season length, crop choice (the use of transgenic v conventional cultivars), the number of insect sprays, with harvest year (season) affecting length, micronaire and trash and cumulative day degrees only influenced micronaire (Table 1).

Table 1. Correlation coefficients for industry wide management factors showing significant influence on lint yield and fibre quality using the Sicot 71 family

Factor	Lint yield (kg/ha)	Length (dec)	Micronaire	Strength (g/tex)	Trash
In crop irrigation	0.13**	-0.19***	0.20***		
Nitrogen	0.10*				
Season length	0.11*	0.14*	-0.33***		0.29***
Plant stand		-0.18***	-0.14*	0.12*	
Phosphorus	0.11*	-0.13*	0.15*		-0.13*
Crop choice		-0.34***		0.22***	-0.12*
No. insect sprays				0.16***	-0.12*
In-crop rainfall	-0.11*	0.18***	-0.18***	-0.24***	0.19***
Previous crop	0.14*	0.14*	-0.29***		0.13*
Cumulative DD			0.44***		
Harvest year		0.78***	-0.32**		0.44***

Significance level * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, DD = Day degrees, Crop choice = Transgenic v non-transgenic cultivars

Using the Sicot 71 family as an industry standard, management inputs significantly correlated with lint yield differ between irrigated and dryland farming systems (Table 2). Similar to lint yield the factors significantly correlated with cotton fibre quality varied between irrigated and dryland systems (Table 2).

Lint yield varied between rotation crops under both irrigated and dryland systems, with yields under irrigation being greater than under dryland (Fig 1 a, b). Also, the number of crops used in rotations has increased under both farming systems with cotton and wheat being the most frequent previous crop and legumes gradually increasing in irrigated systems (Fig 1 c, d).

The spread of lint yield was greater under irrigated than dryland systems with the lint yield increasing over time under both systems (Fig 2a, 3a) from 2004 to 2010.

The range in plant population narrowed over time under both irrigated and dryland systems and the trend with time was for lower populations compared with the beginning of the period (Fig 2b, 3b).

A wide range in the rate of nitrogen applied was observed under irrigated and dryland systems (Fig 2c, 3c)with the trend in application rate increasing under irrigation and decreasing under dryland systems, and the range of application rates became smaller (Fig 2c, 3c) during the period from 2004 to 2010. The range in phosphorus application rates varied between systems being greater under irrigated compared with dryland, however, the application rates narrowed over time and declined in both irrigated (Fig 2d) and dryland (Fig 3d) systems over the same period. Similarly the number of sprays for insect management deceased in both irrigated and dryland systems (Fig 2e, 3e), and the average number of in-crop irrigations decreased in irrigated systems (Fig 2f).

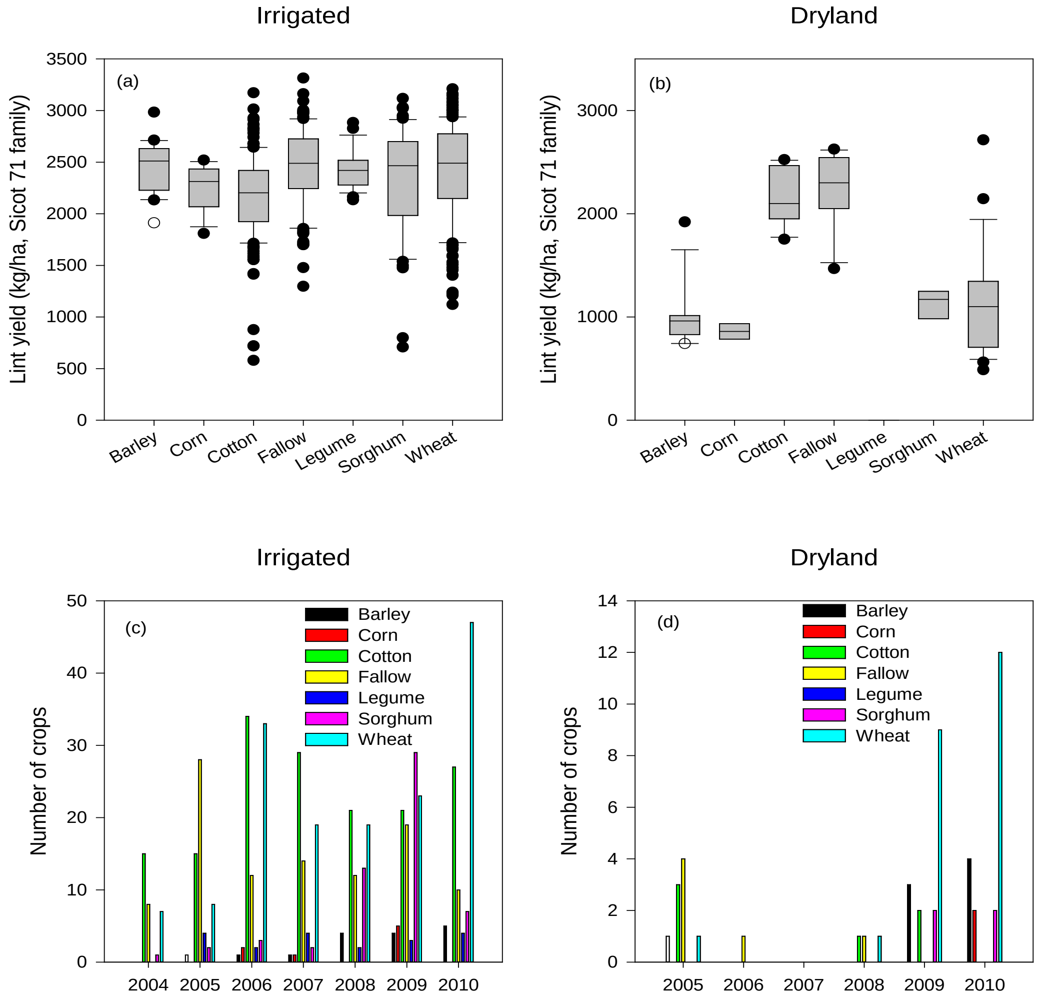


Figure 1 Lint yield (kg/ha) after different rotation crops for (a) irrigated and (b) dryland systems; and the range of rotation crops used in (c) irrigated and (d) dryland systems in Australia (Sicot 71 family data).

For irrigated systems lint yield (Fig 4a) and fibre length (Fig 4b), increased fibre strength (Fig 4c) and micronaire decreased (Fig 4d) and trash levels increased (Fig 4e). For dryland systems, lint yield decreased (Fig 5a), while fibre length (Fig 5b), fibre strength (Fig 5c), micronaire (Fig 5d) and trash levels (Fig 5e) all increased over the period from 2004 to 2010.

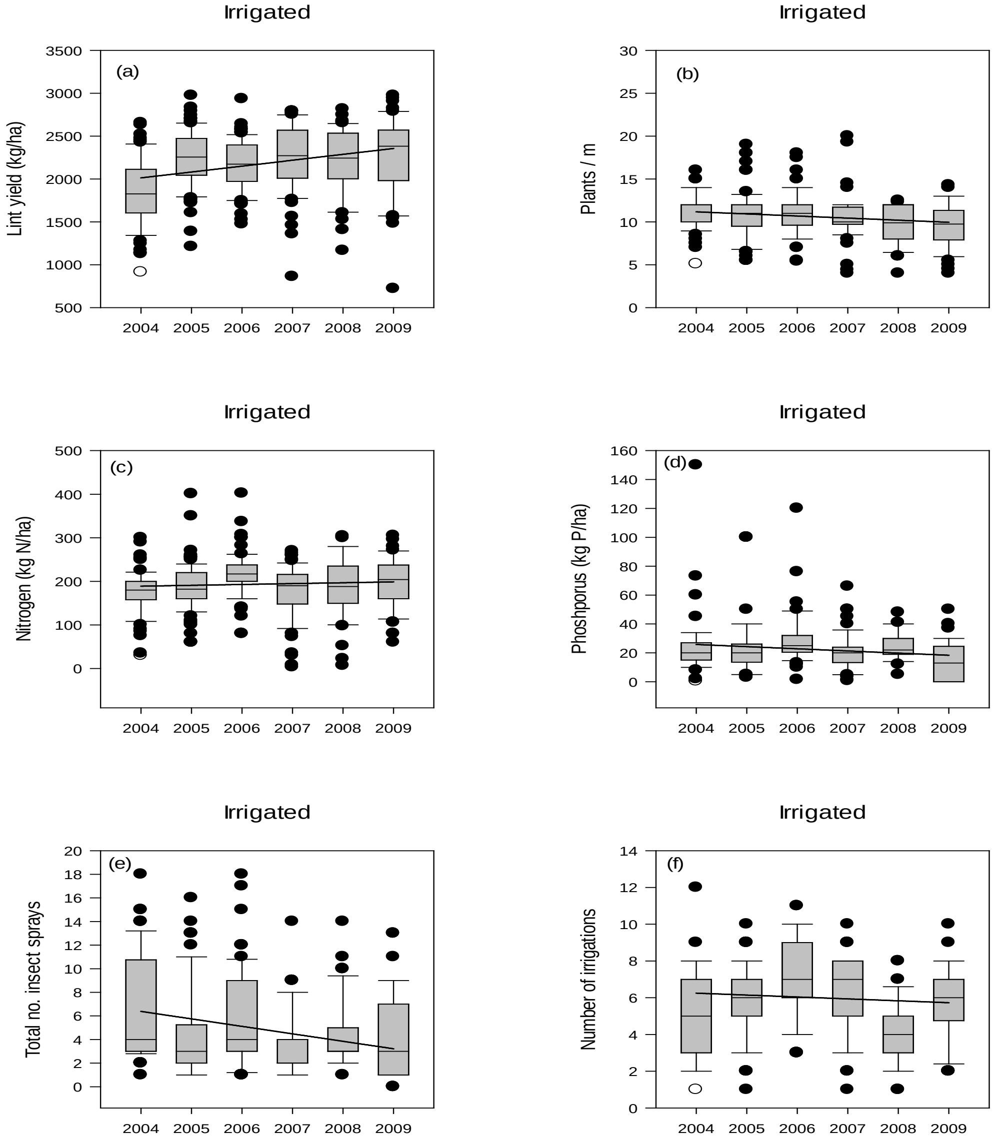


Figure 2 Changes in management; (a) lint yield, (b) plant population, (c) nitrogen application, (d) phosphorus application, (e) number of insect sprays and (f) number of irrigations under irrigated systems from 2004 to 2010 (includes commercial cultivars and breeding lines).

Table 2 Inputs significantly correlated with lint yield and fibre quality for irrigated and dryland farming systems (Sicot 71 family).

		Days to defoliation	Irrigations	Nitrogen	Phosphorus	Potassium	Plant stand	Previous crop	Rainfall	Crop choice	Insect sprays
Lint	Irrigated	0.10^{*}	0.27^{***}	0.13^{**}	0.14^{**}	-0.17^{***}		0.11^{*}	-0.21^{**}		0.10^{*}
	Dryland			0.79^{***}	0.57^{***}	0.36^{**}		-0.38^{*}		0.46^{***}	0.44^{***}
Micronaire	Irrigated	-0.19^{***}	0.18^{***}			0.16^{**}	-0.15^{**}	-0.27^{***}	-0.21^{***}		
	Dryland	-0.36^{**}									
Length	Irrigated	-0.10^{*}	-0.19^{***}	-0.11^{*}	-0.13^{**}	-0.26^{***}		0.20^{***}	0.18^{***}	-0.35^{***}	-0.23^{***}
	Dryland						-0.51^{***}		0.37^{**}		
Strength	Irrigated	0.13^{*}				-0.11^{*}		0.18^{***}		0.15^{*}	0.10^{*}
	Dryland						-0.26^{*}	0.32^{*}			
Trash	Irrigated								0.14^{*}	-0.16^{**}	-0.11^{*}
	Dryland	0.39^{*}		-0.57^{***}	-0.34^{*}			0.38^{*}			

Significance level * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ Crop choice = Transgenic v non-transgenic cultivars

Discussion

This is the first attempt to identify management inputs that are of greater or lesser importance in contributing to lint yield and fibre quality across the Australian cotton industry. Some of the trends observed over the period from 2004 to 2010 have to some extent been in response to seasonal conditions and reduced area planted especially for dryland systems. With few exceptions the changes have been in the same direction in irrigated and dryland systems, with the magnitude of change being greater in irrigated systems. This reflects seasonal conditions and the difference in water availability between the two systems. This is most evident with nitrogen use with a small increase under irrigation and a decrease under dryland. Over the last couple of seasons lint yield has increased in irrigated systems indicating better resource use efficiency. The number of irrigations decreased over the same period. Phosphorus use decreased in both systems, which may indicate build-up of soil P levels, while the number of insect sprays also decreased due to the adoption of transgenic cultivars by the Australian cotton industry. In conjunction with these trends is the large range of nutrient applications being used resulting in a range of outcomes; sometimes a large response in yield with either large or small application of N or P.

Diversity of rotation crops increased in irrigated systems while the number remained static under dryland. The indication is that rotation crops are an accepted part of the farming system.

Using the commercial Sicot 71 family to illustrate changes in lint yield and quality; lint yield increased under irrigation and decreased under dryland systems. Overall lint yield increased from 2004 to 2010 for the Australian cotton industry which is consistent with the observation by Constable et al. (2001). Strength decreased and length increased in irrigated systems and both increased in dryland systems. The increase in fibre length in both systems can be attributed to the adoption of Sicot 71B and Sicot 71BRF cultivars with increasing fibre length (G Constable, pers. com. 2012). The trends for dryland systems were affected by the extended drought during the period considered. This may indicate that differences in management and climate may have a greater influence than the underlying genetics of the cultivar.

The relative importance of components in a farming system differs with season and region and with the management style of individual grower's. The amount of variability in the various responses to inputs is an issue that makes it difficult to assign any certainty to the relative importance of one factor over any other in producing high lint yield and high quality cotton fibre. The fact that there are interactions between inputs also increases the complexity and difficulty in deciding which are the most important. Lint yield response seems to be optimised with 100-200 kg N ha^{-1}, 10-30 kg P ka^{-1} and 0-10 kg K ha^{-1} across the cotton industry.

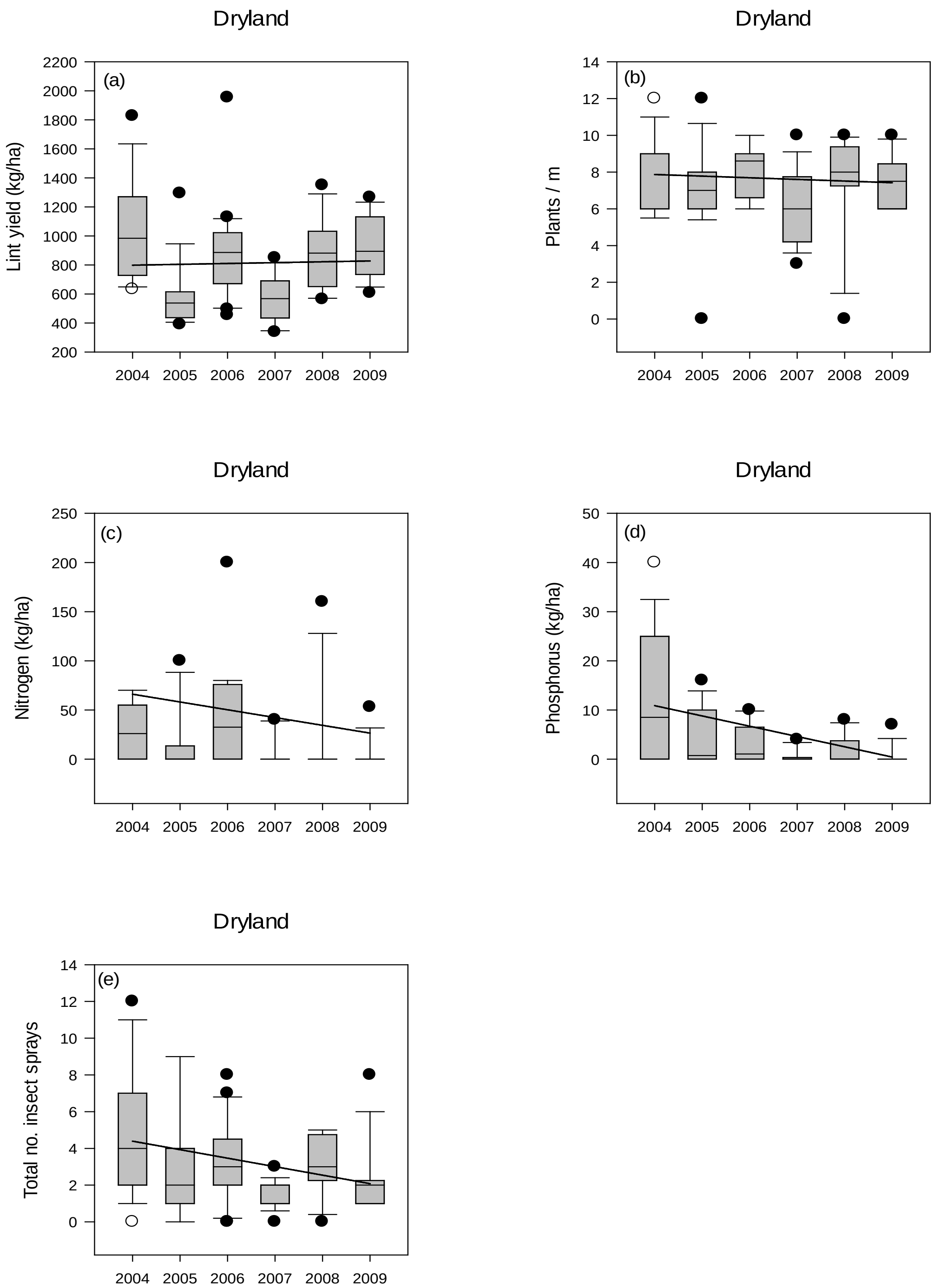


Figure 3 Changes in management; (a) lint yield, (b) plant population, (c) nitrogen application, (d) phosphorus application and (e) number of insect sprays under dryland systems from 2004 to 2010 (includes commercial cultivars and breeding lines).

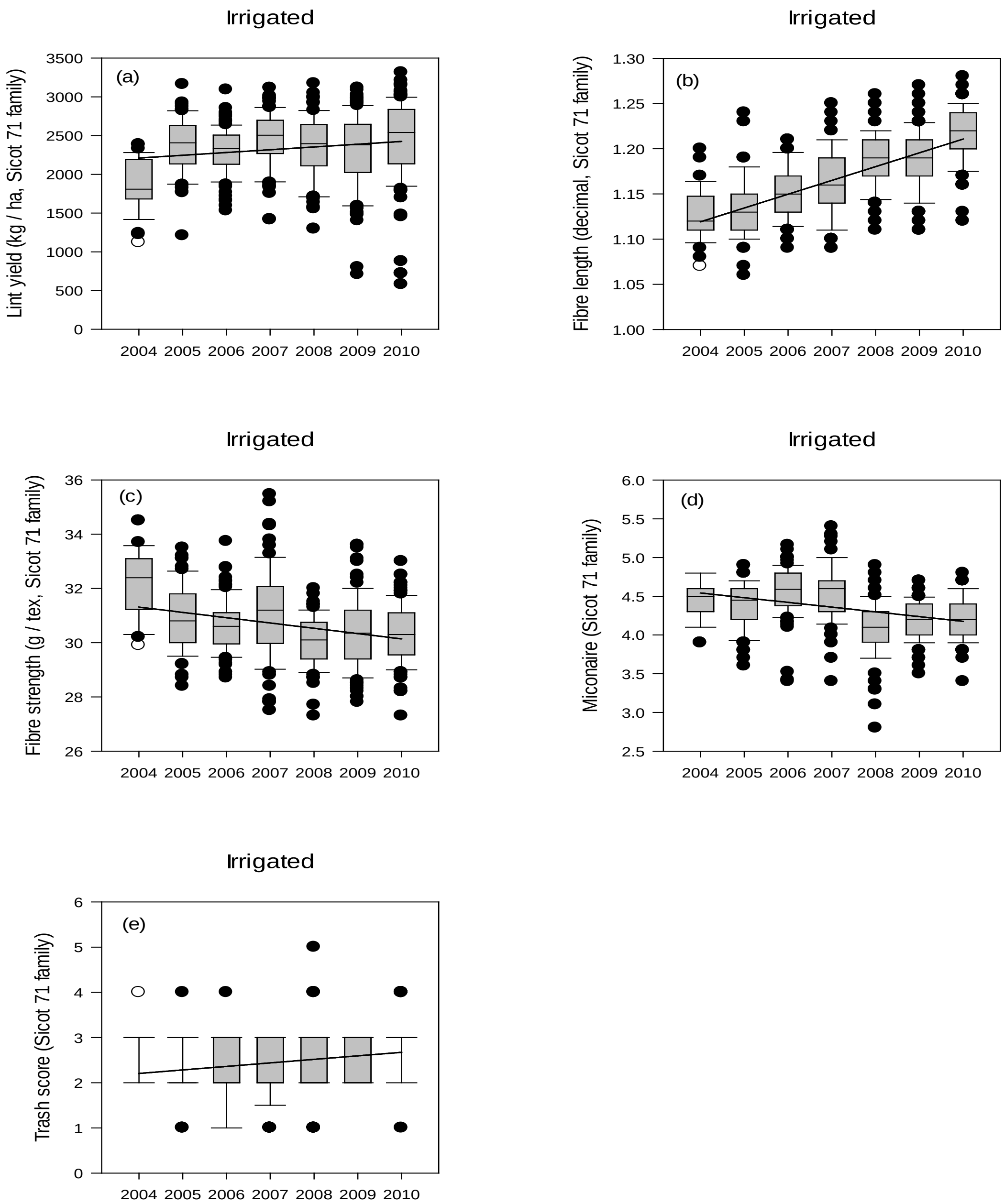


Figure 4 Changes in fibre quality for the Sicot 71 family; (a) lint yield, (b) length, (c) strength, (d) micronaire and (e) trash score under irrigated systems from 2004 to 2010.

