



17th Australian Cotton Conference

CONFERENCE PAPERS AND E-SUMMARIES

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CONFERENCE PAPERS

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TRANSFORM™ INSECTICIDE FOR MANAGEMENT OF COTTON PESTS IN AUSTRALIA

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Summary

Transform™ insecticide is a new insecticide which was registered for control of the key sap-feeding pests in Australian cotton in 2013. Transform is fast acting, has residual activity and is relatively non-disruptive to beneficial insects. Two field trials are summarised in this paper; demonstrating excellent control of *Creontiades dilutus* and *Aphis gossypii*, at 200 and 300 mL/ha. A third trial showed that the addition of salt (0.5% v/v) to Transform™ significantly improved the knockdown of mirids in pigeon peas. Transform insecticide will be a valuable tool for Australian cotton growers for control of the key sap-feeding pests while not flaring secondary pests such as whiteflies and mites.

Introduction

The widespread adoption of transgenic cotton in Australia has resulted in a dramatic change in the pest problems cotton consultants now face, with a change of focus from chewing insects to sap-feeding insects. Sap-feeding insects are implicated in the transmission of plant diseases (i.e. bunchy top), they deprive the cotton plant of nutrients and excrete honey dew, promoting the development of sooty mould which can result in the discolouration of lint leading to harsh quality penalties. Not only have the sap-feeders become more prevalent - possibly through the widespread use of non-IPM compatible products, but they have also increased in importance as insecticide resistance has developed. The resistance profile of green mirids to actives such as fipronil is currently unknown but resistance is likely to develop whenever products are over used.

Transform™ insecticide is a new product containing the active ingredient Isoclast™ active (sulfoxaflor) which has been registered for control of the key sap-feeding insect pests in Australian cotton. In the first year of use, Transform gave excellent control of green mirids (*C. dilutus*) and suppression of silverleaf whitefly (*B. argentifolii*). There were few reports of applications made for aphid (*A. gossypii*) control, but where Transform™ was used, it gave excellent control.

Previous field trials have demonstrated that Transform™ has rapid contact activity as well as systemic residual activity on green mirids and cotton aphids and will

suppress silverleaf whiteflies (Annetts, 2012; Annetts and Thomas, 2012). Further data would be useful.

The addition of salt to products such as fipronil and dimethoate for control of mirids, especially in pulse crops, is well documented (Khan *et al.*, 2002; Khan, 2003; Khan and Murray, 2004). It is unclear whether salt will increase the efficacy of Transform™ on mirids.

Two trials are presented in this paper demonstrating the efficacy of Transform™ on green mirids and aphids in cotton in Australia and one trial is presented which examined the effects of salt on the efficacy of Transform™ against mirids in pulses. These data show that Transform™ will be a critical tool for control of mirids, aphids and other sap-feeding insects in cotton without flaring secondary pests such as mites and silverleaf whiteflies.

Materials and methods

Experiments were carried out between 2010 and 2014 and located across New South Wales and Queensland. All trials were small-scale randomized complete block trials with four replications and an untreated control. Plot sizes were adequate to allow accurate treatment application and the assessment of pests (generally 2-6 m x 10 m plots). Products used are listed below in Table 1. Trial details are shown below in Table 2. Treatments were applied using a variety of application set-ups (precision small-plot sprayers) in order to closely simulate commercial practice, (see Table 2). Applications targeted high infestations

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of pests and were made under good environmental conditions. Assessments of green mirids were made using the beat sheet method, where a section of crop is pushed rigorously onto a yellow canvas sheet and the insects shaken onto the canvas and counted before they have a chance to fly or jump away. 3-4 metres of row were sampled at each assessment and results are displayed in mirids per m. Wingless cotton aphids were counted on 20 randomly selected leaves with results displayed as aphids per leaf. Data were analysed using a homogeneity of variance (Bartlett’s test) and normalized as necessary using a log (x+1) or Arcsine square root percent(x) transformation. Where no transformation symbol exists in the table, no transformation was necessary. Untransformed data are presented, while levels of significance and coefficient of variation reflect analyses on transformed data. Means were separated using Tukey’s HSD (P=.05). The effects of salt on the efficacy of Transform were analysed using a t-test as a factorial for rate vs +/- salt. Visual assessments of crop injury were made in each trial.

Results and discussion

Green mirids

Transform™ insecticide gave rapid knock down of mirids at the first assessment 3 days after application (Table 3). These data show that Transform™ at 200-300 mL/ha gave control significantly superior to the untreated and equivalent to the standard from 1 to 9 days after application. At 21 days after application the pest population had decreased and there was no separation in treatment means. These data supports previous trials where the lower rate (200 mL/ha) was adequate to control mirids in cotton.

Cotton aphids

Transform™ Insecticide at 200 to 300 mL/ha gave good knock down 3 days after application and residual control of cotton aphids to 17 days after application (Table 3). Transform™ Insecticide was equivalent to the standards at all assessments.

Trade Name /Formulation	Active Ingredient	Concentration (g a.i./L or kg)
Transform™ Insecticide	Isoclast™ active (Sulfoxaflor)	240 SC
Regent®	Fipronil	200SC
Dimethoate 400	Dimethoate	400 EC
Pirimor® WG	Pirimicarb	500 WG
Shield®	Clothianidin	200 SC
Pegasus®	Diafenthuiuron	500 SC
Pulse®	Organosilicone	-
Hasten™ spray adjuvant	Esterified seed oil	-

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Regent® is the registered trademark of BASF used under licence by Nufarm Australia Limited
Shield® is a tradename of Sumitomo Chemical Australia Pty Ltd

TABLE 1. Insecticides and formulation used in the trials.

Trial Number	AFS-09-032-2 104009RA	W11-538 124017RA	DOW/13/23, 140036 144005RA
Date of application	12/1/2010	5/3/2012	13/3/14
Author	B. Griffith	N. Pinny	T. Ranchodbhai & P. Warner
	Yelarbon	Narrabri	Branchview
Location	Queensland	NSW	Queensland
Crop	Cotton	Cotton	Pigeon peas
Variety	Sicot 71 BRF	N/R	N/R
Crop stage	21 nodes	Boll opening	67-75 BBCH
Insect stage counted	Nymphs+ adults	Wingless nymphs	Nymphs+ adults
Water rate (L/ha)	120	85	90
Pressure (kPa)	300	300	300
Nozzle type	Flat fan	Flat fan	Flat fan
Nozzle Tip	110-015	11001A	AirMix AM110-01

N/R = not recorded.

TABLE 2. Trial details.