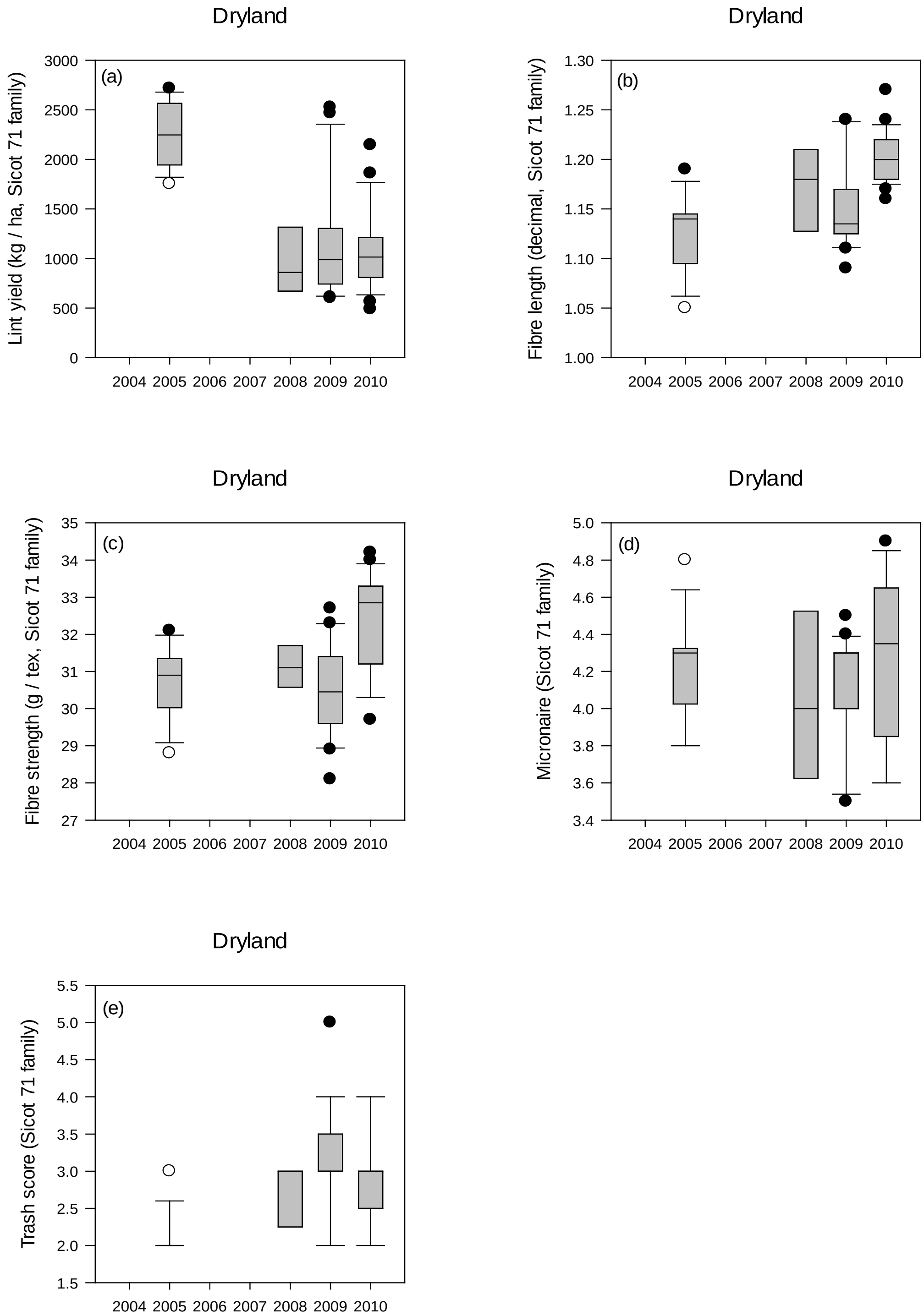


Figure 5 Changes in fibre quality for the Sicot 71 family; (a) lint yield, (b) length, (c) strength, (d) micronaire and (e) trash score under dryland systems from 2004 to 2010.

This however, varied between regions and seasons, which may indicate that research, development and extension needs to be targeted at individual nutrients or the interaction between nutrients in different regions. Lint yield is relatively non-responsive to plant population, which suggests that less research and development effort is required in this area. However, population uniformity may require further investigation to determine whether non-uniform stands are limiting productivity. The management of major insect pests has become easier with the adoption of Bollgard II® cultivars and integrated pest management strategies, which is now part of the best management practice by the cotton industry (Gregg and Wilson, 2008). This has contributed to less spraying for major insect pests and an increase in secondary pest numbers (Gregg and Wilson, 2008); however this will depend on insect pressure and varies with seasonal conditions.

The fact that cotton as a previous crop affects the lint yield of a following cotton crop reflects that back to back cotton is still a common practice in the industry (there were more examples of this practice in the data set than any other rotation). Notwithstanding this, there is a benefit of including wheat, fallow or a legume in the rotation on lint yield of a following cotton crop. A farming system is the result of managers integrating many factors to produce cotton profitably without degrading the vital soil resource or impacting on the surrounding environment. To identify factors that are more important than others is difficult since this will vary depending on the situation of individual growers; soils vary with location which affects the inherent fertility and hence nutrient requirement, water security and availability is determined by climate variability and government policy. A grower's attitude to risk and an individual's farming objectives will largely determine the level of input to achieve that objective (Watson, 2010).

The fact that many if not all inputs contributing to cotton yield and fibre quality interact makes it difficult to ascribe relative importance to any one factor. However, it serves to highlight that certain inputs do have a greater influence on yield and fibre quality; nitrogen management for example. Water certainly is the most important in growing the crop and it needs to be treated in conjunction with nutrition and other inputs. Even when considering nutrition there are interactions between nitrogen and phosphorus and whether the soil is responsive to a nutrient in determining the eventual outcome. The presence of disease complexes, insect pressure and weed numbers all affect the result. The management by growers largely control the level of inputs as determined by economic considerations and seasonal forecast. There is a need for greater certainty of water allocation which would remove some uncertainty in management decisions.

Conclusions

An industry database should be developed to enable trends and changes in management practices that affect yield and fibre quality. This could be promoted by industry organisations or suppliers to encourage growers to fully complete field management input forms when participating in variety trials. Further information may be collected via grower participation in the *my*BMP program.

The current data base is being maintained and updated on an annual basis.

Objective (ii) Farming systems experiments

(a) : Can planting date and cultivar selection improve resource use efficiency of cotton systems?

An experiment was conducted over two seasons at ACRI to examine the effect of planting date and cultivar choice on water use and nitrogen use efficiency.

Experimental details

Field experiments were conducted in the 2007-2008 and 2008-2009 seasons at the Australian Cotton Research Institute (ACRI) at Narrabri, New South Wales (30^0 12' S, 149^0 35' E). The soil is classified as a grey Vertosol (Isbell, 1996) or a fine, thermic, montmorillonitic, Typic Haplustert (Soil Survey Staff 1996). Climate data was measured with a fully serviced weather station located adjacent to the experiments. Reference evaporation (ETo) was calculated using the FAO 56 recommendation (Allen et al. 1998).

Three planting dates (P1, P2, and P3) and a range of cultivars were used for each experiment. The planting dates were used to create different season lengths, which may influence water use, crop yield, and quality parameters. The commencement for planting is usually based on the minimum soil temperature at the planting depth which should be about 15^{o}C for three consecutive days and rising (Quinn and Kelly, 2011). This means that the ideal planting date will vary between cotton regions and seasons. For the experimental site at Narrabri the optimum planting date occurs, on average, by 15 October.

A range of cultivars were planted on each planting date and were chosen for differences in season length and growth habit. Sicala 60BRF (Stiller, 2007a) is of early to medium maturity with compact growth habit; Sicot 70BRFand Sicot 71BRF (Stiller, 2008) are medium to late maturity with compact growth habit and wide adaptation (Sicot 71BRF replaced Sicot 70BRF in Australian commercial production in 2010); DP 12BRF (Richard Leske, Deltapine Australia, pers comm.), Sicot 75BRF (Stiller, 2011), Sicot 80BRF (Stiller, 2007b) and CSX6270BRF a transgenic version of Sicot F-1 (Stiller and Reid, 2005), are later maturing and more vigorous growth habit with CSX6270BRF also having high Fusarium and Verticillium resistance. Cotton was planted 0.05 m deep in 1 m rows with a target of 12 plants m^{-1}. To ensure a uniform plant stand across all planting dates all plots were thinned after establishment as necessary. Plots were 8 rows by 20 m and 17 m long, in 2007 and 2008 respectively. Weed and insect control was per standard recommendations for the Bollgard II® cultivars planted (Monsanto, 2011). The experimental area was managed uniformly with respect to irrigation (target 70 mm irrigation deficit) (Table 2), with the exception that planting 2 and 3 received one extra irrigation in 2008 and planting 3 two extra irrigations in 2009. Nitrogen was applied in August-September (150 kg N/ha) to all plots. Available starting soil nitrate N in the profile (0-0.9 m) at planting was 45 kg/ha in 2007 and 52 kg/ha in 2008. Both experiments used a split-plot (main plots planting date, sub-plots cultivars) with three replicates.

Measurements

Crop Development

A 2 m^2 section for each plot was monitored frequently to determine the date when 50 % plants had reached first flower, and first open boll. Weekly counts were made of the number of open bolls in 1 m^2 of each plot. The lint collected from these samples was kept to calculate final yield components (final boll number and seed cotton per boll). In both seasons the crop did not reach the maturity stage of 60 % open bolls with the last planting date, so the last measurement was taken 125 and 144 days after sowing for the 2007-2008 (07/08) and 2008-2009 (08/09) seasons respectively. This corresponded with decreasing temperatures with no further boll development.

Crop Water Use Efficiency

A single neutron moisture meter access tube was installed to 1.2 m in each plot after crop emergence in 07/08, and only in the Sicot 70BRF and CSX6270BRF plots in 08/09, since these two cultivars had the greatest water use the previous season compared with the other cultivars. A calibrated theta probe was used to measure the surface (0-0.075 m) soil water and a calibrated neutron moisture meter was used to measure soil water content at 0.2 m depth intervals to 1.2 m on a 10 day cycle, and also prior to and 24 hr after irrigation throughout the season. This enabled an estimate of irrigation applied. Soil samples were collected at planting to determine starting soil water and repeated after harvest for finishing soil water profile. Seasonal crop water use (mm ET) was estimated for all cultivars using starting soil water minus finishing soil water plus in crop rain and irrigation applied in 2007-2008. Crop water use efficiency (WUE_{lint} kg/ha/mm) was calculated using lint yield (kg ha^{-1}) divided by the seasonal water use (mm ET) in both seasons (Tennakoon and Milroy 2003). Effective rain was assumed to be falls greater than 10 mm using neutron probe readings in conjunction with measured rainfall.

Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) is a measure of how effectively crop yield is produced from the nitrogen taken up by the crop. Cotton nitrogen use efficiency is defined as the lint yield divided by the crop nitrogen uptake (Rochester, 2007). As such the NUE is independent of the amount of fertiliser applied as it does not discriminate between available soil nitrogen and nitrogen applied as fertiliser. NUE was determined only for the cultivars CSX6270BRF and Sicot 70 BRF in both seasons. Plant nitrogen was determined by cutting 1 m of plants (124 DAS in 07/08 and 144 DAS in 08/09, for all planting dates) at ground level recording total fresh weight and number of plants. A sub-sample of three plants were weighed and partitioned into reproductive (all fruit) and vegetative (leaf and stem) parts and dried at 80^0C for 72 hrs. Lint was then removed from the fruit and all plant material (excluding the lint) was recombined before being ground prior to analysis. Total N was measured by titration following Kjeldahl steam distillation (Rayment and Higginson, 1992).

Lint Yield and Fibre Quality

To determine lint yield of all cultivars and planting dates one central row of each plot was harvested with a spindle picker and the seed cotton weighed. A 250 g seed cotton sub-sample from each plot was ginned using a 20 saw gin with a pre cleaner (Continental Eagle, Prattville, Alabama U.S.A) to determine gin turnout (% lint), which was used to calculate lint yield (kg ha^{-1}). Lint samples were collected to measure fibre length (mm), micronaire (a measure of fibre fineness and maturity, no units), and fibre strength (g tex^{-1}). Fibre quality was measured using a spinlab High Volume Instrument (HVI) model Classing 900 (Uster Technologies, 2008).

Data Analysis

Differences due to planting date and cultivar in water and nitrogen use efficiency, yield and fibre quality parameters were compared using a split plot design ANOVA at the five percent level for significance, with planting date as the main plot and cultivars as the split (Genstat 13, Lawes Agricultural Trust, 2010).

Simulation Analysis

The ability of OZCOT (Hearn, 1994b) to simulate yield, water use, crop water use efficiency and nitrogen use efficiency was compared with measured experimental data for all plantings in both years for the average of Sicot 70BRF and CSX6270BRF. In using OZCOT to explore the effects of planting date on yield and crop water use in other seasons and regions, simulations used generalised conditions based on current practices and typical soils: cracking clay Vertosol soil storing 200, 250, 280 and 240 mm of available soil water in a 1.8, 1.5, 1.5 and 1.2 m profile for Bourke, St George, Narrabri and Hillston, respectively. Row spacing was set at 1 m; a population of 12 plants m^{-1} of row; soil N and irrigation water were not limiting. Climate data for crop simulation were taken from the SILO patched point dataset (Jeffrey et al. 2001) from 1957 to 2010 for each region. Four different cotton growing regions were compared: Bourke, NSW (30^0 05' S, 145^0 56' E) and St George, QLD (28^0 02' S, 148^0 34' E) considered as having a long growing season; with Narrabri, NSW (30^0 19' S, 149^0 46' E) a medium season; and Hillston, NSW (33^0 29' S 145^0 31' E) a short season. Planting dates were simulated for each season in the climate record at 15 day intervals from 15 September to 30 December.

Results

The three planting dates generated different environmental conditions during the period of yield development from first flower to first open boll. For the first planting in 07/08 the crop experienced rising daily ETo (5.5 to 7.5 mm) over 66 days during this period while the second planting experienced steady ETo of 5 mm over 69 days, and the third planting experienced declining ETo (7 down to 4.5 mm) over 74 days (Fig 6a). This corresponded to a

10 and 25 % reduction in ETo for the second and third planting dates compared with the first planting date. In contrast the first planting for the 08/09 season the crop was exposed to rising ETo (6 to 8.5 mm) over 50 days, the second planting experienced steady ETo of 7 mm over 56 days and the third planting was exposed to declining ETo (7.5 down to 2.4 mm) over 64 days during this period of yield development (Fig 6b). This corresponded to an 8 and 13 % drop in ETo experienced by the second and third planting dates compared with the first planting date.

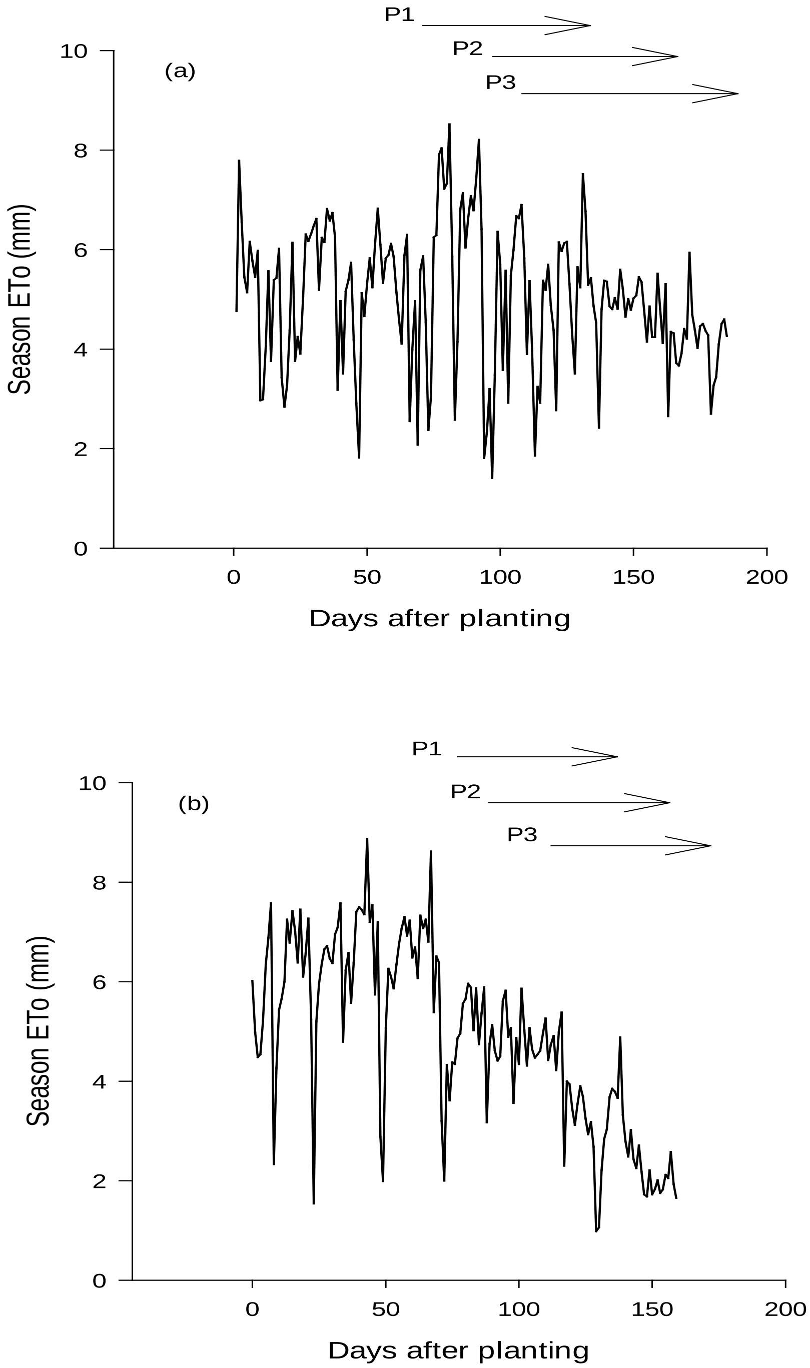


Figure 6 Daily evapotranspiration (ETo, mm) for the (a) 2007/2008 and (b) 2008/2009 seasons for the Narrabri experimental site (Where the arrows indicate the period between first flowering and first open bolls for each planting date (P1, P2, P3)

In both seasons there was no interaction between cultivar and planting date for seasonal crop water use (mm), but there were significant differences between planting dates with the earliest two planting dates having the highest water use, significantly more than the third planting date (Table 3). Comparing WUE_{lint} of cultivars in 07/08 there was a significant interaction between cultivars and planting date; CSX6270BRF had the lowest WUE_{lint} in P2, and had similar WUE_{lint} to the other cultivars in P3 while all cultivars in P3 had lower WUE_{lint} compared with P1 and P2 (Table 3).

Table 3 Seasonal Crop water use (WU, mm) and water use efficiency (WUE, Lint kg/ha/mm) for the 07/08 and 08/09 seasons. (Numbers followed by the same letter are not significantly different)

07/08	P1 WU	P2 WU	P3 WU	P1 WUE	P2 WUE	P3 WUE	Mean cultivar WU	Mean cultivar WUE
DP 12BRF	609	535	501	4.5[def]	4.2	2.1[a]	548	3.7
CSX6270BRF	630	552	456	4.5[abcd]	3.8	3.0[ab]	546	3.8
Sicala 60BRF	628	568	425	5.0	4.5	3.2[abc]	540	4.3
Sicot 70BRF	596	585	423	5.2[def]	5.1	4.7[bcde]	535	5.0
Sicot 75BRF	607	560	421	5.1	4.3	2.6[a]	530	4.1
Sicot 80BRF	594	619	421	4.9	4.5	4.3[bcd]	544	4.6
Mean plant	610a	570a	441b	4.9	4.4	3.3		
lsd cultivar	ns			0.4				
lsd plant	68			1.2				
lsd cultivar*plant	ns			1.2 (within plant 0.7)				
08/09								
CSX6270BRF	782	714	499	3.1[b]	3.5[bc]	2.5[a]	665	3.0
Sicot 70BRF	758	730	518	3.2[b]	3.6[bc]	4.0[c]	669	3.6
Mean plant	770a	722a	509b	3.2	3.5	3.3		
lsd cultivar	ns			0.4				
lsd plant	50			0.1				
lsd cultivar*plant	ns			0.5 (within plant 0.7)				

In the 08/09 season there was a significant interaction between planting date and cultivar where CSX6270BRF had the lowest and Sicot 70BRF had the highest WUE_{lint} in P3 while both cultivars in P2 had similar WUE_{lint} to that measured in P1.

There was no difference in nitrogen use efficiency between CSX6270BRF and Sicot 70BRF in either season, however there was a significant difference between planting date, with the first two planting dates having greater nitrogen use efficiency compared with the third planting date (Table 4).

Yield in both seasons was affected by planting date and cultivar; in the first season there was no significant interaction between planting date and cultivar however, there were significant differences between all planting dates and among cultivars with highest yields were recorded in P1 and the lowest in P3 (Table 5). Differences in yields in the 08/09 season were a result of a significant interaction between planting date and cultivar. For each individual cultivar, yield was less in P3 compared to P1 and P2 which were not significantly different (Table 5).

Table 4 Nitrogen use efficiency (kg lint/kg N) for the 07/08 and 08/09 seasons (Numbers followed by the same letter are not significantly different)

07/08	P1	P2	P3	Mean cultivar
CSX6270BRF	15.6	15.5	8.2	13.1
Sicot 70BRF	17.3	17.4	12.5	15.7
Mean plant	16.5[a]	16.4[a]	10.3[b]	
lsd cultivar	ns			
lsd plant	4.2			
lsd cultivar*plant	ns			
08/09				
CSX6270BRF	14.1	13.9	10.2	12.8
Sicot 70BRF	15.2	14.5	12.7	14.1
Mean plant	14.1[a]	14.2[a]	11.4[b]	
lsd cultivar	ns			
lsd plant	2.26			
lsd cultivar * plant	ns			

Table 5 Yield for each cultivar and planting date. (Numbers followed by the same letter are not significantly different)

07/08	Lint yield (kg ha^{-1})			
	$P1_1$	P2	P3	Mean
DP 12BRF	2734	2269	1068	2027[bc]
CSX6270BRF	2826	2092	1357	2092[bc]
Sicala 60BRF	3125	2579	1359	2354[bc]
Sicot 70BRF	3291	2988	1950	2743[a]
Sicot 75BRF	3070	2360	1087	2172[b]
Sicot 80BRF	2909	2694	1813	2472[c]
Mean	2994[a]	2497[b]	1606[c]	
LSD cultivar	212			
LSD plant	434			
LSD cultivar*plant	ns			
08/09				
DP 12BRF	1981[c]	2103[cd]	1322[ab]	1802
CSX6270BRF	2433[ef]	2475[efg]	1237[a]	2048
Sicala 60BRF	2439[ef]	2539[efg]	1537[b]	2172
Sicot 70BRF	2428[ef]	2599[efg]	2078[cd]	2368
Sicot 71BRF	2511[efg]	2736[g]	1501[ab]	2249
Sicot 75BRF	2485[efg]	2647[fg]	1571[b]	2234
Sicot 80BRF	2357[de]	2418[ef]	1583[b]	2119
Mean	2376	2502	1547	
LSD cultivar	162.2			
LSD plant	106.2			
LSD cultivar*plant	280.9			

All quality parameters were significantly affected by planting date and cultivar in both seasons (Table 6) with the exception of planting date on fibre length in 07/08. Delayed planting increased fibre length and strength and reduced micronaire. Fibre strength was significantly different between each planting date with P1 the lowest and P3 the highest.

Table 6 Quality parameters for each cultivar and planting date. (Numbers followed by the same letter are not significantly different)

07/08	Length (dec)				Micronaire				Strength (g tex^{-1})			
	P1$_1$	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
DP 12BRF	1.17	1.18	1.19	1.18[a]	4.2	3.6	2.7	3.5[b]	28.3	29.2	32.6	30.1[a]
CSX6270BRF	1.23	1.23	1.25	1.24[bc]	3.9	3.0	2.8	3.2[a]	29.8	32.7	33.5	32.0[b]
Sicala 60BRF	1.21	1.24	1.24	1.23[bc]	3.9	3.1	2.5	3.2[a]	31.2	34.5	34.2	33.3[c]
Sicot 70BRF	1.21	1.21	1.23	1.21[b]	3.9	3.5	2.8	3.4[ab]	31.0	33.1	34.1	32.7[bc]
Sicot 75BRF	1.26	1.24	1.26	1.25[c]	3.9	3.1	2.6	3.2[a]	30.2	32.7	33.9	32.3[bc]
Sicot 80BRF	1.21	1.24	1.24	1.23[b]	4.3	3.4	3.1	3.6b	30.4	33.7	33.7	32.6[bc]
Mean	1.22	1.22	1.23		4.0[c]	3.3[b]	2.8[a]		30.2[a]	32.7[b]	33.7[c]	
LSD cultivar	0.023				0.233				1.18			
LSD plant	ns				0.165				0.83			
LSD cultivar*plant	ns				ns				ns			
08/09												
DP 12BRF	1.12	1.19	1.15	1.15[a]	4.8	4.6	3.0	4.1[bc]	28.5	28.9	31.9	29.8[a]
CSX6270BRF	1.22	1.25	1.22	1.23[cd]	4.6	4.3	3.0	4.0[ab]	30.6	31.9	34.7	32.4[d]
Sicala 60BRF	1.18	1.23	1.21	1.20[b]	4.5	4.4	2.9	3.9[a]	30.5	30.9	35.1	32.2[d]
Sicot 70BRF	1.80	1.21	1.23	1.20[b]	4.7	4.6	3.3	4.2[c]	30.1	30.6	33.2	31.3[bc]
Sicot 71BRF	1.21	1.23	1.20	1.21[bc]	4.7	4.4	2.7	3.9[a]	30.4	29.4	32.8	30.8[b]
Sicot 75BRF	1.24	1.25	1.24	1.24[d]	4.8	4.6	3.0	4.1[bc]	29.6	30.2	34.5	31.5[c]
Sicot 80BRF	1.15	1.24	1.20	1.20[b]	4.6	4.5	3.1	4.1[bc]	31.4	31.6	34.5	32.5[d]
Mean	1.18[a]	1.23[c]	1.21[b]		4.7[c]	4.5[b]	3.0[a]		30.1[a]	30.5[b]	33.8[c]	
LSD cultivar	0.022				0.177				0.51			
LSD plant	0.015				0.116				0.33			
LSD cultivar*plant	ns				ns				ns			

Simulated lint yield across the regions was less sensitive to planting date from 15 September to 30 October with the exception of the medium (Narrabri) and short (Hillston) season areas where the potential for frost (daily minimum temperature < 2^{o}C) affecting crop establishment depressed yield by 15 and 10 % (342 and 268 kg/ha) respectively at the earliest planting date (Fig 7a). With delayed planting the simulation indicated that yield loss was greater in medium and short season regions compared with longer season regions (Bourke and St George), especially with very late planting compared with the regions normal target planting date (15 Oct) (Fig 7a). This equated to yield losses of 6 – 4 % (150 and 104 kg/ha) at Bourke and St George compared with 28 – 80 % (690 and 2140 kg/ha) at Narrabri and Hillston. Crop water use efficiency increased with a delay in planting date from 15 September to 15 October for each region until 30 November when water use efficiency dropped (Fig 7b). This corresponded with a decrease in evapotranspiration by the crop (Fig 7c) and resulted in a decrease in yield potential as noted above. Simulated nitrogen use efficiency showed a similar response to yield across all regions (Fig 7d) being relatively constant over planting dates from 30 September to 30 October in the medium and short season areas and from 30 September to 30 November in the long season areas.

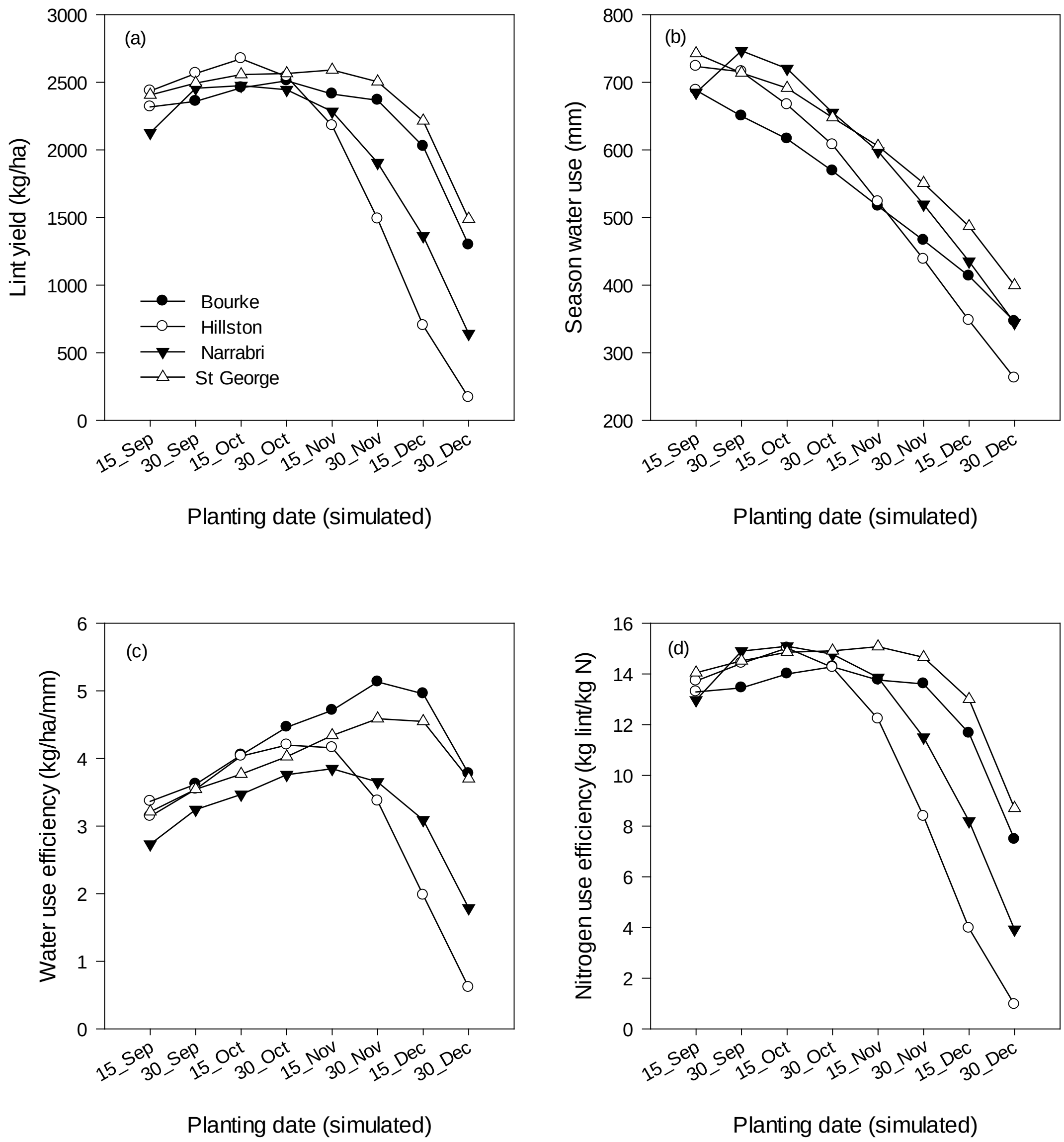


Figure 7 OZCOT simulation for (a) lint (kg/ha, 227 kg bales), (b) season water use (mm), (c) water use efficiency (kg/ha/mm) and (d) nitrogen use efficiency (kg lint/kg N) for different season lengths in Australian cotton regions. (Bourke and St George are long season areas, Narrabri is a medium season area and Hillston is a short season area, with values being the mean of 53 years)

When comparing simulated season water use, water use efficiency, nitrogen use efficiency and lint yield using OZCOT with measured data from the Narrabri experiments, the model provided a reasonable estimate of lint yield (Fig 8a), however it tended to over-estimate water use (Fig 8b) and therefore under-estimated water use efficiency (Fig 8c). NUE was also generally overestimated (Fig 8d). Despite differences in the predicted values compared to the measured values, there were however, consistent changes in these variables in response to planting date, indicating that OZCOT could be used as a guide to further investigate the impacts of planting date on yield, water and nitrogen use across regions.

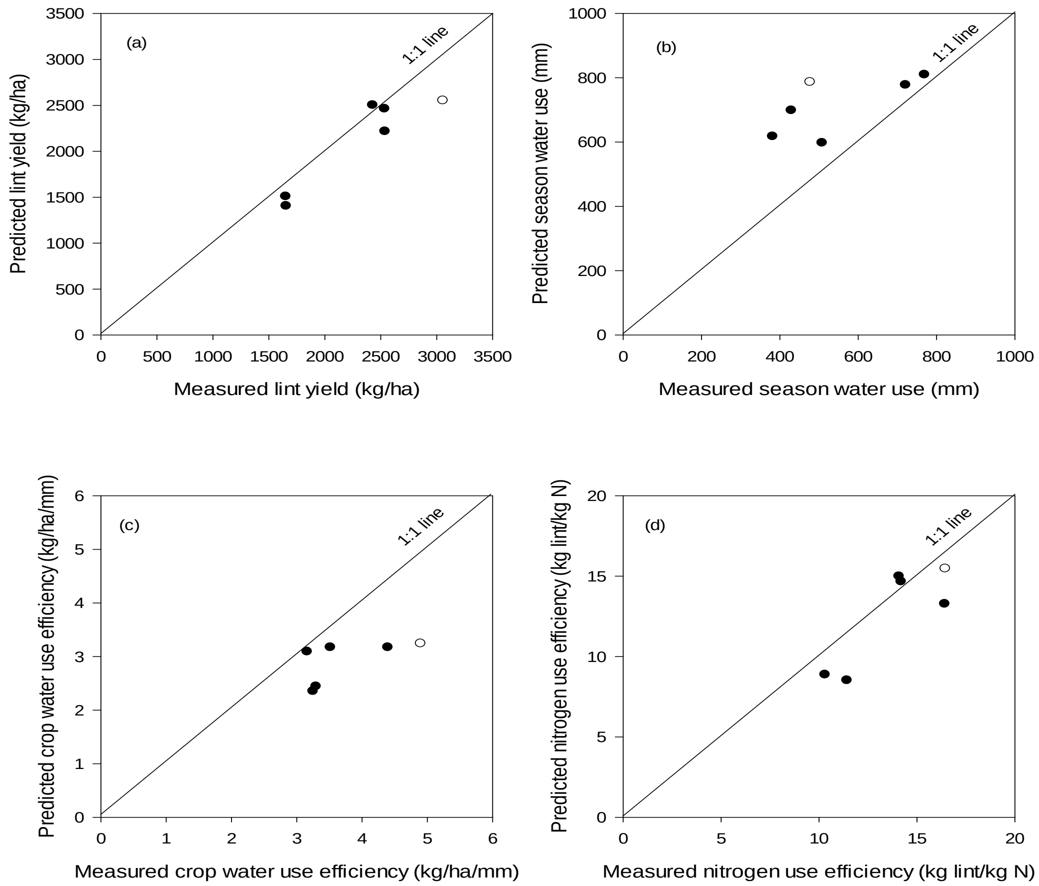


Figure 8 OZCOT simulation using actual data from Narrabri experiments 2007/2008 and 2008/2009, (a) lint yield (kg/ha), (b) season water use (mm), (c) crop water use efficiency (kg/ha/mm) and (d) nitrogen use efficiency (kg lint/kg nitrogen)

Discussion

This is the first study to examine cotton planting date effect on resource use efficiency in Australia. The optimum planting date will vary between regions and seasons. In the reported experiments planting dates were delayed 28 and 49 days compared to the normal planting date in 07/08 and were 21 days before and delayed 15 and 50 days compared with the normal planting date in 08/09. Clearly the crop was exposed to different climatic conditions during the yield development phase in both seasons and that this phase varied with planting date as indicated from the results above.

The reduction in average water use across cultivars from P1 to P2 of 17% was commensurate with a 19% reduction in yield so WUE_{lint} did not change. While water use efficiency of all cultivars in P3 was consistently lower across planting dates cultivars with the lowest WUE_{lint} were those that had the lowest yields (DP 12BRF and Sicot 75BRF), not from differences in water use.

Higher yielding cultivars corresponded to those that had higher WUE_{lint}. CSX6270BRF with a more vegetative growth habit had poorer WUE_{lint}; this was especially evident with the later plantings. Greater leaf area in this cultivar would have maintained water use without improvement in yield. Sicot 70BRF had better WUE_{lint} resulting from higher yield as it is a high yielding cultivar with a less vigorous growth habit.

Nutrient use efficiency ranged from 8-17 kg lint/kg N and were similar to those reported by Rochester (2007, 2010). Nitrogen use efficiencies greater that 12 kg lint/kg N indicate that the crop was under fertilised or was stressed at some stage during growth (Rochester, 2010). NUE was low for late plantings as the N fertilizer rate was too high for the yield potential; likewise NUE was slightly lower in 08/09.

Simulating the effect of planting date from 15 September to 15 November for Bourke and St George, both long season regions, suggests that delaying planting can increase crop water use efficiency (WUE_{lint}) since season ET (evapotranspiration) decreased for the same yield. For early plantings similar to Narrabri (discussed previously) Hillston, a short season region, also had an increased risk in planting early. There was also no benefit in delaying planting beyond 30 October at Hillston, although ET decreased and there was an increase in WUE_{lint}, there was a large yield penalty associated with a late plant. Yield in long season regions began to be affected after a late plant around 15 December, whereas a medium length season region (Narrabri) was affected earlier around 30 November and short season area (Hillston) was affected with a planting date of 15 November. The drop off in yield occurred later in long season regions compared with short season areas, and medium season areas fell between the two. While there are differences between regions, the overall trend in all regions is that there is potential for flexibility in planting date with later plantings using Bollgard II® cultivars without impacting resource use efficiency

Late plantings (approximately 50 d after the target planting date) had substantially less yield, and the earlier planting date P1 in 08/09 had no change in yield. Cotton yield decreased with these late plantings due to the season length being reduced (Wrather et al. 2008) and reducing the number of fruiting branches and bolls.

Fibre quality was also significantly affected by planting date. Later plantings increased fibre strength in both seasons, increased length in 08/09, and lowered micronaire in both seasons. Fibre strength was not affected by sowing date or cultivar. There was no significant difference between cultivars for each of the quality parameters assessed. Changes in quality resulted from boll development occurring in the cooler months with later planting. In contrast to studies by Bange et al (2008) fibre strength was affected by planting date. The reason for this response is most likely associated with the very low micronaire values (< 3.3) with the later plantings in both seasons possibly due to low fibre maturity as a result of cooler growing conditions during boll filling and more immature bolls at harvest. When considering the overall responses of fibre quality attributes to planting date, there were no instances where fibre length or strength would have incurred penalties across all planting dates, but shows that there is general improvement as planting date was delayed. For micronaire the optimum date to avoid high and low micronaire is from around the current target planting date 15 October until 10 November.