Transform™ +/- salt for control of green mirids

Transform™ gave excellent control of mirids and was significantly superior to the untreated at all rates (100-300 mL/ha) at all assessments. When the effect of salt on the efficacy of Transform on mirids was analysed, salt was shown to significantly increase knockdown of mirids 1 days after application (P=0002) and 4 days after application (P=0.0052), while control 7 days after application was equivalent with or without salt.

Discussion

Transform™ gave excellent initial and residual control of green mirids and cotton aphids at 200 to 300 mL/ha. The addition of salt to Transform™ significantly improved knock-down of mirids one and four days after application. This trial was carried out in pigeon peas where the effects of salt are generally more noticeable. Until trial work is conducted in cotton it is not clear if the same improvement in efficacy would occur with

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the addition of salt; although it can be concluded that the lower rate (200 mL/ha) is sufficient to control mirids in most instances.

Transform™ has a favourable beneficial insect profile at field use rates. Many of the insecticides used for control of mirids, aphids and whiteflies are disruptive to beneficial predators and parasitoids. This is especially true of early season use of fipronil, dimethoate and pyrethroids. Field trials in Australia have shown that Transform will not cause flaring of mites when used as per label instructions. During the first season of use, there were no reports of Transform™ flaring silverleaf whiteflies, a common occurrence which often results after the use of fipronil.

Transform™ has demonstrated excellent efficacy on the key sap-feeding pests and suppression of silverleaf whiteflies in Australian cotton. Transform™ has also shown good activity on solenopsis mealybug (*Phenacoccus solenopsis*) in glasshouse bioassays (Miles, 2012) and field work is now needed to confirm this activity. As a result, Transform™ will be a valuable tool for Australian cotton growers because of its spectrum of activity and low impact on key beneficial insects.

Acknowledgement

Agritech, Agrisolutions and Eurofins carried out trial work reported in this paper. The author would like to acknowledge their contribution. Thanks to Paul Downard and John Gilmour who reviewed this paper and provided advice.

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Annetts, R. and Thomas, J. (2012). Sulfoxaflor for management of cotton pests in Australia. 2012 Beltwide Cotton Conferences, Orlando, Florida, January 3-6, 2012. 1067-1075.

Treatment	Rate (mL/ha)	Green mirid ^①				Cotton aphid ^②			
		3**	6**	9**	21	3	10*	14*	
Transform™ insecticide	200	0.7 b	0.0 b	0.1 b	0.2	0.9	1.1 b	0.1 b	
Transform™ insecticide	300	0.2 b	0.1 b	0.1 b	0.2	0.9	0.5 b	0.1 b	
Regent®	62	0.7 b	0.0 b	0.1 b	0.2				
Regent®	125	0.6 b	0.1 b	0.1 b	0.1				
Movento®♥	300					1.0	0.3 b	0.1 b	
Shield®♣	125					0.6	0.4 b	0.5 b	
Pegasus®	600					1.5	1.0 b	0.6 b	
Pirimor®†	500					0.5	0.6 b	0.2 b	
Dimethoate	250					0.7	0.1 b	0.3 b	
Untreated		2.8 a	1.7 a	1.5 a	0.2	1.3	7.5 a	4.6 a	
					NSD	NSD			
CV		40.4	65.6	88.7	8.8	81.7	42.5	83.1	

Means followed by same letter do not significantly differ (P=.05, Tukey's HSD). NSD= no significant difference

* Data transformed log (x+1)

** Data transformed Arcsine square root percent(x)

CV= coefficient of variation

① Number of adult and nymphal green mirids (per M)

② Number of wingless cotton aphids (per leaf)

♥ Movento plus Hasten 1 L/ha

♣ Shield plus Pulse 0.2% v/v

† Pirimor is in g/ha

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TABLE 3. Transform efficacy on green mirids (per m) and cotton aphid (per leaf)

Treatment	Rate (mL/ha)				
			1	4	7
Transform™ insecticide	100		1.4 bc	0.5 b	0.5 b
Transform™ insecticide	200		2.8 ab	0.2 b	0.2 b
Transform™ insecticide	300		1.4 bc	0.3 b	0.1 b
Transform™ insecticide	100	+ Salt (.5%)	0.6 c	0.0 b	0.2 b
Transform™ insecticide	200	+ Salt (.5%)	0.3 c	0.1 b	0.4 b
Transform™ insecticide	300	+ Salt (.5%)	0.2 c	0.0 b	0.1 b
Untreated			6.0 a	2.9 a	2.5 a
CV			35.26	61.76	67.26

Means followed by same letter do not significantly differ (P=.05, Tukey's HSD). NSD= no significant difference

All data transform Log (x+1)

CV= coefficient of variation

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TABLE 4. Number of adult and nymphal green mirids (per m)

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RENIFORM NEMATODE SURVEYS IN CENTRAL QUEENSLAND COTTON

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Summary

The reniform nematode is a major constraint to cotton production in the USA. Recent detections in Central Queensland have led to an extensive soil survey of the Theodore district. Reniform nematodes were found to be widespread, inhabiting 72-75% of fields in the northern districts, 49% of sampled fields to the south of Theodore as well as a limited area in Emerald. Although summer/winter fluctuations have been observed, there is some early indication of net population increases between cotton seasons. Further data collection is required to establish economic thresholds to enable prediction of potential yield decrease associated with a population density.

Introduction

The reniform nematode, *Rotylenchulus reniformis* Linford and Oliveira, 1940, was associated with 193 900 bales of yield loss in the 2013 USA cotton crop. In certain states, the proportion of disease-related loss associated with reniform nematode was as high as 45% (National Cotton Council of America 2013). In Australia, this species has been documented in horticultural crops in and north of Bundaberg (J. Cobon, pers. comm., February 5, 2013).

On November 11, 2003, the first detection of this plant parasite in Australian cotton was recorded in a single field in Emerald. No further detections were made until an investigation of stunted plants led to the identification of reniform nematode in Theodore on November 23, 2012. A comprehensive soil survey of Theodore cotton fields was commissioned to map distribution of the pathogen with ongoing data collection to gain an understanding of population dynamics.

This research included a return to Emerald to investigate the current incidence and density of populations at the original site of detection and in surrounding fields. Although the potential for cotton crops outside of Central Queensland to support populations of this tropical/subtropical species is currently unknown, some routine sampling in other Queensland cotton-growing districts will be conducted during cotton disease surveys.