Conclusions

These field experiments and crop simulation analyses showed that for Bollgard II® crops, yield and resource use efficiencies (water and nitrogen) were statistically unaffected by planting dates up to 30 d later than the current target planting date, but can be affected by cultivar. Only very late plantings resulted in low yields substantially reducing crop efficiencies. Planting later, in this environment also improved some fibre properties. The simulation analysis highlighted that there were differences between regions and that there is more opportunity to improve crop water use efficiency in long season areas with later planting. The wider planting window for growers affords flexibility at the start of the growing season and potentially provides opportunities to plant on rainfall rather than using irrigation water resources. Further investigation is necessary to understand the reasons for differences between the measured outcomes and the model with respect to crop water use, crop water use and nitrogen use efficiency as it presently tends to over and under estimate these parameters. This would require further datasets to undertake this assessment. Also, the use of varying planting date needs to be tested over a number of seasons across long season growing regions.

(b): Potential for thin biodegradable plastic film in cotton farming systems

Preliminary work was conducted at ACRI to examine the potential of thin biodegradable plastic film in the cotton industry, on crop emergence and seedbed soil water conservation and by following degradation of the film through the season.

Field experiments were established at the Australian Cotton Research Institute, Narrabri ($149^0$40’ E, 30^0 10’ S) NSW, Australia on a grey self mulching vertosol (Isbell, 1996).

Nitrogen fertiliser was applied as a gas pre-planting at the rate of 180 kg N/ha. Weeds and insects were managed as per Bollgard® II protocol and plots irrigated on the station schedule.

The maximum and minimum soil temperature at the planting depth, on the soil surface and in the head space under the film was monitored with J-type thermocouples and logged 3 hourly in experiment 1, 3 and 4 while tiny tag sensors were used in experiment 2. Soil water was measured daily at 09:00 with a theta probe in experiment 1 and using GBLite gypsum blocks for all other experiments. Plots were monitored daily to determine emergence and final establishment and whether cotton seedlings had penetrated the film, and for changes in the film, such as colour and appearance of lateral tears.

Experiment 1

The cotton cultivar Sicot 71BRF (germination percentage 96 %) was planted on 5 November 2009 with the plastic film being placed over the planted row on the following day. The trial compared 4 thin films (designated 491, 501, 502 and 503) with a control which was a non-covered conventional cotton planting. Each plot was 5 rows by 10 m long. The film was placed by hand, over 3 adjacent rows for a length of 5 m with the edges buried with 50 mm soil and the 2 outside rows were not covered. There were 4 replicates of each treatment in a completely randomised block design. The films had a treated and an untreated edge to compare the breakdown under soil.

A photographic record was maintained to assess the surface degradation of the 4 thin films.

Yield data when available were analysed using standard ANOVA at the five percent level with Genstat 13 (VSN 2010). Soil temperature and soil water data were unable to be statistically analysed due to instrumentation restrictions, however standard errors are presented in figures as an indication of differences between treatments.

Experiment 2

This experiment looked at the degradation of the film in the field and whether cotton could penetrate the film. Sicot 71BRF was planted on 21 October 2010 in three rows by 5 m long and three (542, 544, 557) thin films were placed over the three rows as in experiment 1. Small sections of each film were placed in mesh cages to observe break down over time.

Experiment 3

This experiment examined the degradation of thin film in the field at a potential early planting date. No cotton was planted in this experiment. Three films (542, 543, 544) were placed over three rows by 5 m on 20 June 2011 along with thermocouples and gypsum blocks to monitor soil surface, head space and planting depth (5 cm) temperature and soil water potential at planting depth (5 cm).

Experiment 4

This experiment examined the time of planting to determine whether emerging cotton could penetrate the film. Cotton was planted on 15 September, 28 September and 20 October 2011 to provide a range of soil water and soil temperatures for cotton germination and emergence. Three films (542, 544, 557) were placed over three rows by 5 m along with thermocouples and gypsum blocks to monitor soil surface, head space and planting depth (5 cm) temperature and soil water potential at the planting depth.

Results

Experiment 1

Unfortunately sensor malfunction resulted in no data for plastic 502 or the control treatment (the two measurements registered at 15:00 and 18:00 for the control indicated a temperature of 21˚C, which is considerably lower than under the thin films). Soil temperatures at the planting depth were lower compared with the head space (fig 1a). Over the duration of measurement the average soil temperatures under the thin films were ten degrees greater than the suggested optimum range (14 to 18 C) at the depth of planting (fig 9a), while the head space reached temperatures were in excess of 50 C (fig 9a).

The mean volumetric soil water content for the surface (0-50 mm) was not significantly different between treatments, but showed a trend to be slightly greater under the thin film compared with the control (fig 9b).

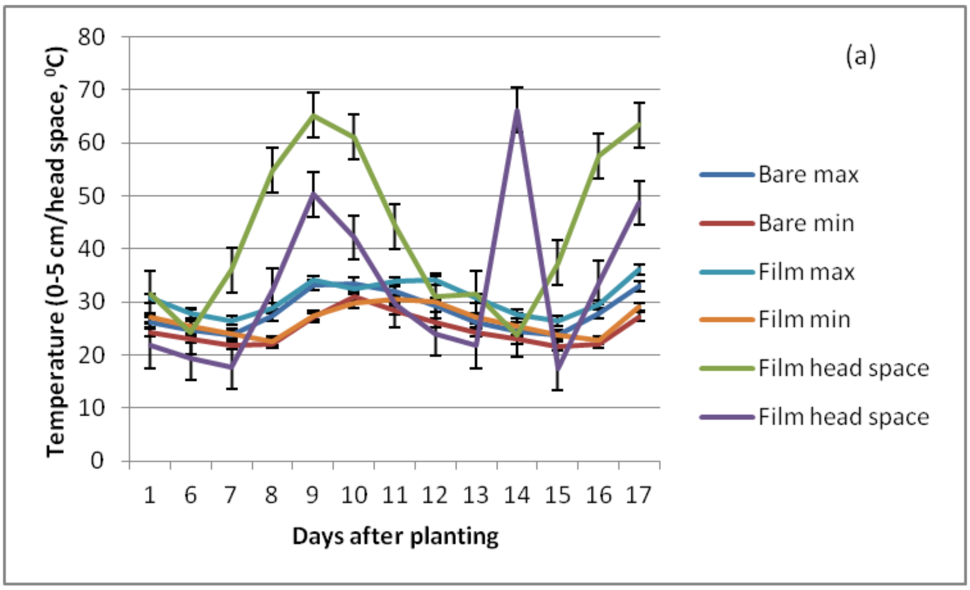
Emergence under the thin film was early, rapid and uniform compared with the control (fig 8c). However, the survival of the emerged cotton was poor due to the high temperatures experienced in the head space under the film (fig 9a).

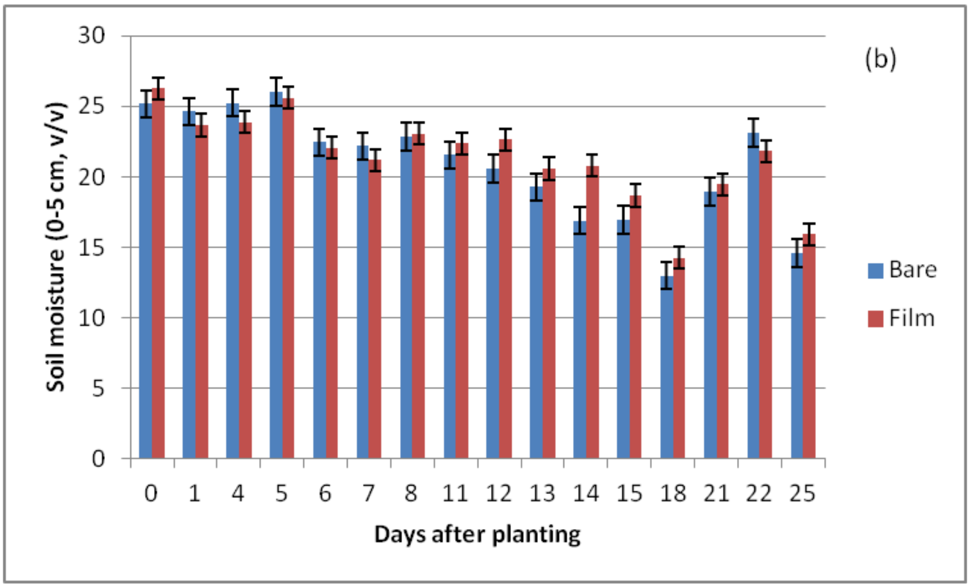
The film above emerged cotton seedlings was slit on 10th November (5 DAS) in an attempt to promote their survival; a section above the temperature sensors was not slit to allow monitoring to continue. However, by this stage the emerged cotton had desiccated and did not survive. No yield was recorded for this experiment since no seedlings survived beneath the film. Slitting of the film resulted in accelerated breakdown of the film as wind caused shredding of the edges.

No observations were possible on brittle development of the film as cutting the film allowed wind to tear the exposed edges. Degradation of the film tended to be relatively rapid as most surface film had disappeared by 14th December 2009. Sub-surface samples were collected until picking of cotton. A general observation when collecting the sub-surface samples was that the film while maintaining integrity seemed to be weaker at each subsequent sampling time. The film while not obviously brittle tore more easily.

Firstly it should be noted that the optimum planting time for cotton in northern NSW, (Narrabri) is mid-October with growers' generally planting by the 15th October. However, the late arrival of the test thin film resulted in a delay of 21 days past the optimum planting date for cotton. This limited the outcome of the trial, but provided an indication that there may be a place for thin film in cotton in that crop emergence was earlier and uniform under the thin film compared to the control.

Photo 1 shows the film after application and appearance as it degraded through the season.





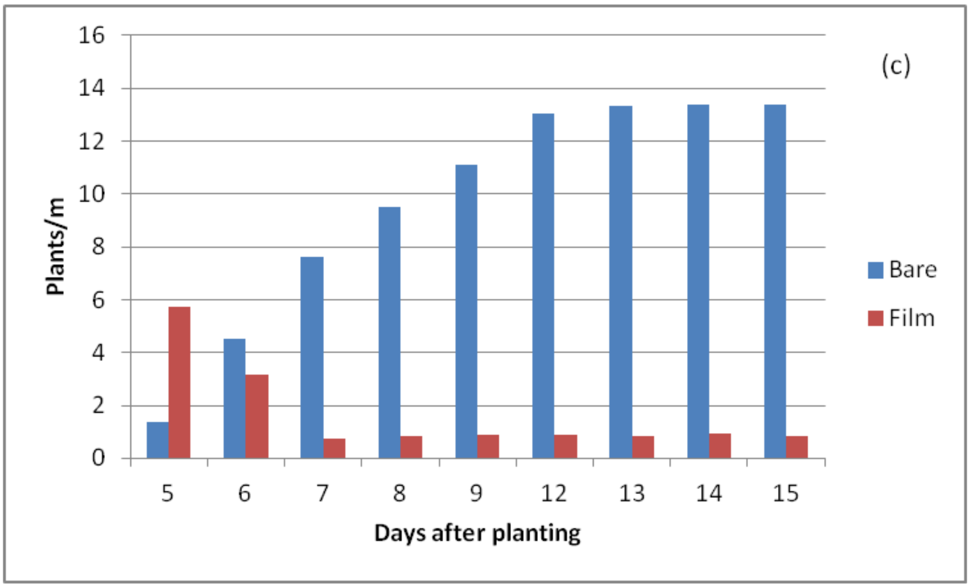


Figure 9 Experiment 1 November 2009 (a) Soil and head space temperature (^{o}C) on bare and film covered plots, (b) Soil water (0-5cm) at planting depth on bare and film covered plots and (c) establishment (plants/m) for each treatment(bars are standard error of the mean) .

TRIAL 2009-10	**DATE 6.11.09**	**DATE 10.11.09**	**DATE 20.11.09**
Initial Trial. Plastics 491, 501, 502 and 503			

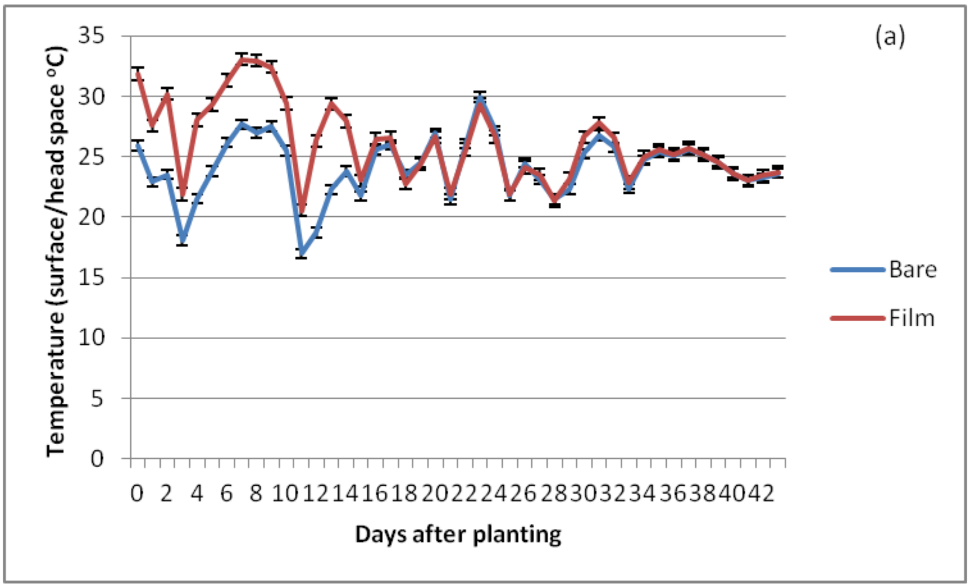
Photo 1 Appearance of thin film at application, after slitting and end of season in experiment 1.

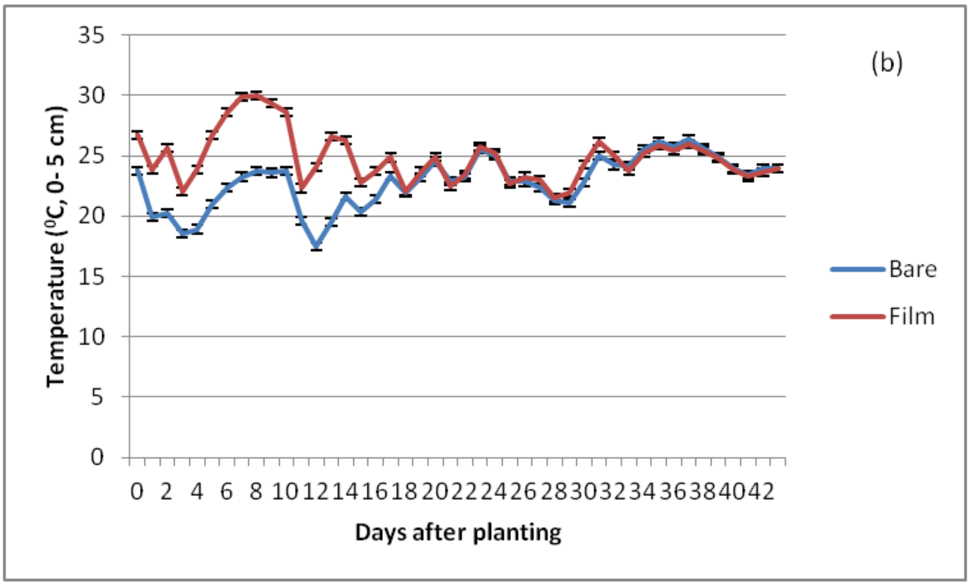
Experiment 2

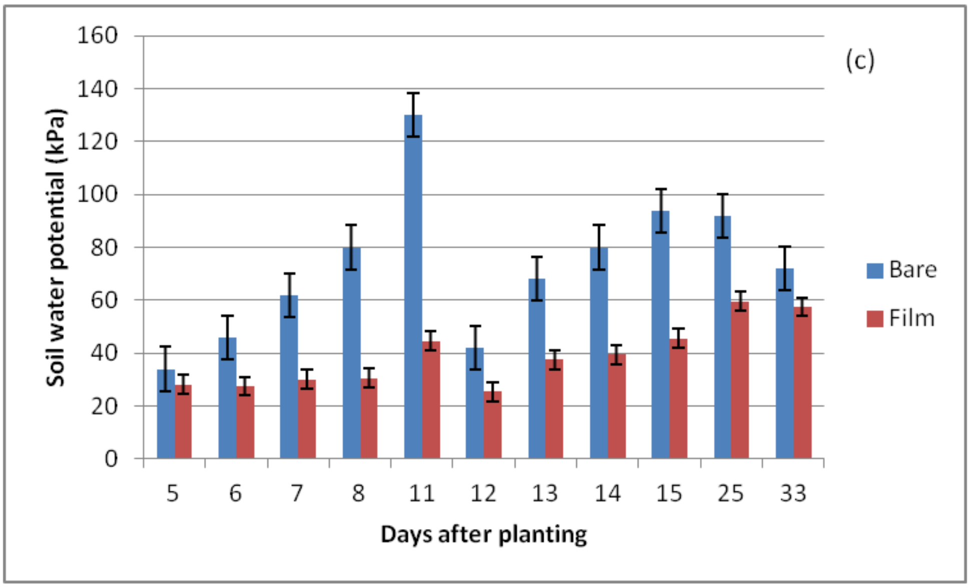
Head space temperatures were significantly elevated, until 14 days after planting (DAP) compared with the bare soil surface temperature and were not as great as the previous season (Fig 10a), while soil temperature at the 5 cm depth was similar to the previous season under both plastic and bare soil with that under the film being significantly greater than the bare soil up to 17 DAP (Fig 10b).

Soil water was monitored using GBLite blocks since the theta probe compromised the integrity of the film and measurement of soil water as holes were made when inserting the probe. The soil was significantly wetter under the film compared to the bare soil (Fig 10c, the smaller the number the wetter the soil). Readings in the range 40-60 kPa indicate moisture is readily available to the plant, while readings above 80 kPa indicate water is not readily available.

Cotton emerged earlier under the film compared with the bare soil plots and the numbers declined with time (Fig 10d).







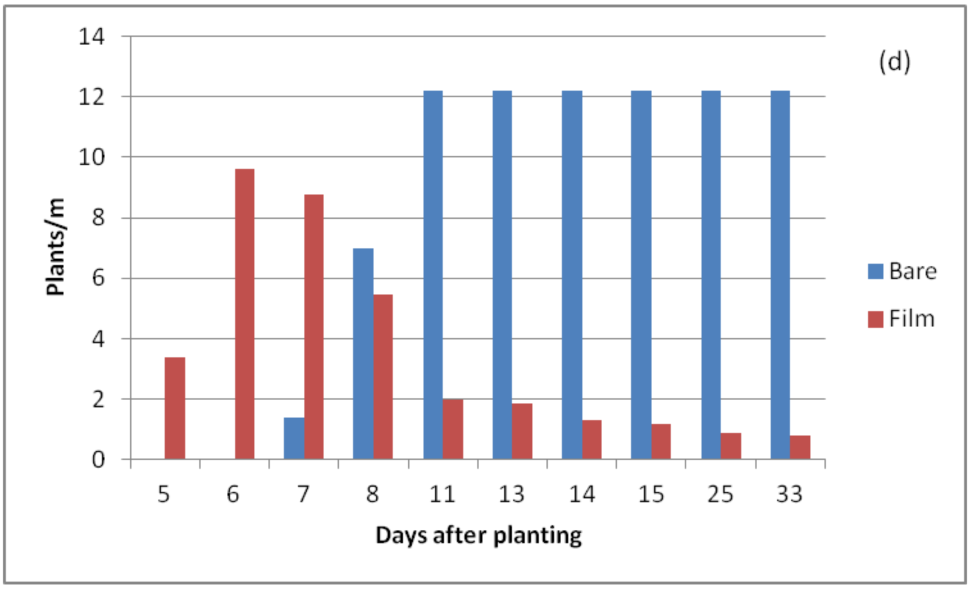


Figure 10 Experiment 2 October 2010 (a) Soil surface and head space temperature (^{o}C) on bare and film covered plots, (b)Soil temperature (0-5 cm) at planting depth on bare and film covered plots and (c) Soil water (0-5cm) at planting depth on bare and film covered plots and (d) Establishment (plants/m) for each treatment(bars are standard error of the mean) .

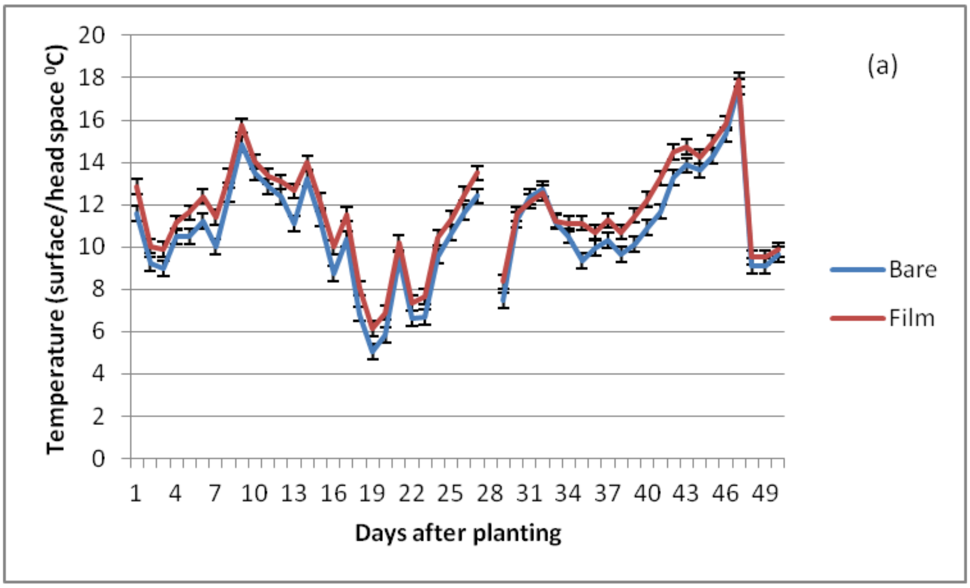
TRIAL 2010-11	DATE 4.11.10	DATE 15.11.10	DATE 22.11.10
Mesh cages			

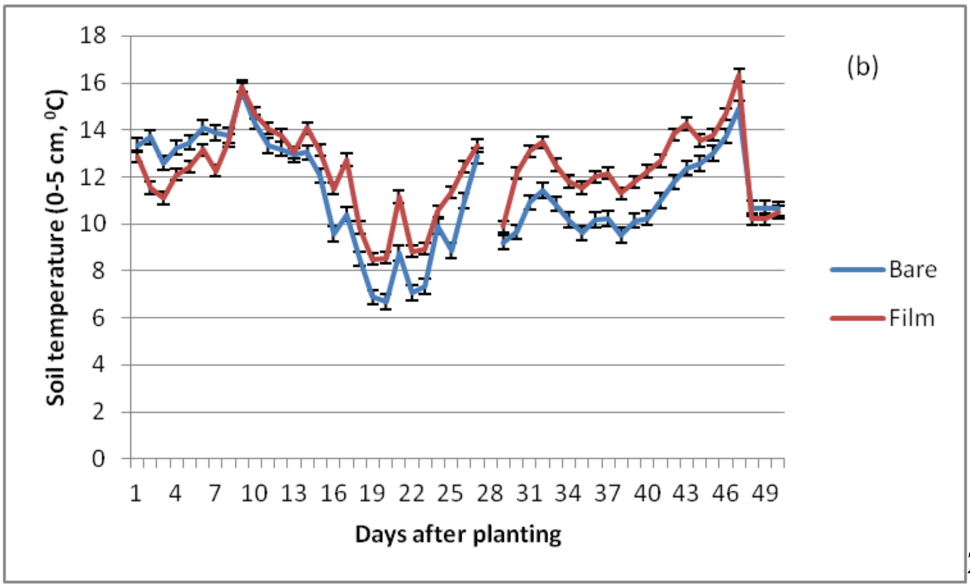
Photo 2 Degradation of plastic film (film 554) with time (experiment 2 the surface film degraded completely with only a small strip of buried film visible).

Photo 2 shows the level of film degradation with time, this film degraded most rapidly compared with two others tested.

Experiment 3

Head space temperatures tended to be greater than soil surface temperatures; not always significantly (Fig 11a), while soil temperature was greater under bare soil up to 7 DAP after which the reverse occurred (Fig 11b). Soil under the thin film remained significantly wetter than that in the bare plots (Fig 11c). The bare plots dried to the point where water would not be readily available to the crop while water was more than adequate beneath the thin film.





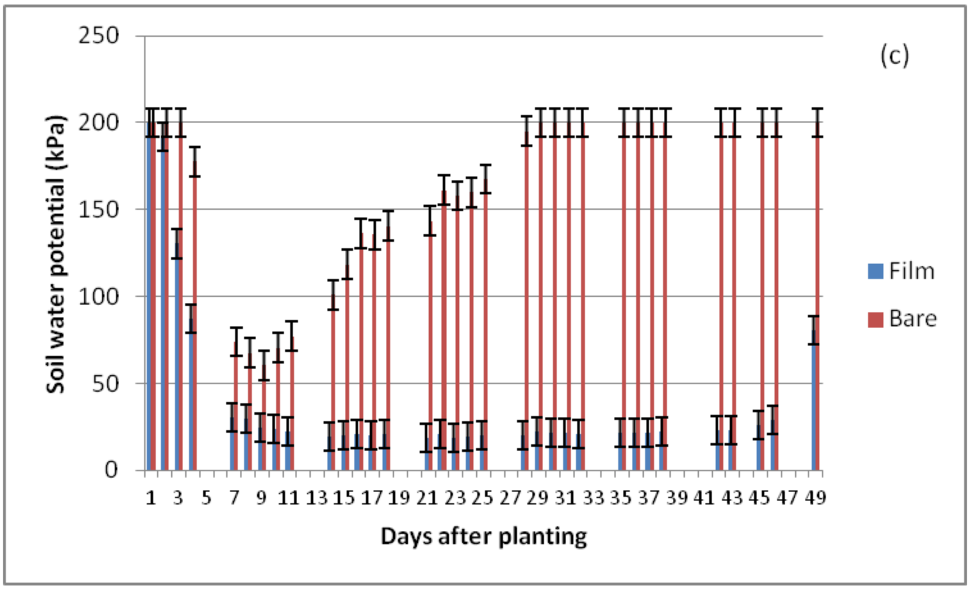


Figure 11 Experiment 3 June 2011 (a) Soil surface and head space temperature (^{o}C) on bare and film covered plots, (b)Soil temperature (0-5 cm) at planting depth on bare and film covered plots and (c) Soil water (0-5cm) at planting depth on bare and film covered plots(bars are standard error of the mean) .

A3 TRIAL 2011	**DATE 20.6.11**	**DATE 18.7.11**	**DATE 1.8.11**
PLASTIC 542			
PLASTIC 543			
PLASTIC 544			

Photo 3 Degradation of thin film with time (experiment 3)

Degradation of three biodegradable films applied in June 2011 to assess breakdown over time is illustrated in photo 3.

Experiment 4

Soil surface and head space temperatures for the first planting were between 20-25 C during the emergence phase (Fig 12a), with the soil temperature being around 20 C for both the bare and film covered treatments (Fig 12b). The film covered plots were warmer than the bare soil. Logger failure restricted soil water measurement to the film plots only and indicated that sufficient water was available for emergence (Fig 12c).

For the second planting soil surface temperature was lower than the head space temperatures as was soil temperature compared with the film covered plots and both increased with time (Fig 13 a, b). Soil under the film was wetter than that on the bare plots and did not dry to the same extent as the bare plots (Fig 13c).

Soil surface temperature was lower compared with the head space temperature under the third planting (Fig 14a). Soil temperatures were higher under the film plots compared with the bare plots and lower than surface or head space temperatures (Fig 14b). Soil moisture dried on the bare plots compared with the film covered plots, until rainfall re-wet the bare plots with soil moisture being similar under both treatments (Fig 14c). Soil moisture under the bare and thin film treatments always remained in the readily available range.

Plant establishment was affected by the combination of temperature under the film and soil moisture, which resulted in desiccation and non-survival of plants with the last two planting dates (Fig 15).

The appearance of the film and growth of cotton for each planting date is illustrated in photo 4.

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TOS TRIAL 2011 Sowing 1: 15.09.2011	DATE 16.9.11	DATE 10.10.11	DATE 1.11.11	DATE 15.12.11	DATE 28.2.12
PLASTIC 542					
PLASTIC 544					
PLASTIC 557					
CONTROL					

TOS TRIAL 2011 Sowing 2: 28.09.2011	DATE 10.10.11	DATE 21.10.11	DATE 1.11.11	DATE 15.12.11	DATE 28.2.12
PLASTIC 542					
PLASTIC 544					
PLASTIC 557					
CONTROL					

TOS TRIAL 2011 Sowing 3: 20.10.2011	DATE 21.10.11	DATE 27.10.11	DATE 1.11.11	DATE 15.12.11	DATE 28.2.12
PLASTIC 542					
PLASTIC 544					
PLASTIC 557					
CONTROL					

Photo 4 Timeline for each planting date illustrating appearance of film and growth of cotton

Discussion

The main issue at this preliminary stage is the fact that cotton seedlings did not penetrate any of the thin films and as a result the crop did not survive. However, the trials were generally established late in the planting window when temperatures were increasing with the exception of experiment 4.

The only rain that fell during experiment one was 0.4 mm 1 day after planting (DAP). There was no irrigation applied to the trial during the period of monitoring soil temperature or soil water. The optimum soil temperature (minimum) for emergence of cotton ranges from 14 to 18 C (CSD, 1997). However, due to the late establishment of the trial, average soil temperatures were considerably higher than this, which promoted rapid germination and emergence. The head space temperatures were also high and this contributed to cotton seedling mortality, even after slitting the film above the seedlings. Humidity under the film was high as condensation was observed under the film and the combination of high temperature and humidity is the equivalent of 'cooking' the seedling. Similar observations have been made by Anderson et al (2006) and Nehl et al (2004) when investigating the use of plastic mulch to solarise the soil for Fusarium and Black Root Rot control.

There was a distinct diurnal pattern in temperature both in the head space and at the planting depth, with the highest temperature occurring at 12:00 in the head space and 15:00 at the planting depth. Film 491 resulted in the highest temperatures both during a daily cycle and over the period of measurement. Depending on the rate of degradation of this film may this may be the choice for early planting.

Soil temperature at the depth of planting remained higher under the thin film compared with the bare control for the period of monitoring. A similar result was obtained by Nehl et al (2004) on the same soil type during their solarisation studies.

However, due to the late planting date soil and head space temperatures were elevated above the optimum for seedling survival, which compromised the original objective of the trial. The thin film had effectively broken down on the soil surface 25 days after application. This was probably accelerated by having to slit the film above emerged seedlings. The remnant surface film had disappeared completely 68 days after planting, with the buried edges of the film still just visible at the soil surface. It is not certain whether this will pose any problems at harvest and contamination of the lint.

Soil surface temperatures were lower and similar for experiments two, three and four compared with experiment one, reflecting the difference in environmental conditions. This also indicates the importance in selecting a plant date as cotton seedlings were unable to penetrate any thin film trialled. It was only in experiment 4 in combination with a new film formulation, which began to break down (approximately 20 days) as the cotton was emerging, that plants have survived. An interesting observation was that after the film was slit, the emerged plants appeared healthy however, a period of cool overcast conditions resulted in many plants not surviving.

The main constraint for the research was the delayed availability of film, which compromised planting of field experiments. Also, replication of soil measurements was not possible due to equipment availability. Notwithstanding these issues the results indicate that thin film promotes emergence and conserves seedbed moisture. Further development of the film for cotton needs to be done in the timing of the breakdown of the film in relation to crop emergence. The work has generated more questions than in providing answers; how does the field hydrology change by using thin film, do the buried edges affect irrigation, what is the effect on soil conditions and so on. The main benefit in using thin film is perceived to be in short season growing regions to extend the season length and to conserve soil moisture in other growing regions. Management issues will need to be resolved; such as timing of planting, nutrition, irrigation, weeds and pest control.

Conclusions

Thin polymer film promoted earlier and uniform emergence of cotton seedlings, however, the late planting compromised seedling survival.

The exposed film degraded completely prior to harvest, which suggests that contamination of the harvested lint may not be an issue.

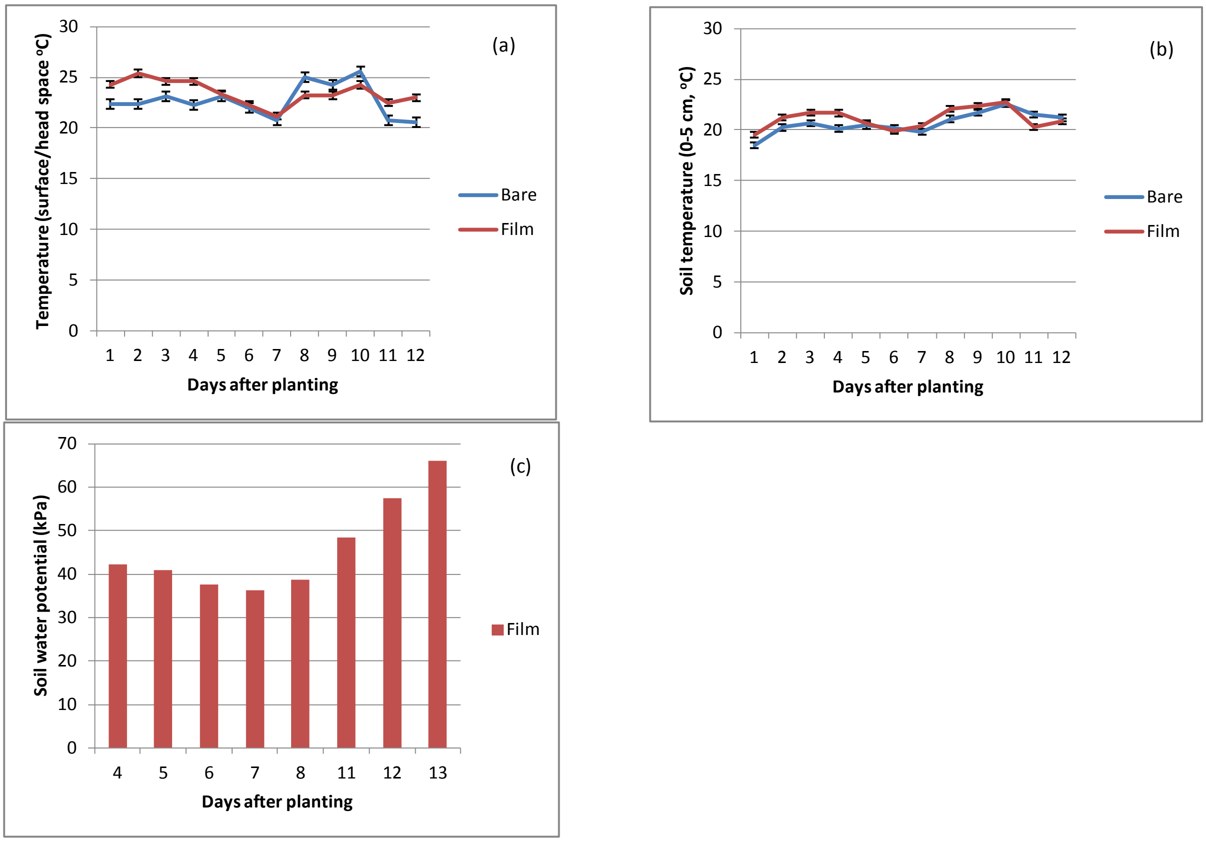


Figure 12 Experiment 4, Planting 1, 15 Sep 2011 (a) Soil surface and head space temperature (^{o}C) on bare and film covered plots, (b)Soil temperature (0-5 cm) at planting depth on bare and film covered plots and (c) Soil water (0-5cm) at planting depth on bare and film covered plots(bars are standard error of the mean) .

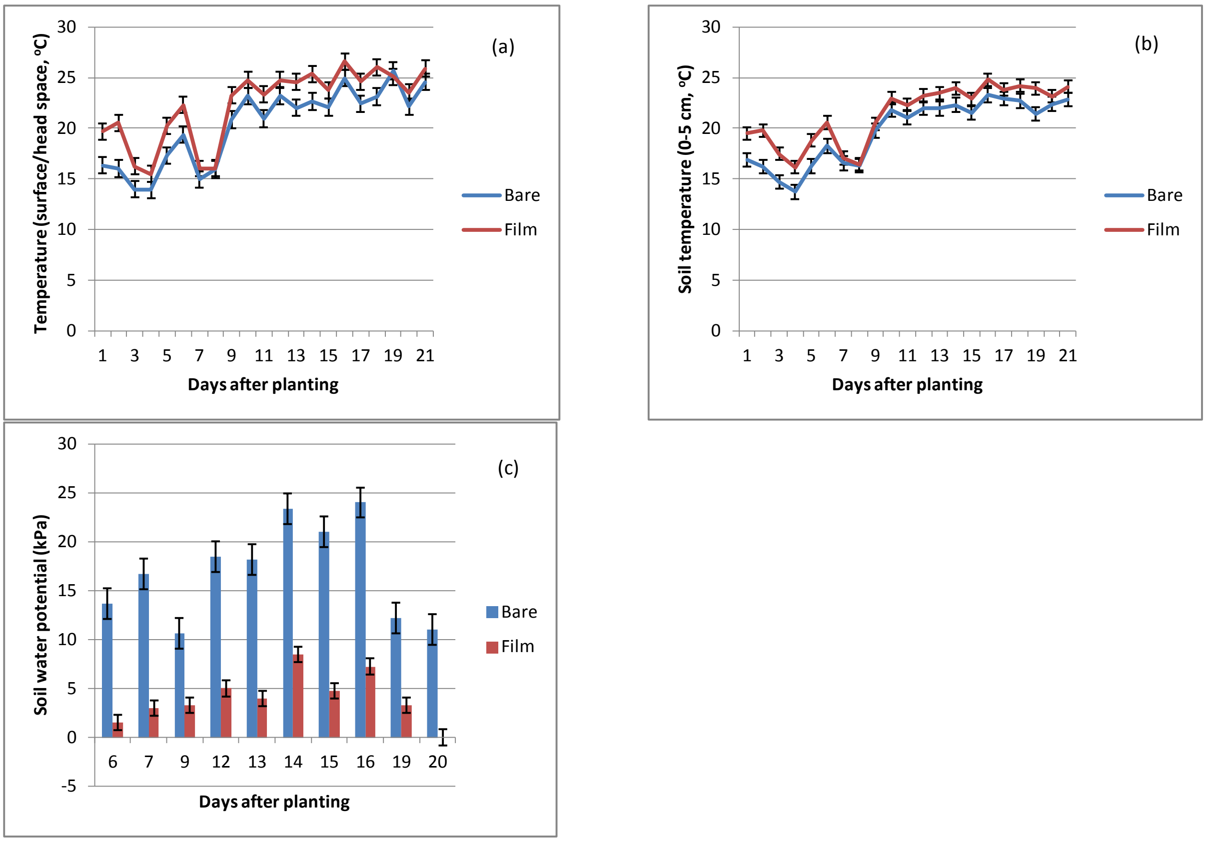


Figure 13 Experiment 4, Planting 2, 28 Sep 2011 (a) Soil surface and head space temperature (^{o}C) on bare and film covered plots, (b)Soil temperature (0-5 cm) at planting depth on bare and film covered plots and (c) Soil water (0-5cm) at planting depth on bare and film covered plots (bars are standard error of the mean)