Methodology

A soil survey of all fields used for cotton production in the Theodore district

commenced directly after picking of the 2012-2013 crop. As soon as practical following root-cutting and mulching, 100 soil cores were collected per 10 ha of field, using corers with an internal diameter of 17 mm. Cores were extracted from cotton rows to a depth of 15 cm, following a uniform pattern to cover representative areas in each field. For each 10 ha field section, cores were mixed thoroughly and approximately 400 g of soil was sub-sampled into plastic bags for transport at moderate temperature to a nematology laboratory. Extraction of nematodes was achieved through incubation of 200 mL of soil from each sample over 3 days using the Whitehead tray technique (Whitehead and Hemming, 1965). The extract was then examined under a light microscope to identify and count individuals within each plant-parasitic nematode species.

At planting of the following cotton crop (2013-2014 season), a selection of fields across Theodore's central cotton-producing areas (Theodore East, Theodore West and Gibber Gunyah) was sampled again, following the same protocols used in the original postharvest survey (2013). These fields were chosen to obtain a range of reniform nematode population densities (including nil populations) as well as a representation of the local soil types and cultural practices. These fields were sampled for the third time at the end of the season (postharvest 2014).

The same methodology was employed in postharvest sampling in Emerald in 2013 and 2014 and in fields selected because of poor yields in St George, Dirranbandi and

the Darling Downs in the early stages of the 2013-2014 season.

Results and Discussion

Samples for the initial postharvest 2013 survey were collected in order to maximise the probability of detection in fields with relatively small populations, as nematode density will peak at the termination of a host crop (Stetina et al., 2007). Weather-related harvest delays prevented access to 25 fields on properties along the Dawson River (Theodore South). Data collected from accessible fields illustrates a widespread distribution of reniform nematode with 72%, 75%, 72% and 49% of sampled fields infested in Gibber Gonyah, Theodore West, Theodore East and Theodore South respectively.

Figure 1 depicts the number of samples (10 ha field sections) associated with nil detections and with two broad nematode density categories for the four production areas in Theodore. These density categories are used to arbitrarily convey some range of the nematode densities measured and are not associated with a particular level of crop damage. There is a general increase in incidence (decreasing proportion of nil detections) in order of Theodore South, Gibber Gonyah, Theodore West and Theodore East. Although incidence in Theodore South was comparatively low, it should be noted that relatively high densities were detected throughout all four production areas.

The subsequent surveys (pre-plant and postharvest of the 2013-2014 season) were associated with a focus on population dynamics. Figure 2 illustrates the decline and growth of reniform populations observed in Theodore West and Theodore East over the 12 month period of the three surveys. Gibber Gonyah population data (one farm only) is not displayed due to unsatisfactory sampling. The population decline that is seen through winter (from postharvest to pre-plant in 2013) and the sharp rate of increase shown through the following cotton season (2013-2014) is consistent with population flux described

Figure 1. Proportion of soil samples that represent, for each of the four main production areas, a nil presence or populations of less/more than 500 nematodes per 200 mL of Relative Reniform Nematode Incisoil.

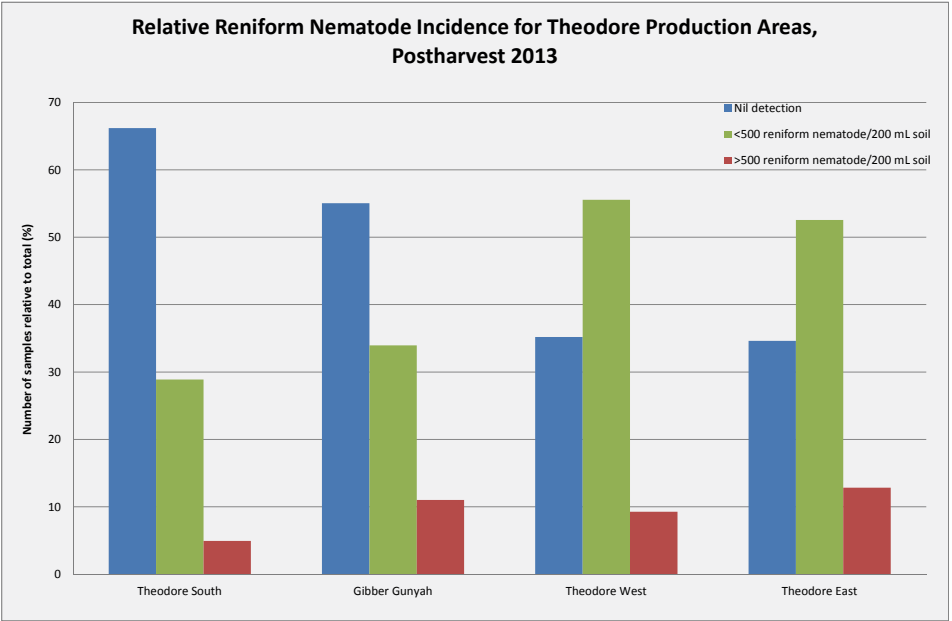
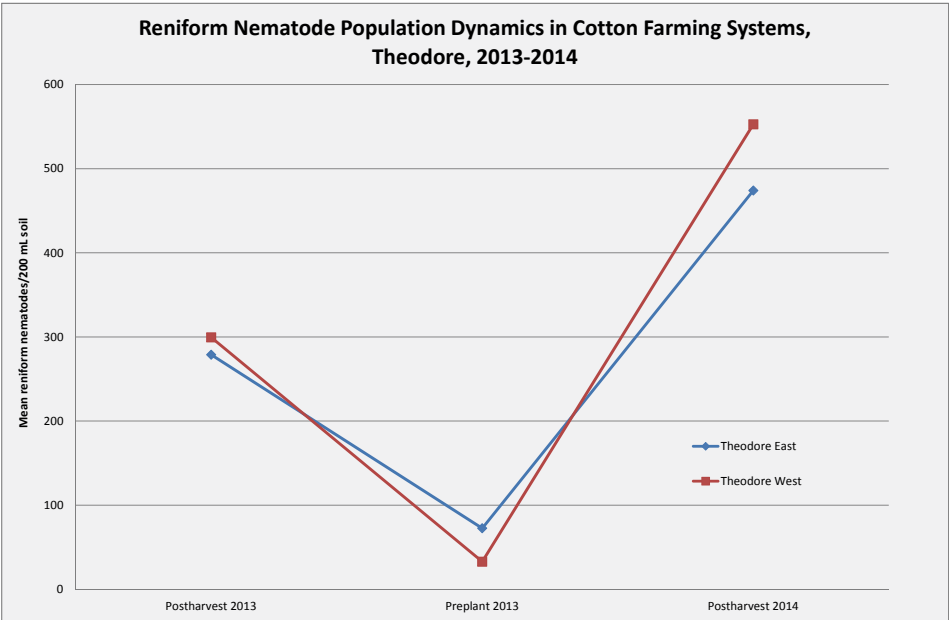


Figure 2. Reniform nematode population decline through the 2013 winter and subsequent increase in the following cotton season.



in the absence and presence of a host crop in USA studies (Davis et al., 2003).