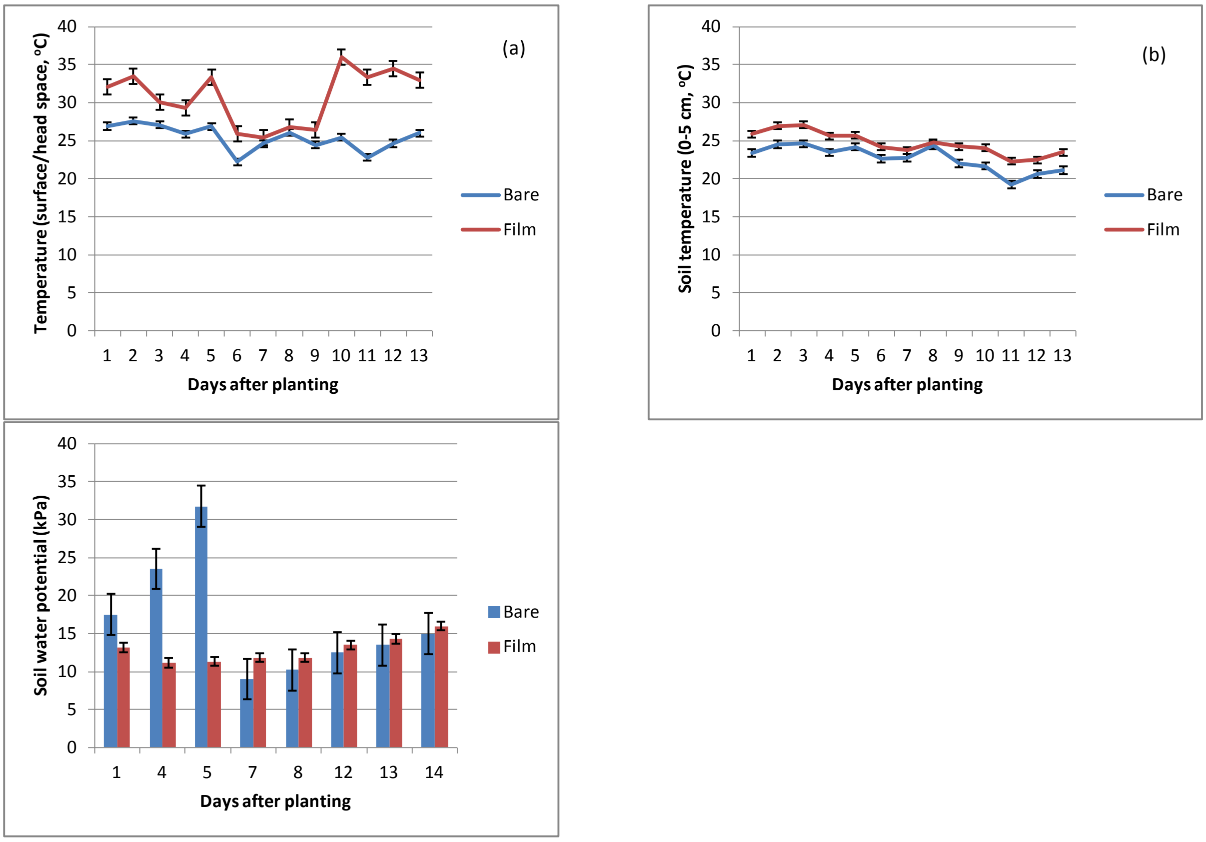


Figure 14 Experiment 4, Planting 3, 20 Oct 2011 (a) Soil surface and head space temperature (^{o}C) on bare and film covered plots, (b)Soil temperature (0-5 cm) at planting depth on bare and film covered plots and (c) Soil water (0-5cm) at planting depth on bare and film covered plots (bars are standard error of the mean)

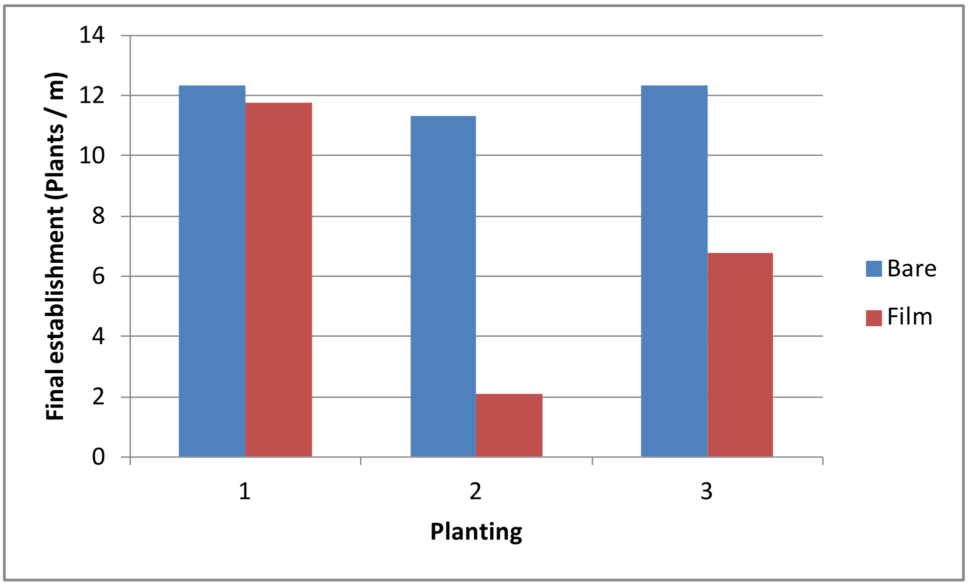


Figure 15 Experiment 4, Final establishment for each planting date (1= 15 Sep 2011, 2= 28 Sep 2011 and 3= 20 Oct 2011)

Objective iii. New initiatives in cotton farming systems.

(a): Inter-cropping cotton and legumes in close proximity

Experiments were undertaken to determine if a benefit in nitrogen supply to cotton could be achieved by planting legumes adjacent to cotton rows.

A field experiment was conducted in field A3 (2009/2010), field B2 (2010/2011) and field A3 (2011/2012) at the Australian Cotton Research Institute (149^{o} 47' E, 30^{o} 13' S), near Narrabri, New South Wales. The soil at the site is classified as a Vertosol (Isbell, 1996). Three treatments were compared namely a control consisting of cotton (Sicot 71 BRF, planted 15/10/2009, 14/10/2010 and 14/10/2011) grown on 1 m row spacing and cotton with a short-term legume (inoculated with Type E) grown either side the cotton row (Faba bean, *Vicia faba* & Namoi woolly pod vetch, *Vicia villosa*, planted 11/11/2009, 27/9/2010 and 4/11/2011). These treatments will be referred to Cotton (C), Cotton-Faba bean (C-F) and Cotton-Vetch (C-V) respectively. The legumes were planted completely out of sequence since they are normally used as winter crops. Plots were 8 rows wide by 15 m long. Nitrogen at the rate of 0 & 150 kg N/ha of was applied (29/09/2009, 8/9/2010 and 22/8/2011) to enable an estimate of the legume contribution to soil nitrate, nutrient use efficiency and apparent fertiliser recovery by cotton. Cotton was harvested on 21/05/2010, 16/5/2011 and X/X/2012. Weed control, insect and pest monitoring was standard practice for Bollgard cultivars for the area. The experimental area was irrigated at a deficit of 70 mm of water on a 7-10 day cycle.

Soil water was monitored every 0.2 m to 1.2 m using a calibrated neutron moisture meter. Measurements were taken after planting and harvest and before and after irrigation to determine season water use and to calculate crop water use efficiency. Soil samples were collected from the same depths and bulked to determine soil nitrate and carbon profiles for each treatment close to the beginning, mid-season (weather permitting) and after harvest of the experiment.

Twenty plants were monitored in each replicate to determine the time to 50 % squares, 50 % flowers and time to maturity. The number of nodes and plant height was recorded at maturity. A single row from each plot was mechanically harvested and weighed to determine a commercial yield with sub-samples being ginned and tested for quality using HVI (High Volume Instrument, determines colour, grade, length, micronaire, strength and uniformity).

Nitrogen uptake was determined by cutting all plants in a metre length of row and weighing. A sub-sample of three plants was selected for nitrogen analysis using Kjeldahl digestion (Rayment and Higginson, 1992). Nitrogen use efficiency (NUE, kg lint/kg N uptake) is calculated as the lint yield (kg) divided by the nitrogen uptake (kg N) (Rochester, 2007). Apparent fertiliser recovery was calculated as nitrate in 150 N treatments minus nitrate in 0 N treatment divided by the applied rate expressed as a percentage.

The experimental design was a split plot with six replicates with cotton being the main plot, the legumes sub-plots and nitrogen the split plots.

Difference between treatments was determined by standard analysis of variance at the five percent level using Genstat v13 (VSN, 2010).

Results

Previous studies have examined intercropping in the normally accepted form where two crops are grown as alternate rows, in strips/blocks or as relay strips, where one crop is grown after the other with a small overlap between planting and harvesting. The legumes in these experiments were planted either side of the cotton row and then removed after a short growth period. The legumes were also grown out of season, which will limit their ability to fix nitrogen.

2009-2010

Cropping treatment did not significantly affect lint yield (Table 7). However, there was a significant effect of nitrogen with 0N yielding less than 150N. Seasonal water use was not significantly different between treatments (Table 7), which indicates that intercropping cotton and legumes did not affect water use. Nitrogen had a significant effect on crop water use efficiency with greater efficiencies at the high application rate (Table 7). This coincided with plants being taller (76 v 72 cm) but not significantly so with 150N compared with 0N.

There was variability in the initial soil nitrate profiles under 0 N and 150 N rates with higher levels of nitrate in the soil surface under C compared with the C-F and C-V plots (Fig 16a, b). This may reflect previous cropping history of the site although a cereal crop was grown between cotton crops to reduce the effect of previous nutrient treatments. After harvest the soil nitrate was similar and uniformly low below 25 cm under both 0N and 150N treatments (Fig 16c, d). In considering the soil nitrate at the end of the season C-F contributed 0.4 kg N/ha while C-V contributed 1.4 kg N/ha in the 0-30 cm layer, which is reasonable since the legumes were only growing for 39 days.

Similarly there were no differences between soil carbon profiles at the beginning of the experiment under the two nitrogen treatments or after harvest (Fig 17a, b). Soil carbon levels decreased more under the 0N compared to the 150N treatment between the start and end of the experiment (Fig 17 a, b). Average profile soil carbon decreased under all treatments during the time of the experiment (Fig 18).

Apparent fertiliser recovery (AFR) was in the order of C > C-V > C-F, which reflected the level of soil nitrate in the profile at the beginning of the experiment.

Table 7 Effect of treatment and nitrogen rate on lint yield (kg/ha), season water use (mm), crop water use efficiency (kg/ha/mm) and nitrogen use efficiency (kg lint/ kg N uptake) for the 2009/2010, 2010/2011 and 2011/2012 seasons.

	Crop						
	Cotton		Cotton-Faba bean		Cotton-Vetch		LSD (P<0.05)
	Nitrogen applied (kg/ha)						
2009/2010	0	150	0	150	0	150	
Lint (kg/ha)	2048	2746	1888	2584	2098	2600	Nitrogen 211
Season water use (mm)	721	730	733	724	749	745	ns
Water use efficiency (kg/ha/mm)	2.6	3.7	2.5	3.5	2.8	3.5	Nitrogen 0.2
Nitrogen use efficiency (kg lint/kg N)	31.2	26.0	25.6	26.2	27.9	23.4	ns
2010/2011							
Lint (kg/ha)	2419	2884	1701	2330	1925	1918	Crop*nitrogen 370
Season water use (mm)	589	646	505	560	545	587	Crop 42
Water use efficiency (kg/ha/mm)	4.1	4.5	3.4	4.2	3.5	3.3	Crop 0.5
Nitrogen use efficiency (kg lint/kg N)	18.5	13.1	18.2	14.4	19.4	12.8	ns
2011/2012							
Lint (kg/ha)							
Season water use (mm)							
Water use efficiency (kg/ha/mm)							
Nitrogen use efficiency (kg lint/kg N)							

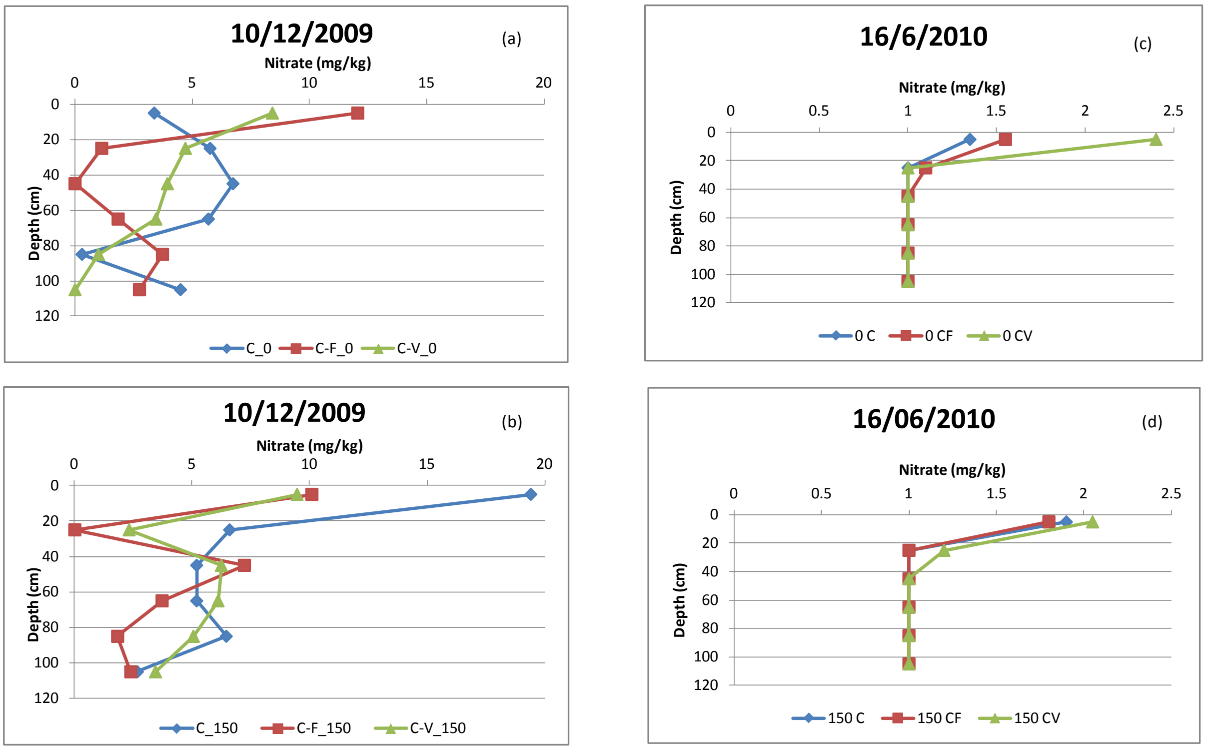
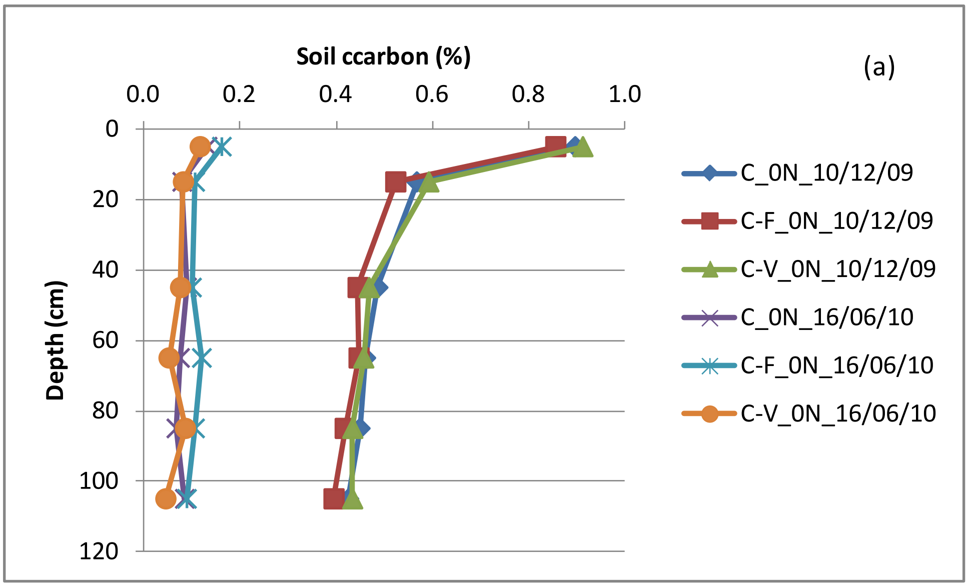


Figure 16 Soil profile nitrate (mg/kg) distribution at the start (10/12/2009) for (a) 0N and (b) 150 N and after harvest (16/6/2010) for (c) 0N and (d) 150N for each treatment in the 2009/2010 season

2010-2011

There was a significant crop by nitrogen interaction on lint yield this season with 150N having significantly greater yield than 0N for all treatments except for C-V and all crop treatments being significantly different (Table 7). Seasonal water use was only significantly greater under C compared to C-F, while water use efficiency was only significantly greater with C compared to C-V (Table 7). As for the previous season there were no differences between treatments for nitrogen use efficiency, although the efficiencies were lower than for the previous season (Table 7).
Initial soil profiles of nitrate varied with depth and were greater in 0-40 cm under 150N compared to 0N (Fig 19a, b). By mid season the surface nitrate had been depleted, while subsoil levels were similar to that at the commencement of the experiment (Fig 19c). By the end of the season nitrate levels were low under both the 0N and 150N treatments (Fig 19d, e), however, there was more nitrate under the C-F and C-V at depth compared to C under 150N (Fig 19e). In considering the soil nitrate at the end of the season C-F contributed 1.8 kg N/ha while C-V contributed 0.3 kg N/ha in the 0-30 cm layer the reverse from the previous season, which is reasonable since the legumes were only growing for 84 days.
Soil carbon profiles tended to vary with depth, and there was little change in soil carbon over the duration of the experiment except for the bulge in carbon at 45 cm under C 0N decreasing (Fig 20a, b). Average profile soil carbon levels were consistent over the duration of the experiment except for C 150N which increased slightly (Fig 21).
AFR was in the order of C > C-F > C-V which reflected the initial soil nitrate profiles. Cotton recovered more N from the C-F this season while it recovered more from C-V the previous season.



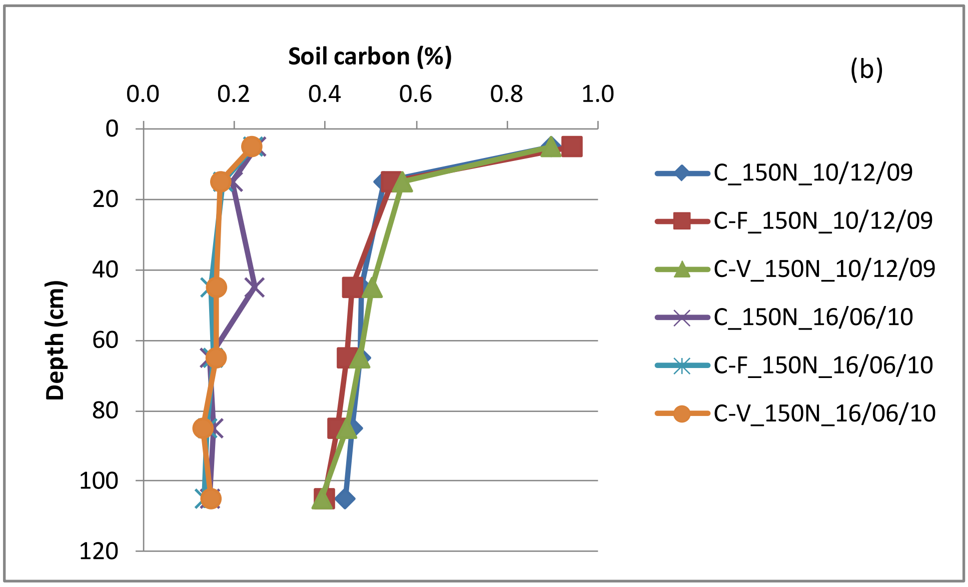


Figure 17 Soil carbon levels (%) for (a) 0N and (b) 150N treatments at the start (12/10/09) and after harvest (16/6/2010)

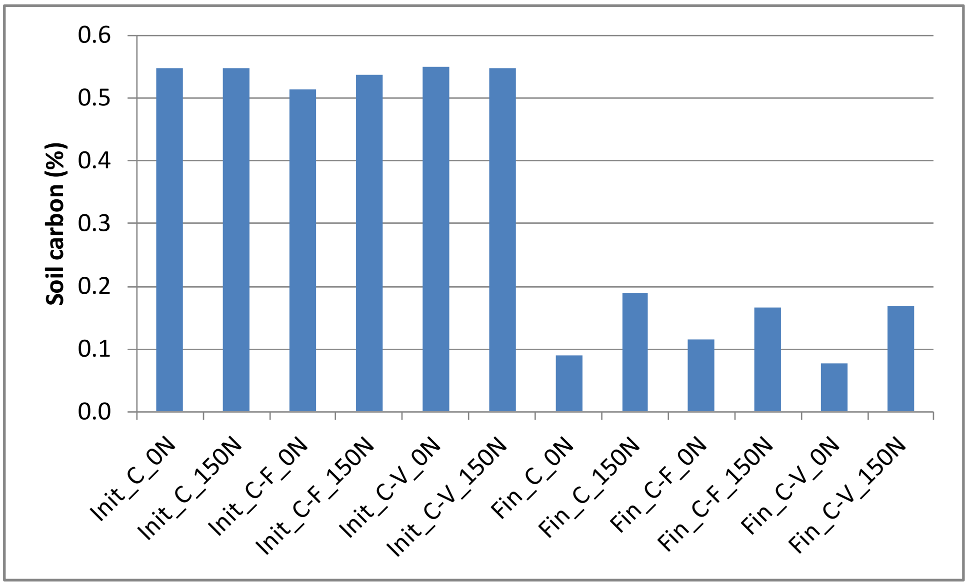


Figure 18 Average soil carbon levels (%) 2009/2010 (Init= start expt. amount, Fin= end expt. amount)

2011-2012

Data to be added when available

Discussion

Over the two seasons the control (C 150N) yielded 18% more than either legume treatment, with no indication that nitrogen fixation was effective. The initial aim was test the hypothesis that growing cotton and a legume in close proximity may enhance nitrogen supply to the cotton crop and that the decaying legume would provide a pathway for irrigation infiltration, thereby improving seasonal water use. Although there was no difference in water use during the first season, significant differences occurred over the second. The experiment was conducted in a different field in both seasons which may account for this variation.