During the winter of 2013, some of the surveyed fields were maintained as bare fallow while others were planted to wheat or chickpea. Although chickpea is generally described as a host and wheat as a non-host crop (Mahapatra and Padhi, 1986; Birchfield, 1983), the difference in population decline between fallow (73.11%), chickpea (74.05%) and wheat (77.04%) was not statistically significant. The lack of reproduction observed on chickpea poses the question: do winter soil temperatures in Theodore restrict the nematode from infesting a host crop? This will be investigated in future research.

A comparison of postharvest sampling results between years is relevant in understanding the long-term trend in population dynamics. Although significant, annual fluctuations are evident in Figure 2; the increase between postharvest values for 2013 and 2014 (approximately 77%) indicates a potential trend of increase in a larger time-frame.

Reniform nematode populations have been confirmed in a relatively small number of fields in Emerald. Further survey work is required in this district to define the extent of distribution. At the time of submitting this paper, none of the diagnostic samples provided from fields outside of Central Queensland have tested positive for reniform nematode.

Conclusion

Future research will focus on management strategies. Collection of population data and correlation with yield data will enable the generation of population thresholds as a tool for effective, economic management. The tolerance/resistance of cotton and rotation crop cultivars will be examined and the industry value of crop rotation and various other treatments will also be assessed.

While further recommendations are pending, best practice management should primarily minimise nematode movement in transported soil and

exposure to host plants. This can be achieved by following the measures outlined in industry's "Come Clean, Go Clean" campaign and farm hygiene recommendations, including timely and effective postharvest root-cutting and control of volunteer cotton plants.

Acknowledgement

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SKILLS BENCHMARKING IN THE AUSTRALIAN COTTON INDUSTRY

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Introduction

The cotton industry has invested heavily over many years in the development of a wide range of technology and services to enhance the farming, management, marketing and support systems driving industry productivity and sustainability. The research and development investment has been complemented by a broad based extension and training program delivered across both the private and public sectors which has resulted in strong adoption of new ideas, systems and technology.

The cotton industry has in place mechanisms to monitor and analyse the effectiveness of research investment in improved farming systems, environmental management and other innovations. Monitoring of outcomes across all programs has allowed a good picture of return on investment to be developed and maintained. By contrast, the cotton industry has been investing heavily in the development of human capacity but has never directly or formally monitored and analysed changes in the skills and knowledge of the population.

The Human Capacity Assessment and Benchmarking project is a system to gather data and provide an analysis tool to monitor the effectiveness of cotton industry extension and training activities. This will provide the industry with an effective tool to collect benchmarking data on changes in Human Capacity over time, thus better informing decisions about investment in extension and training.

Problems addressed

In order to grow capacity for any industry there needs to be a rigorous and transparent benchmarking approach to assess existing capacity. The Human Capacity Assessment and Benchmarking process allows industry to clearly articulate and demonstrate existing skills, competence and capacity as land stewards and, more importantly, strategically invest in capacity building by identifying any areas of skill deficiency. Auditing and benchmarking capacity across all levels of industry will allow targeting of training programs to address identified gaps and leverage of existing skills resulting in an increased return on training investment.

Tocal College in partnership with CRDC and industry leaders has developed and delivered an online Human Capacity Assessment and Benchmarking system which is hosted on the web at www.agskills.com.au. This system is based on the Units of Competence from the nationally endorsed Agriculture Horticulture and Conservation and Land Management (AHC) Training Package (See <http://training.gov.au/Training/Details/AHC10>). This web address and the online system are owned by Cotton Research and Development Corporation.

The Cotton Industry Skills Benchmarking is a web based system that allows participants to carry out a self-assessment (Boud. D, 1995) in a wide range of relevant skills which are categorised into 21 Skill Areas. These skills are all based in Units of Competence from the AHC (Agrifood

SKILLS BENCHMARKING IN THE AUSTRALIAN COTTON INDUSTRY

Skills Australia, 2011) as a tool to carry out an audit of skills and knowledge and give a broad picture of human capacity in the industry and therefore align to what is considered to be current industry best practice.

The Cotton Industry Skills Benchmarking system is structured to not only provide industry wide information on skills, but to also be used as a tool that farm managers can use to develop a profile of the skills of their own staff. This will be useful for making decision about investment in training and could also be used as a recruitment tool.

Each enterprise owner or manager participating in the Benchmarking system simply needs to register their business and all of their staff members to commence the process. Once workers have completed the assessment process the manager can view a report for all of their staff presented in a graph format. A farm manager will only have access to data about staff working on that farm.

What does the Benchmarking tell us?

Table 1 is an example of information which can be extracted from the system demonstrates its usefulness to industry. Data can be extracted to focus on many issues including ranking the Training Preferences in the 21 Skill Areas within the Cotton Industry Skills Benchmarking system. Examples of Training preference generated by Cotton Industry Skills Benchmarking are shown in Table 1 to the right.

In order to confirm the accuracy of the benchmarking data, it was compared to the results of Skills Needs Analysis workshops which were convened across various areas including Narrabri, Goondiwindi, Griffith, Hillston and Darlington point. The findings can be seen in Table 2.

This comparison demonstrates that the results produced by the online system align to a reasonable degree with data collected from focus groups with industry.

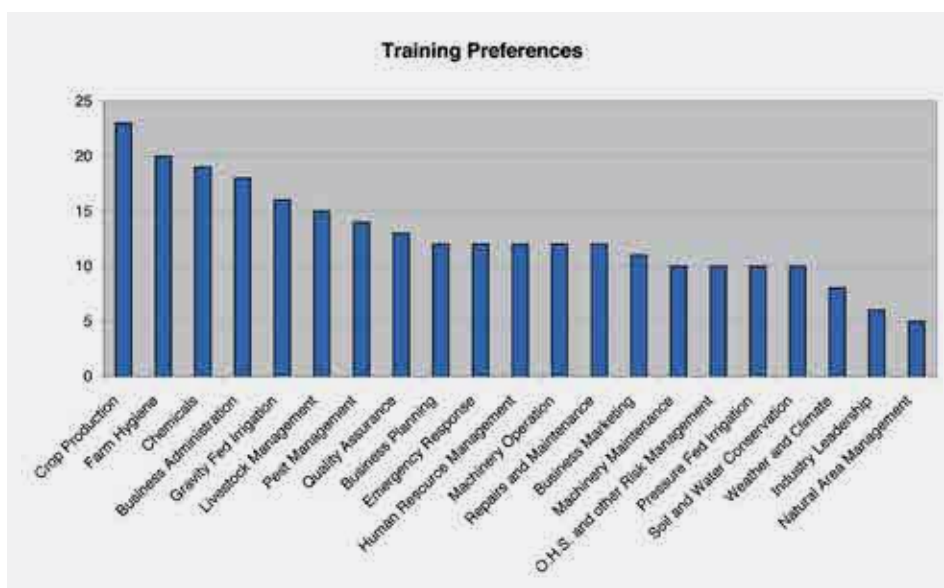


TABLE 1: Training Preferences data generated by the online Cotton Industry Skills Benchmarking. This ranking will be helpful in ordering priorities for investment in training programs.

	Ranking Cotton Industry Skills Benchmarking system	Ranking Skills Needs Analysis Workshops	Correlation
1.	Crop Production	3	Good
2.	Farm Hygiene	9	Poor
3.	Chemicals	8	Poor
4.	Business Administration	-	
5.	Gravity Fed Irrigation	4	Very Good
6.	Livestock Management	-	
7.	Pest Management	8	Very Good
8.	Quality Assurance	-	
9.	Business Planning	-	
10.	Emergency Response	-	
11.	Human Resource Management	5	Poor
12.	Machinery Operation	2	Very Poor
13.	Repairs and Maintenance	2	Very Poor
14.	Business Marketing	-	
15.	Machinery Maintenance	2	Very Poor
16.	O.H.S. and other Risk Management	1, 6	Very Poor
17.	Pressure Fed Irrigation	-	
18.	Soil and Water Conservation	-	
19.	Weather and Climate	-	
20.	Industry Leadership	-	
21.	Natural Area Management	-	

TABLE 2 Ranking Cotton Industry Skills Benchmarking system

Outcomes

Cotton Industry Skills Benchmarking has delivered a fully tested and functional online tool for the cotton industry to assess and monitor the skills base in the industry on an ongoing basis. Over time this system will allow the industry to monitor the development of skill and address any areas of skill shortage by targeted investment in training and other mechanism for skills development.

Validation of Cotton Industry Skills Benchmarking has been successful and has demonstrated that confidence can be placed on the Training Preferences across industry produced by the system.

Conclusion

Skills Benchmarking and Needs Analysis in the Australian Cotton Industry has been developed tested and validated by industry. It is freely available to the cotton industry as a tool to assist with the assessment of skill and to monitor changes over time. Uptake of the system by industry has been poor to date and this has limited the value of data collected.

Skills Benchmarking and Needs Analysis has the potential to be a valuable tool for the cotton industry if usage rates are increased. These key values are:

- As a tool for farmers and managers to carry out an audit of the skills base of their business
- As a tool for recruitment of new staff
- As a tool to assist the business to develop training and personal development programs for staff
- As a tool for industry to monitor skills acquisition and identify skill gaps
- As a tool for industry to monitor skills and direct investment in development and delivery of training programs.

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NUTRIENT INPUTS OTHER THAN NITROGEN IN COTTON SYSTEMS – SOME OBSERVATIONS AND PERSPECTIVES

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Introduction

The clay soils used for irrigated and dryland crop production (grains and cotton) originally had relatively good background fertility, but that has declined with time under cropping due to nutrient removal in harvested produce. The most obvious changes have been in soil nitrogen (N) status, with the rise in fertiliser N application rates indicative of both increasing crop yields but also declining soil organic matter. The latter reduces the ability of the soil to mineralise (release) N during a fallow, hence the greater reliance on fertilisers. However, not only N is removed in harvested produce. We are seeing reserves of phosphorus (P), potassium (K) and sulphur (S) decline due to removal rates exceeding replacement in fertilisers or soil amendments. Even in the situations where inputs exceed removal rates, the lack of mobility of some of these nutrients in soil (especially P and K) and the limited amount of deep tillage or soil inversion mean that while the topsoil (0-10 cm) looks ok or has even improved, subsoils (10-30 cm and deeper) continue to decline. We are increasingly seeing responses to deep placed nutrients (especially P but increasingly K as well) in many crop areas in grain cropping systems. Given that cotton is often grown on the same soils on the same or nearby farms, how does cotton respond to these different fertiliser placement strategies? In considering these issues, we need to note the generally higher fertiliser inputs (of P and K fertilisers in particular, and perhaps of S through use of soil ameliorants like gypsum) in cotton systems, particularly

under irrigation, and also the fact that irrigation should give root systems better access to the surface soil layers where these less mobile nutrients tend to concentrate (the top 10cm in dryland systems, and the hills or the top 15-20cm in irrigated systems).

How much fertiliser is used in cotton systems? The recent industry survey shows that fertiliser costs represent a significant proportion of the variable costs of growing a cotton crop. Approx 75% of irrigated growers invested \$300-\$600/ha on nutrient inputs while >60% of dryland growers invested \$150-\$350/ha. While the majority of this investment was typically in N, P was applied on 62% (dryland) - 76% (irrigated) and K was applied on 23% (dryland) - 43% (irrigated) of all properties. The cost of average P and K rates combined were \$65/ha (dryland) - \$150/ha (irrigated), or about 25% of overall fertiliser costs. While there is still uncertainty about the decision rules surrounding the need to apply these fertilisers (ie. will I get a crop response?), there is no doubt about the need to replace nutrients removed in the cotton harvest - typically 2 kg K, 1.3-1.4 kg P and 0.6-0.8 kg S/bale. The questions are (i) are we applying the right amounts of P, S and K; and (ii) are we applying them in the right place and in the right form to ensure crop access?

Some preliminary answers to those questions are presented in the Lester et al. (2014) paper at this conference, which suggest that in many cases the nutrient we apply (and in this case the research is focussed primarily on P and K) makes a small contribution to early

growth and nutrient uptake, but once the crop enters peak dry matter and nutrient accumulation after flowering, the P and K fertiliser applied has little net effect on crop growth or nutrient uptake. To think our way through why this may be happening, we need to go back to basics, considering how these nutrients behave in soil, how crops acquire these nutrients and how the cotton root system and our crop management practices (fertiliser application methods, irrigation method and timing etc.) may influence that acquisition.