The greater yield under C-V compared with C-F suggests that vetch may contribute more nitrogen than faba bean, however, the yield loss compared with cotton makes the strategy impractical at this point in time.

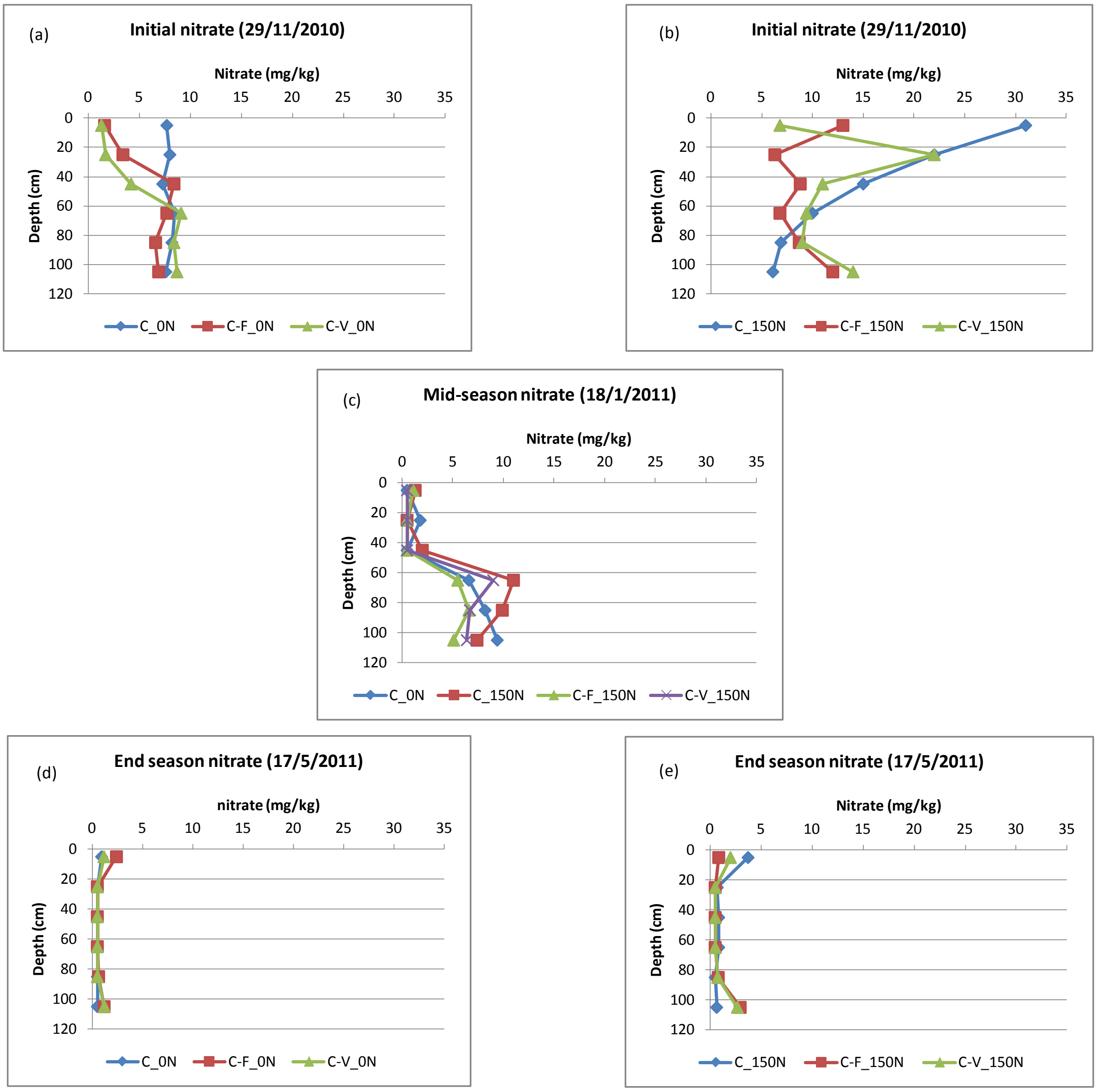
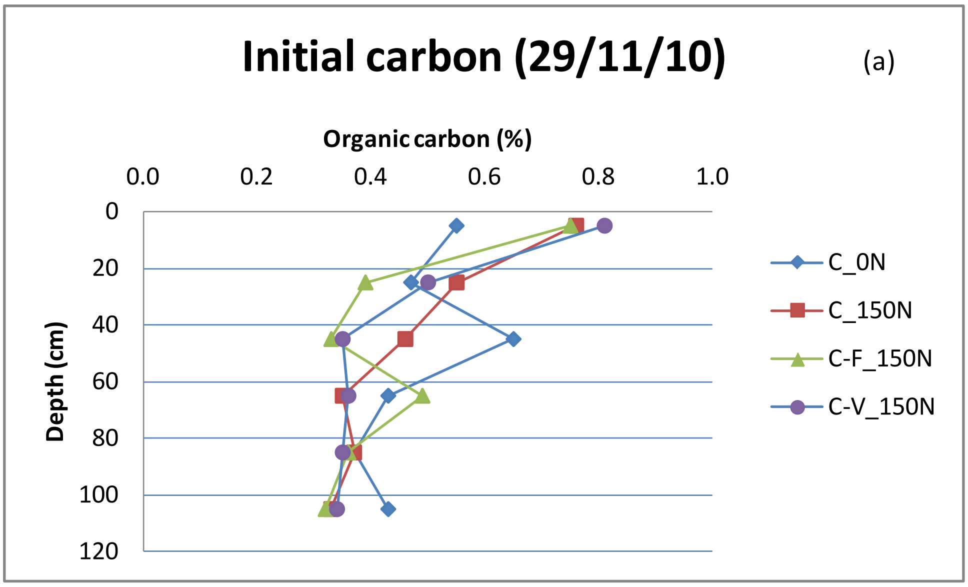


Figure 19 Soil nitrate (mg/kg) profiles for the (a) 0N and (b) 150N initial, (c) 0N and 150N mid-season nitrate profiles and (d) 0N and (e) 150N treatments end of season in the 2010/2011 season



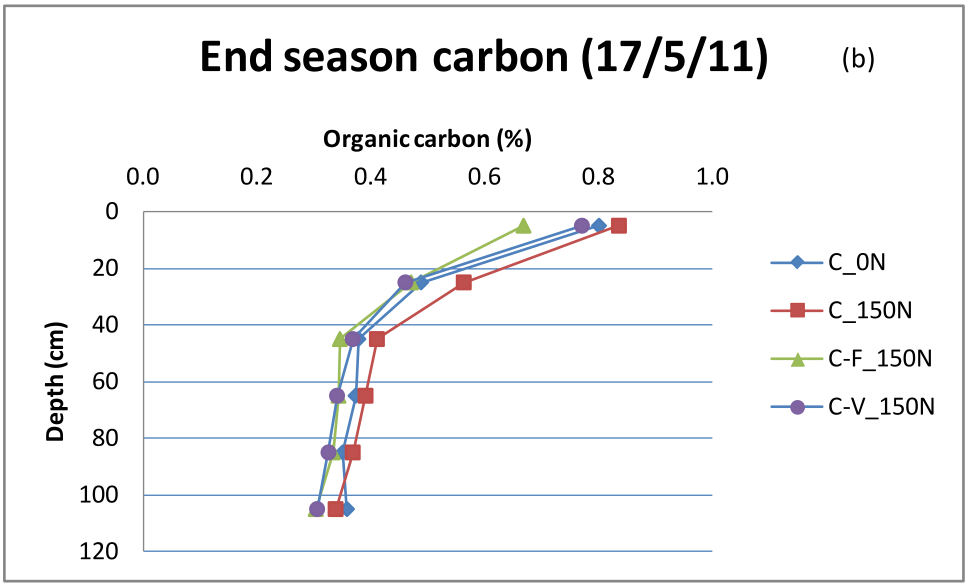


Figure 20 Soil carbon levels (%) (a) initial, (b) end season for all treatments during the 2010/2011 season

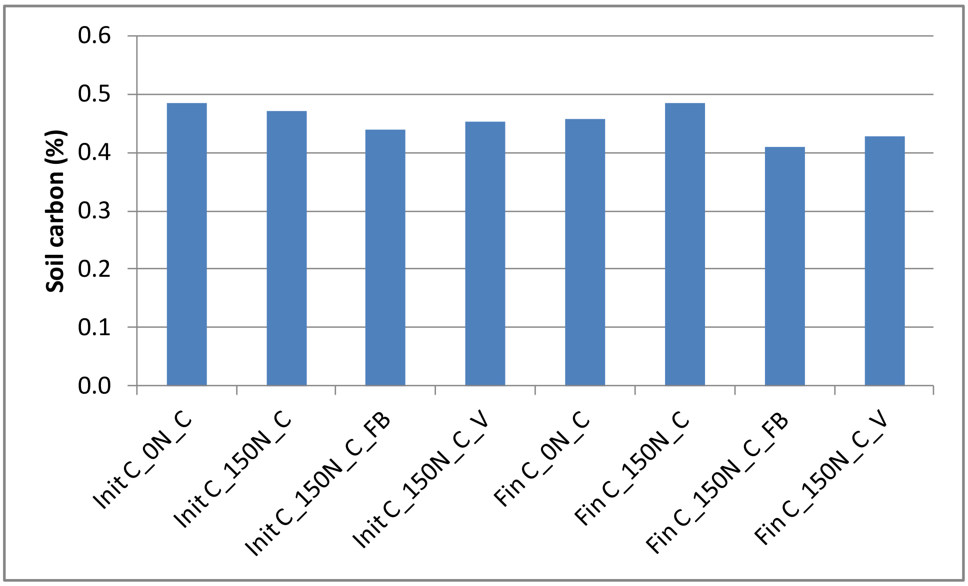


Figure 21 Average soil carbon levels (%) 2010/2011

INTERCROP TRIAL 2010-11	DATE 1.10.10	DATE27.10.10	DATE 15.11.10	DATE 23.11.10	DATE 23.12.10	DATE 4.2.11	DATE 17.5.11
Cotton 0kgN/Ha							
Cotton – Vetch 0kgN/Ha							
Cotton – Faba 0kgN/Ha							
Cotton 150kgN/Ha							
Cotton – Vetch 150kgN/Ha							
Cotton – Faba 150kgN/Ha							

Photo 5 (above) Timeline to illustrate growth of legumes in relation to cotton

Photo 6 Faba bean and vetch either side of cotton rows

Photo 7 Overview of inter-cropping experiment, light coloured plots in background are 0N

(b): Preliminary survey on change in soil strength under round bale pickers

Growers have expressed some concern about the effect of the new round bale pickers on soil conditions, especially under wet harvest situations.

A number of cotton fields were selected during the 2011 cotton harvest to cover a range of soil types and soil moisture conditions at harvest. Soil cone resistance was measured, to depth of 0.6 m at intervals of 0.02 m, with a recording penetrometer (12.3 mm dia. cone, 30^{o} included angle) across trafficked and un-trafficked furrows and crop rows before and after the passage of a cotton picker. Soil samples were collected at the same time from 0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5 and 0.5-0.6 m depths for gravimetric water content and assessment of plastic limit (Australian Standards Association, 1995). Soil bulk density profiles were estimated from the cores. Three transects five metres apart were measured 20 m in from the tail drain end of the field perpendicular to the direction of picker travel. Soil resistance data were contoured using SigmaPlot 11.0.

Equipment parameters collected included empty and loaded weights, tyre size and inflation pressure and vehicle track and working width.

Results

It should be noted that since soil strength is dependent on soil moisture the strength profiles shown will change as soils become drier, through extraction by a rotation crop, or wetter, through rainfall or irrigation.

At the sites sampled soil strength profiles changed after traffic compared with before traffic with greater changes being measured under fully laden pickers compared with empty pickers. Comparisons can only be made between before and after picker traffic at any one site since soil strength is dependent on soil moisture. Soil water content did not change before and after traffic by the pickers (Table 8).

Table 8 Details of sites, soil type and equipment measured.

Site	Soil	Equipment	Weight (t)		Soil water (%)	
			Empty	Loaded	Before	After
Narrabri	Grey cracking clay	Round bale+trailer	38	47	24	24
Hillston	Red brown clay	Round bale	32	34	19	19
Boggabilla	Cracking clay	Basket	16	18	22	22

The colours in the soil strength profiles indicate soil strength, and the blue colours represent soils with low strength of 2000 kPa or less where roots will grow. The change in colour from green to yellow to red zones indicates increasing soil strength, and from the green colour onwards roots will experience difficulty in penetrating the soil. The literature suggests that roots stop growing at strengths above about 2000 kPa (290 psi), the green zone.

At all sites there was a degree of compaction before harvest. Soil strength profiles before traffic are the result of previous operations; such as listing, fertiliser application, sowing and other operations and exhibit a degree of variability reflecting the variation in soils and soil water at the time of trafficking. Before traffic the zones with higher soil strength were generally deeper at all sites.

The after traffic profiles for a round bale picker plus trailer (Figure 22) at a site in the Namoi Valley showed that the area of soil of low strength (blue) was reduced and the area of high strength (yellow/red) was increased. At this site soil strength was measured to a depth of 0.7 m and showed that the area of yellow to red is closer to the soil surface compared with before traffic (0.1 m compared to 0.3 m) and has become more uniform across the rows. Also note that the strength at depth has increased.

On a different soil type in southern NSW the effect of traffic by a round bale picker is again evident (Figure 23). At this site it was only possible to measure soil strength to 0.5 m. Soil strength was increased closer to the surface (green) after traffic by the picker, and also at depth (yellow/red) as a more uniform zone. At both sites lateral movement of soil has resulted in an increase in soil strength under the crop row. The vertical blue zones before traffic correspond to cracks along wheel furrows which have closed after traffic.

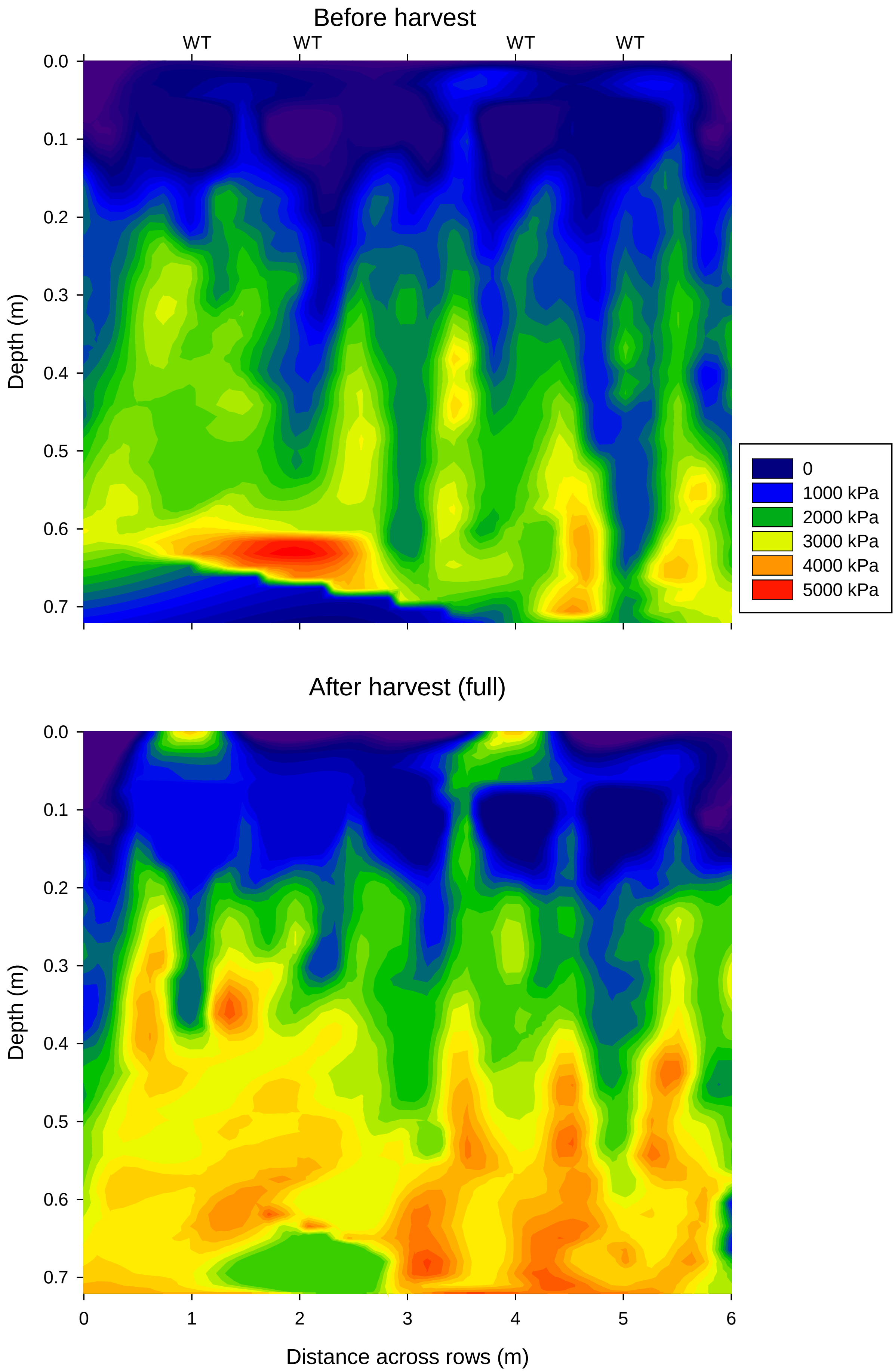


Figure 22 Change in soil cone resistance due to picker traffic on a black-cracking clay (Namoi Valley 2011); the larger (kPa) the number the greater the soil strength.