Behaviour of Phosphorus (P), Potassium (K) and Sulfur (S) in clay soils

Perhaps the most important distinction between nutrients in soil is how much they interact with the soil particles around them and the water that flows into and through the soil into deeper profile layers. Both N and S in their mineral forms (those taken up by plants) are mainly negatively charged (nitrate and sulphate anions) and so do not interact strongly with soils (unless those soils have a high content of iron oxides with ‘variable charge’ characteristics). This means that when these nutrients are dissolved in water in the soil, they tend to move with the soil water. This is why we see the phenomenon of leaching of nutrients like nitrate-N ($\text{NO}_3\text{--N}$) into deeper profile layers (and sometimes so deep as to be beyond reach of the root system). It is also probably why we saw a spike in the incidence of crops with S deficiency symptoms after a few recent wet seasons - soils that had marginal S status were tipped over the edge into being S-limited due to leaching of sulphate anions.

This behaviour is almost the exact opposite of both P and K, which react much more readily with the soil particles and are much less mobile in soil water – so much so, in fact, that in our clay soils they are effectively immobile, and stay where they are put (as fertiliser, crop residues, manure etc.). These sorption processes that occur are different for P and K, and can vary in importance between soil types.

Potassium is typically held on exchange surfaces (negatively charged) of clays or organic matter by electrostatic attraction, although there can also be some K that gets effectively ‘trapped’ in positions in the clay structure that open and close (allowing release and entrapment) during the swell-shrink processes that occur during wetting and drying of the cracking clay soils (Vertosols) that support a large proportion of cotton and grain industries. The K held electrostatically is called exchangeable K (you see this reported in a soil test), and this K tends to be easily released into the soil solution as concentrations there fall (i.e., in response to plants taking up K). This behaviour is fairly consistent across soil types, although the size of the exchange complex, and hence the amount of positively charged ions like K that it can hold, varies with clay content and clay type.

Phosphorus, on the other hand, can behave in very different ways depending on the soil type – particularly in response to things like the amount of iron and aluminium oxides, the amount of calcium and the soil pH. In acidic soils and those with lots of iron and aluminium oxides (like red volcanic soils), P tends to be held very tightly to these materials and so is less available to plants. People often refer to P that is held tightly in this way as ‘tied up’, as it is not readily available to plants – even when the plants reduce the soil solution P concentration during P uptake. Soils that behave like this have a high phosphorus buffer index ($\text{PBI} > 250\text{--}300$), and P fertiliser has to be managed carefully (e.g., applied in bands) to minimise contact with the soil to ensure enough remains available for crop uptake.

However in alkaline clays like most of those upon which cotton is grown, PBI is low (< 150) and P is not held tightly to soil particles. That means we have much more flexibility in how we apply our P, as we are not concerned with preventing ‘tie up’ like we are in high PBI situations, and this makes it easier to enrich more of the soil volume with P to give roots a chance to intercept it. However, in these soils there also tends to be a lot of available calcium

(Ca) and much of the P dissolved in the soil solution may precipitate out as Ca phosphate minerals. These Ca phosphates can be soluble to varying extents, but as a general rule, the longer they have been in that form in the soil the less soluble they tend to be. Some of our alkaline clays can have lots of P in this form in them as naturally occurring minerals while others have little (depending on the parent material). P fertiliser residues also tend to accumulate in this form in topsoils, and the availability of these residues will tend to decrease with time. The BSES soil test (using dilute acid as the extractant) is a measure of these ‘mineral’ forms of P, while the Colwell P test (an alkaline extractant) tends to measure mainly the easily available P held on the clay and organic matter surfaces.

Key factors influencing P, K and S acquisition by crops

These differences in nutrient behaviour are very important in determining how crop roots access those nutrients in soil. In the case of N and S, where the nitrate and sulphate forms taken up by the plant are in the soil water rather than held to soil particles, most crop uptake occurs by a process called mass flow. That is, as the crop takes up water from the soil, the dissolved nutrient in that water comes along for the ride. Provided there is enough nutrient in the soil layers where that water is being taken up from, the crop can meet the demand for N and S simply by acquiring water.

This is not the case for P and K, however, as the concentrations of both nutrients in the soil water tend to be much lower – because of the interactions with the soil particles described earlier. Some P and K get into the plant by mass flow, but the bulk has to move through the soil water column towards the root by a process called diffusion. That is simply the process of dissolved particles moving from an area of high concentration towards an area of low concentration. Visually, this is like how a drop of dye slowly disperses (diffuses) through a bowl of water until it is reasonably well distributed throughout.

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Concentration gradients in the soil water are generated by active nutrient uptake by the plant roots, creating an area of low concentration around the root and higher concentrations away from the roots in unexploited soil. The bigger the difference in concentrations, the faster the process of diffusion tends to occur.

There are therefore a number of soil-related factors that could affect the rate and extent of the diffusion process, and hence the ability to meet crop P and K demand. These include –

- *The concentration gradient.* In soils that have low nutrient contents, strong gradients do not develop around roots. We can influence this by fertilising to create zones of enriched nutrient content, and hence high solution concentrations. Banding (a highly concentrated source of soluble nutrient) is an extreme example which creates a strong gradient to the nutrient-depleted soil away from it.
- *The distance over which diffusion occurs (the path length).* The further a zone of high solution nutrient concentration is from a zone of low concentration (i.e., where roots are active), the slower the diffusion process will be, and hence the less able to meet demand.
- *The barriers in the way of diffusion (tortuosity).* The less direct the path from a high to low zone of concentration, the slower and less effective the diffusion process becomes. In sands and well-structured soils, diffusion works very efficiently, but in clay soils (especially sodic clays with low porosity and poor structure), diffusion is quite inefficient.

So what does this mean for crop nutrient acquisition and subsequently fertiliser application strategies? In the case of N and S, there seems to be a range of options, given the relative mobility of the nutrient in soil water. No matter how the nutrient is applied, there is likely to be redistribution of that nutrient with time as water moves through the profile. This process is much slower in heavy clays than it is in sands, but it does happen. One possible complication may be the recent evidence

that shows crop acquisition of S from banded S sources (in this case gypsum) may be slower than expected due to both reduced P availability around the band (due to the high Ca precipitating P out of the soil solution) and also to slower than expected movement of the S out of the band and into the surrounding soil. This was only a problem in heavy clays.

In the case of P and K, particularly in heavy clays, overcoming low soil nutrient status becomes a balancing act between (i) creating zones of high nutrient concentration to deliver strong gradients for diffusive supply to occur efficiently; (ii) enriching enough volume to ensure that enough of the root system can exploit these enriched zones. A single narrow band can create a strong gradient, but if only a very small proportion of the crop root system can get around it, the impact on crop nutrient uptake is small; (iii) ensuring those enriched zones are accessible to roots and moist enough for root activity to acquire nutrients when the crop needs it; and (iv) ensuring that the form of nutrient applied does not create a mini-environment around the fertiliser band that inhibits root growth (e.g., chloride concentration from banded muriate of potash; potential short term induced calcium deficiency from banded DAP).

Clearly the crop root system and soil moisture dynamics have a major role to play in these processes.

The cotton root system

The cotton root system is characterised by a large tap root capable of going very deep into the soil profile, but with a relatively limited number of laterals within the various layers – adaptations of a plant successful in arid climates where there is a strong reliance on tapping into subsoil water for survival. Cotton has a reputation for not being very efficient at exploiting nutrients in topsoil and begins to senesce older roots (presumably those first formed and in the upper soil layers) after flowering. Given these characteristics, it is perhaps not surprising that cotton

is strongly dependent on arbuscular mycorrhizae (VAM) for nutrient uptake, especially nutrients like P. The VAM hyphae compensate for the lack of fine crop roots to allow the development of an efficient P supply framework – lots of zones of P-depleted soil with strong concentration gradients allowing diffusion from untapped soil around them.

The characteristics that have the greatest implications for fertiliser application strategies are –

- The lack of fine roots and the apparent inability to exploit a nutrient rich zone (ie. the fertilised hill), compared to grain crops
- The generally inhibitory effect of supplying concentrated sources of nutrients (e.g., P) on VAM colonization of root systems
- The apparent sloughing off of older roots that starts at about the same time that the crop commences rapid dry matter accumulation, and hence has highest nutrient demand.

While these characteristics may not be significant for nutrients that can redistribute through the profile in soil water (like N and to possibly a lesser extent S) and which are taken up by the plant via the water stream, they would appear to be critical for immobile nutrients that are confined to the soil layers in which they are applied and that rely on diffusive supply to the plant root system.

Nutrient acquisition and fertiliser P and K (non) recovery in field trials

Soils with relatively high inherent fertility, including a source of P and K (even if sparingly soluble) throughout the root zone, have allowed cotton production to thrive on the Vertosols in northeast Australia. The large soil volumes in which moisture has accumulated (either naturally or with irrigation) allow a large volume for roots to explore, and the relatively low P and K concentrations in the soil solution allow VAM to efficiently exploit these native fertility reserves to grow high yielding crops. In normal

conditions a ‘trickle supply’ of P and K from a large root volume allows the crop to accumulate enough nutrients to achieve high yields, and the only time problems emerge is when either (a) that large rooting volume is suddenly drastically reduced (e.g., during a water-logging event), or (b) we raise yield potential and hence nutrient demand so high (e.g., for K during boll filling) that even the trickle from the large volume can’t keep up.

However, as that deeper native fertility is depleted, as it must be with unreplenished removal from the field, the crop is increasingly forced into relying on imported nutrients to meet demand, and we have limited options for application and placement. This should not present challenges for mobile nutrients like N and S (other than issues of loss mechanisms by leaching or gaseous emissions), as water infiltration will take these nutrients deep into the soil profile. However for the immobile nutrients like P and K we are limited to the depth of cultivation. The impact of this is evident in the Lester et al. paper elsewhere in these proceedings. Briefly -

- When roots are largely in the bed and nearby the starter fertiliser application in the early parts of the season (before peak growth and nutrient acquisition), the crop can get some recovery of P and K applied in the hill
- Later in the season, presumably when the bulk of the root system is deeper in the profile, nutrients in the hill make little further contribution to crop uptake.

The unknowns around these observations are many, but include things like (i) does this non-exploitation of P and K in the bed occur because the crop can still find adequate reserves deeper down? If so, will that change as those reserves are depleted? (ii) Is the crop simply not able to use those enriched topsoil layers later in the season, as the root system in those layers has ceased to be functional? If so, can we change management or genotype to influence this?

Where to from here?

The cotton industry urgently needs to find answers to both (i) and (ii) above, while also trying to better define the soil nutrient levels below which fertiliser application will deliver a yield response. The latter is a key part of the decision process about the make up of a fertiliser program, but finding answers to that is proving a major challenge when one is unsure if the lack of fertiliser response at a trial site is because the soil was able to supply enough nutrient to meet crop demand, or the fertiliser was unable to be used effectively by the plant and yields were still P or K limited in the fertilised treatments.

Regardless, it is clear that at present much of the significant investment in P and K fertilisers in the cotton cropping system is being utilised poorly at best, and there is significant room for improvement. A better understanding of the growth and nutrient acquisition processes by cotton grown in clay soils (under dryland or irrigated conditions), would appear to be a major precursor to delivering improved management systems.



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UNDERSTANDING THE JD7760 ROUND MODULE PICKER IMPACTS

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Summary

This paper communicates further the findings, pertaining to the John Deere 7760 (JD7760) round module picker, of the Cotton Growing Practices 2013 industry survey and current research at the National Centre for Engineering in Agriculture. The grower data is used to highlight decision making processes used and provides insight into potentially latent impacts on system components, particularly the land resource. Adoption drivers and considerations are discussed against machine potential, the Australian picker market and the potential for soil compaction is demonstrated to contrast considerations.

Introduction

The inception of the John Deere 7760 on board module picker (JD7760) has seen what is generally agreed as the fastest uptake of cotton system technology in Australian cotton industry history. In the season picked in 2013, 82% of cotton was picked (entire industry average) using the JD7760, while John Deere reports that the current supply of this picker to the Australian market is capable of picking 125% of the industry cotton produced (Pers. Comm. Broughton Boydell). This paper reports on the harvesting section of the Cotton Growing Practices 2013 survey (Bennett 2013) and uses this information to highlight impacts of the JD7760 on the Australian cotton industry, with a particular focus on the land resource and future decision making processes.

Method

The primary data for this paper was obtained from a grower survey conducted by Roth Rural (2013) on behalf of the Cotton Research and Development Corporation (CRDC). The survey was mail-based and included the survey, a quick response sheet for those not wanting to complete the survey and a stamped self-address envelope. There was opt-in ability through cotton research and development officers. The total number of surveys sent out was 1000 and the effective sample size was reduced to 837 by removing a portion of respondents who indicated they didn't grow cotton, had not grown cotton that year, return to sender mail-backs,

and duplicate addresses. From the valid responses (165), this represented a 20% return rate and approximately 23% and 27% of the irrigated and dryland cotton area grown in 2013. Non-response was not assessed for bias.