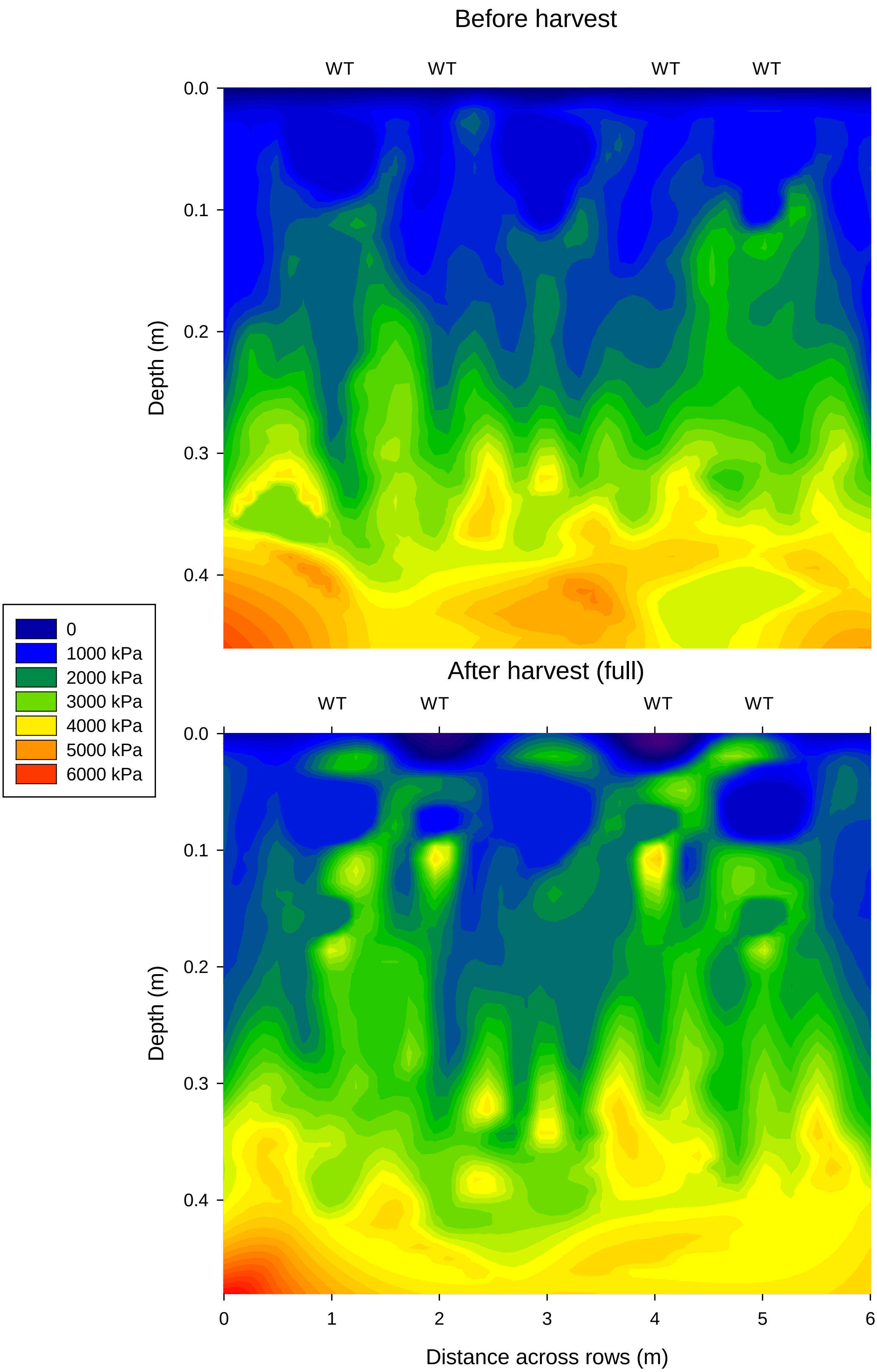


Figure 23 Change in soil cone resistance due to picker traffic on a red-brown clay (Southern NSW 2011)

Discussion

Of concern is the fact that changes in soil strength are being detected at depth (0.4 to 0.6 m). Problems will eventuate if soil strength remains above 2000 kPa after the soil wets, which will restrict root growth, water and nutrient uptake. Roots will grow through high strength soils if there are cracks and bio-pores through the profile, but not if compaction has resulted in pores smaller than the diameter of the root. Another issue is the proximity of wheels to the crop row due to spacing between dual wheels and track widths of pickers. This results in soil compaction beneath the row due to lateral soil movement.

Notwithstanding that the measurements were done on different soils and at different soil moisture, the change in soil strength is greater under the round bale picker compared with the basket picker (data not shown). If this is generally indicative of differences between the picker types then the wide spread uptake of round bale pickers may mean that growers need to be aware of this risk. There is a need to investigate this further to substantiate it and test if it occurs over a wider range of soil types and soil moisture profiles with side-by-side comparisons of the two picker types. Furthermore, if it is clear that the risk is higher, and under what conditions, options for reducing the risk (eg managing last irrigation more carefully) or amelioration need to be assessed so that growers can gain the most benefit from new technology and avoid future problems with compaction potentially limiting yield.

The ball game has changed with the rapid adoption of round bale pickers by the industry so growers need to be aware of potential changes to soils in both the short and long-term.

Conclusions

With more specific information of heavy traffic on immediate soil effects and the consequences on subsequent crop yield, amelioration decisions (rotation, tillage, etc) can be more informed.

(c): Assessment of long-term trials at ACRI

The long-term experiments at ACRI are a valuable resource which enables changes in various soil properties to be evaluated over many seasons. Soil organic carbon (SOC) is one of topical interest at present. When SOC changes in the 0 – 30 cm depth of soil is examined trends are emerging; when tillage is involved there is a decrease in SOC over time, however if minimum tillage is practiced SOC levels remain higher compared with maximum soil disturbance (C1, Fig 24). When rotation crops are included in cotton systems there is a trend for SOC to increase over time (D1 and F6, Fig 24). There are differences in the magnitude in SOC between the long-term trials and this is largely due to the fact that each experiment had different levels of SOC at the beginning of the experiment (Fig 24). Also, the soils in C1 and D1 have the subsoil constraint of sodicity, while the soil in F6 does not. This will affect crop growth and the biomass produced and hence the amount of organic material being returned to the soil and ultimately SOC. The large spike in SOC in D1 in 2007 is due to a large crop after a period of drought producing biomass in the 0-10 cm depth and the lower values the following season less biomass being produced, however the trend is upward.

The main conclusions that can be drawn from these experiments are, reducing tillage and including wheat in rotation with cotton slowed the rate of SOC decline compared with the back to back cotton under conventional tillage; including rotation crops in the cotton system increases SOC over time albeit at different rates depending on the crop and stubble management.

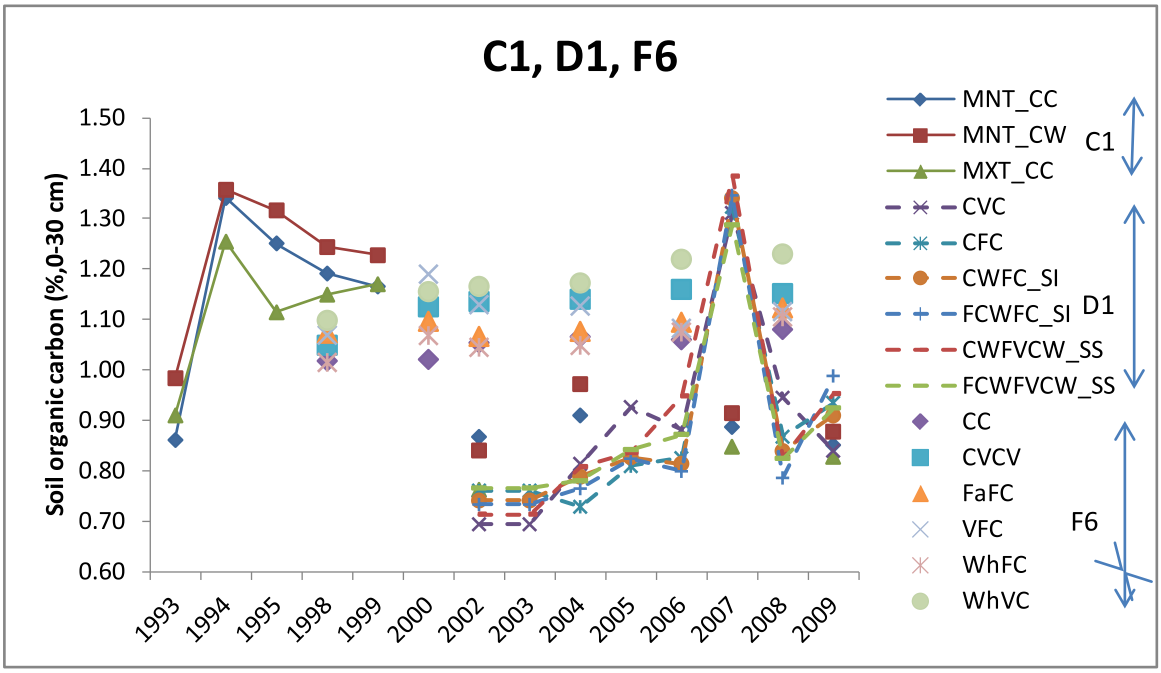


Figure 24 Changes in soil organic carbon with time under long-term experiments at ACRI (C1 cotton-wheat with conventional and reduced tillage, D1 cotton rotation with standing or incorporated stubble, F6 cotton legume rotation with stubble incorporated). Note different stating levels of SOC and level of response at the different sites.

Outcomes

The Cotton CRC and CRDC have over the years invested heavily in production related research. Much of this research has been world-class. However, the challenge for industry is to integrate research findings across a range of areas (e.g. pests, nutrition, agronomy, diseases), when the recommendations are often contradictory, or the outcomes of combining research findings is poorly understood. This project is of significance to cotton growers and consultants because it will (a) evaluate scientifically and logically options to improve farming systems for higher yield and quality (b) extend these outcomes widely to industry so that there is less uncertainty and greater clarity about the pathways to achieve high yield and fibre quality in a sustainable system (c) provide information on the fit of new technologies into the farming system (d) provide better co-ordination of farming systems research so that growers can gain benefits from the experiments of other research projects and from better integrated research outcomes, this can be linked with BMP.

Economic - Better integration of research outcomes will reduce risks of unnecessary or even counterproductive practices on farm, and enable growers and agronomists to make more informed decisions that will contribute to sustained or higher profitability.

Environmental – Rational integration of research outcomes will reduce unnecessary use of inputs or unnecessary practices that can affect the on-farm sustainability of cotton production or the risk of off-farm movement of inputs.

Community – Cotton is a major source of wealth, employment and opportunity in the regional communities in which it is grown. This project will help to ensure a competitive and viable cotton industry, thereby at least indirectly benefiting rural communities.

This project aimed to develop farming systems and extension materials and processes that support growers in producing high yielding / high fibre quality cotton more consistently, profitably and sustainably. It thereby contributes directly to the profitability and competitiveness of the industry. This has implication both on-farm but also for cotton's role in the catchment through more rational management of inputs, especially, water, pesticide, fertilizer and energy. A second contribution is to co-ordination and integration of much production related research and the linkages with BMP. This is a clear aim for the Cotton CRC and it is important that the CRC can show that it is meeting it.

During the conduct of the project a review of the long-term experiments on soil organic carbon at ACRI was undertaken, with Drs Hulugalle and Rochester kindly providing access to relevant data. Briefly the field experiments are located in field C1, D1 and F6 at ACRI and are examining the effect of tillage and rotation with wheat on soil conditions and profitability of cotton (C1), determining the effect of rotation crops and stubble management on soil conditions and profitability of cotton (D1) and examining the effect of legumes and stubble management on soil N and cotton productivity (F6). The results cannot be directly compared due to differences in soils and soil sampling times and depths. However, notwithstanding this the messages from these experiments should be similar with respect to rotations within cotton systems. There are differences with respect to stubble management, however pupae busting is a common tillage activity across all experiments. The main difference between sites is that field C1 and D1 are sodic at depth, while field 6 is not and that each experiment had different starting soil organic levels. The sodicity would affect crop growth and hence the amount of biomass produced and returned to the system. The varying starting soil organic carbon levels will affect the magnitude and rate of change in each system. The various changes in treatments over the initial treatments will impact on carbon dynamics and it will take time before a new equilibrium is established.

Key Outcomes:

- Interrogation of industry data relating management inputs to lint yield and fibre quality has demonstrated that positive changes have occurred over the past eight years. Although rates of nitrogen application continue to increase, the range of application rates has narrowed. The number of insect sprays has declined as has the number of in-crop irrigations, providing a positive image for the industry. The management factors affecting productivity and fibre quality tend to vary between seasons and regions, reflecting differences in soils and climate.

- The project has shown that planting date and cultivar selection has an effect on resource use efficiency and does not impact productivity, except for delayed planting.

- The project has also shown that there may be potential for thin biodegradable film in promoting emergence and for conserving soil moisture at planting. The benefits may be greatest for cooler regions as soil temperatures are elevated beneath the film, thereby accelerating germination and emergence.

- The current system of inter-cropping cotton and legumes in close proximity is not commercially feasible. The concept of spatial rotation is attractive given developments in precision agriculture, where crops can be precisely planted in the landscape. There are perceived benefits in being able to rotate cotton and legumes in the same space over time; soil physical, chemical and biological properties will change which may improve cotton root growth, water availability, nutrient supply and pest and disease resistance. There were no practical benefits.

- Preliminary measures of soil strength have highlighted the possibility of subsoil compaction developing from the use of increasingly heavy harvesting equipment. Strategies need to be developed to minimise subsoil compaction and for amelioration in the long-term.

- An assessment on changes in soil organic carbon in three long-term experiments at ACRI was undertaken; where one has demonstrated nitrogen and carbon benefits from rotation with legumes, one has shown a benefit in soil carbon from rotations with both wheat and legumes and one the benefit from minimum tillage and wheat rotation

Extension Opportunities

Future dissemination of project outcomes will be in the form of presentations at grower group meetings, participation in the Australian Cotton Conference and articles in grower publications.

Future research should explore new technology (plastic mulch) and current practices (round bale pickers) on future productivity to address specific constraints in cotton systems.

In cool regions, production can be limited by the need to replant due to prolonged cold conditions. New biodegradable thin films provide an opportunity to overcome this limitation without the risk of contaminating lint at harvest. The project will investigate the potential of thin film for early planting in south NSW and to conserve water in other areas (linked with UQ, PolymerCRC, Integrated Packaging & NSW DPI). Preliminary results suggest the films enhance early establishment. The plan is to plant cotton and apply film in one pass, with the film degrading as cotton emerges so the crop grows as if planted with no film. Thin film could also be used to establish a winter rotation crop in cool regions. However, many questions need to be answered such as: how to manage nitrogen under thin film? What is the effect of the film on field hydrology? Will early planting expose seedlings to cooler temperatures? Will crop development be compromised? Can the first irrigation be delayed? Can rain or irrigation sub across hills? What will the cost/benefit be? Planting date experiments will test the ability of cotton to penetrate film and N management. Experimental and demonstration sites will be established in short season regions on major soil types testing current thin film and pre-plant N versus applying N at planting and side dressing N. Potential new developments that will require testing are spray on film and shredded film more suited to stubble retention systems.

Growers have expressed concern about round bale pickers and soil compaction and preliminary research suggests these concerns are valid especially for subsoil compaction. The project will measure the impact of round bale pickers on soil conditions at harvest, assess the potential damage and develop amelioration strategies. Past research on soil compaction due to machinery traffic, emphasised compaction of upper soil layers and strategies were developed to minimise and ameliorate this issue. The widely adopted new pickers have greater axle loads (21 t) compared to basket pickers (12 t) which increases the risk of subsoil compaction, an issue that has not been researched. The longevity and effect of such compaction on subsequent crops is unknown. Compounding the problem is the risk that damage may accumulate and can to some extent be compensated by irrigation strategies (more frequent irrigation to offset poor root growth). The issue is invisible and may impact on the industry's profitability in the long-term. It is vital that soil be preserved for the benefit of growers and the communities in which the industry operates.

A project will need to quantify the impact of the new pickers on soils at harvest and initiate development of strategies for amelioration. It could link with Post Graduate root proposal (Brodrick) to evaluate soil compaction-root interactions and amelioration. Experiments on farms across cotton regions and soil types will assess the picking system including the effect on soils (structure, water holding capacity, infiltration, soil carbon and biological activity), the degree to which soil properties are currently ameliorated and the response of the next cotton crop. Experiments will assess timing of the last irrigation and row spacing as strategies to reduce traffic impact, and test if combining rotation and tillage can be used to repair subsoil compaction. Rotations may need to be extended to maximise amelioration. Simulation modelling will be used to complement field studies to assess the frequency soil is susceptible to compaction and to test the value of management options in the long term. This research will alert the industry to the hidden issue of subsoil compaction and assess the extent and potential cost to growers and identify the frequency of risk and strategies to minimise the problem.

Publications

Refereed Journal articles

MV Braunack, MP Bange, DB Johnston 2012. Can planting date and cultivar selection improve resource use efficiency of cotton systems? (In preparation for submission to Field Crops Research).

MV Braunack, 2012. Cotton farming systems in Australia: management factors contributing to yield and fibre quality and changes over time. (In preparation for submission to Agricultural Systems).

Refereed conference papers

MV Braunack, MP Bange, 2010 Can planting date and cultivar selection improve resource use efficiency of Australian cotton systems? In "*Food Security from Sustainable Agriculture*" Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand.

Conference papers/Posters

MV Braunack, 2010. Assessment of factors contributing to high cotton yield. 15th Australian Cotton conference, 10-12 August, 2010, Broadbeach, Qld (Poster)

MV Braunack, 2010. Assessment of factors contributing to high fibre quality. 15th Australian Cotton conference, 10-12 August, 2010, Broadbeach, Qld (Poster)

MV Braunack, NR Hulugalle, IJ Rochester, 2012. Soil organic carbon: in Australian cotton soils. EGU Assembly, 22-27 April, 2012, Vienna, Austria.

Grower magazine articles

MV Braunack, J Price, D Hodgson, 2012. The effect of picker traffic on soil compaction: A preliminary survey. The Australian Cottongrower 32(7), 12, 14-16.

Reports

MV Braunack, IJ Rochester, MP Bange, 2010. Nitrogen use in a changing climate: implications for the Australian cotton industry.

MV Braunack, 2011. Assessment of long-term experiments at ACRI.

Presentations (conference, field days, workshops etc)

2008

M Braunack project ideas presented to the local CRC management team.
M Braunack presented at the CRC Science forum.
M Braunack attended CRDC Farming Systems workshop, by invitation.

2009

M Braunack participated in cotton crop judging.
M Braunack attended Macintyre field day.
M Braunack attended the Lower Namoi field day.
M Braunack attended two Lower Namoi grower group meeting.

M Braunack invited to talk to Auscott farm managers meeting, Moree.

M Braunack presented at the CRC Science Forum.

2010

M Braunack had discussions with a group of farm managers from USA (Boswell farms).

M Braunack attended a field trip examining 0.76 v 1.0 m rows spacing, Lower Namoi grower group.

M Braunack made a presentation to the CRC board.

M Braunack attended Lower Namoi Grower group meeting, by invitation

M Braunack displayed posters at cotton conference

M Braunack presented at the CRC Science Forum.

2011

M Braunack participated in field tour with CRC board.

M Braunack attended two Lower Namoi Grower group meetings.

M Braunack presented at the Cotton Collective, Narrabri.

2012

M Braunack presented at the CRC Science Forum.

M Braunack had discussions with an African delegation on farming systems

M Braunack had discussions with a Pakistan delegation on farming systems

M Braunack presented a paper at the EGU Assembly 22-27 April, Vienna, Austria

Part 5 – Final Report Executive Summary

Project Title: Integrating agronomic inputs to improve profitability and sustainability

Principal Researcher:s MV Braunack (Researcher)/J. Price (Technical Officer)
Supervisor: MP Bange

This project aimed to develop farming systems and extension materials and processes that support growers in producing high yielding / high fibre quality cotton more consistently, profitably and sustainably. It thereby contributes directly to the profitability and competitiveness of the industry. This has implication both on-farm but also for cotton's role in the catchment through more rational management of inputs, especially, water, pesticide, fertilizer and energy. A second contribution is to co-ordination and integration of much production related research and the linkages with myBMP.

Key Outcomes:

- Interrogation of industry data relating management inputs to lint yield and fibre quality has demonstrated that positive changes have occurred over the past eight years. Although rates of nitrogen application continue to increase, the range of application rates has narrowed. The number of insect sprays has declined as has the number of in-crop irrigations, providing a positive image for the industry. The management factors affecting productivity and fibre quality tend to vary between seasons and regions, reflecting differences in soils and climate.

- The project has shown that planting date and cultivar selection has an effect on resource use efficiency and does not impact productivity, except for delayed planting.

- The project has also shown that there may be potential for thin biodegradable film in promoting emergence and for conserving soil moisture at planting. The benefits may be greatest for cooler regions as soil temperatures are elevated beneath the film, thereby accelerating germination and emergence.

- The current system of inter-cropping cotton and legumes in close proximity is not commercially feasible. The concept of spatial rotation is attractive given developments in precision agriculture, where crops can be precisely planted in the landscape. There are perceived benefits in being able to rotate cotton and legumes in the same space over time; soil physical, chemical and biological properties will change which may improve cotton root growth, water availability, nutrient supply and pest and disease resistance. There are no practical benefits at this point in time.

- Preliminary measures of soil strength have highlighted the possibility of subsoil compaction developing from the use of increasingly heavy harvesting equipment. Strategies need to be developed to minimise subsoil compaction and for amelioration in the long-term.

- An assessment on changes in soil organic carbon in three long-term experiments at ACRI was undertaken; where one has demonstrated nitrogen and carbon benefits from rotation with legumes, one has shown a benefit in soil carbon from rotations with both wheat and legumes and one the benefit from minimum tillage and including wheat in the rotation.