Through grower consultation at regional discussion groups and through face-to-face discussions with field trial participants in early 2013 a cotton system impacts framework was constructed to display the identified impacts of the JD7760. A total of 12 growers attended the discussion groups held in Dalby, Goondiwindi, Narrabri and Warren with a further 8 extension and industry staff attending. Face-to-face discussions were held with a further 8 growers. These and the survey data were used to draw out potential latent impacts.

Soil propagation stress diagrams were drawn using Matlab from SoilFlex (Keller *et al.* 2007) output. Input variables used in SoilFlex were provided by John Deere scale drawings and specifications, while tyre inflation pressures and characteristics were used as those recommended by John Deere. Soil pre-consolidation stress was taken from the average of 18 Vertosols in the Australian cotton industry for a range of moisture contents (air-dry to saturation) provided by Kirby (1991). This data was used on the basis it provided an estimate of a likely soil moisture and pre-consolidation stress likely to be encountered by the industry on average for at least one soil depth under the influence of JD7760 propagation stress.

Results and discussion

Motivations to switch to the JD7760 were primarily driven by decrease in labour requirement for picking (76% selecting defining (D) or major (M) motivation), ability to pick cotton crops more quickly (75% selecting D and M motivation), and decreased WH&S risk (64% selecting D and M motivation). Whilst there was an industry response suggesting that the JD7760 system cost as much to run as previous basket system (Fig 1), 52% of growers had adopted the JD7760 with the view they would be saving money. The decision to adopt was indicated as being an on-farm, or individual, decision with growers indicating 16% and 6% M and D motivation due to discussions with neighbours or a dealer, respectively. Hence, it is highlighted that a sound economic understanding of the technology integration into the current system should be undertaken. To address this, we developed the impact framework in Fig 1 to demonstrate the findings from interaction with the Australian cotton industry and available literature.

Supply chain impacts such as gin pressure and picker transport (not identified due to being largely dealt with) have been acted upon by the industry quickly, which is a testament to the Australian industry ability to deal with rapid change. However, some of the more latent impacts have been identified as a possible over supply of the JD7760 to the Australian market and soil compaction ramifications such as energy consumption during field preparation for subsequent crops.

Adding emphasis to the John Deere estimation that 125% of Australian cotton could be picked with the current supply of JD7760 machines, it was observed that the average area being picked by these machines (excluding contract picking) was 650 ha, although some growers indicated picking almost twice that. This suggests that these machines are being underutilised, which is something that 61% of growers owning/leasing their machine sought to offset by contract picking. However, whilst more growers

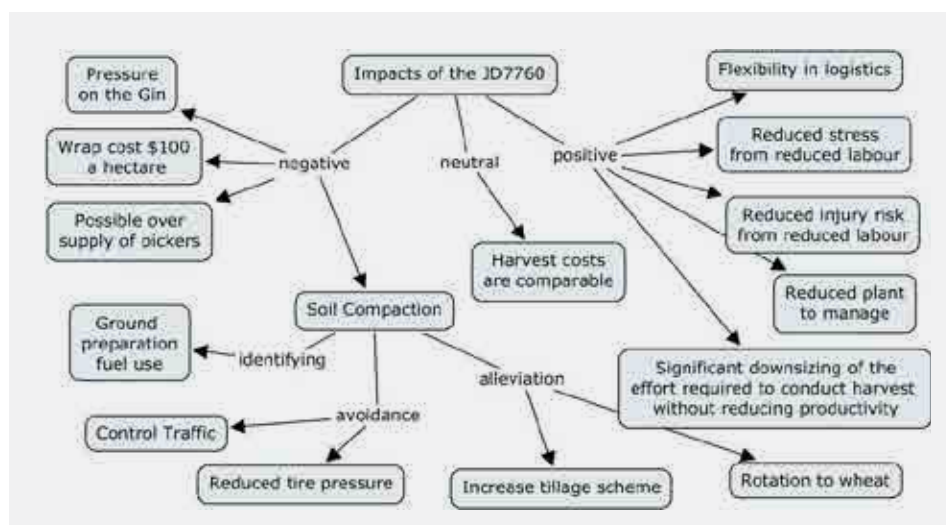


FIGURE 1. Framework of impacts of incorporating the JD7760 into the Australian cotton system drawn from Australian perspective and literature. Components of “identifying”, “avoidance” and “alleviation” were inferred from literature and face-to-face follow up discussion, not the survey data.

indicated using a contractor with a JD7760 than using an owned/leased JD7760, contractors picked less cotton area. This certainly seems to suggest that the contract picking market is becoming saturated and that contract picking may not be a viable way to pay off the JD7760 investment into the future.

When asked about operational factors that were considered immediately prior to the point of purchase it was found that the major considerations were the ability to get the machine serviced, cost of module wrap, availability of parts, as well as machine and module transport. Consideration of soil compaction or the machine weight was low in comparison and the ability for the machine to integrate into a controlled traffic system even less so (15% of growers believing this was a M or D consideration). Whilst growers did indicate that getting cotton out of the field is priority, they also suggested that traversing soil at undesirable soil moisture content would be avoided where possible.

Given the weight of the machine and the specified standing wheel loads at their maximum under machine standard conditions (Front 5432 kg; Rear 8441 kg) it becomes apparent that soil compaction is inevitable if soil moisture conditions are not soundly adhered to. To demonstrate this here we have produced Fig 2 whereby a single pre-consolidation stress (P_c)

is used based on average data ($P_c=99$ kPa) of Kirby (1991) and SoilFlex wheel propagation stress (Keller *et al.* 2002). At stresses above the P_c soil compaction is permanent, while at imposed stress less than the P_c the effects of stress are more tolerable and will rebound to a certain extent. Tillage can help to shatter compacted layers, but the soil structure is effectively permanently altered at stress above the P_c .

For the single wheeled basket system it can be seen that compaction effects are limited, with every row afforded an equal amount of white space, which can be thought of as undeterred access to water and nutrients, all other things equal. On the other hand, two out of every set of six rows are impeded by the dual wheel system and white space is reduced. Whilst the blue zones (propagation stress $< P_c$) rebound and don't undergo permanent compaction, they do undertake some modification of soil structure that may compound throughout subsequent seasons.

The point of this demonstration is not to suggest that a reversion to the basket system should be made, but to highlight the importance of considering the effects on the soil resource when adopting large machinery. Anecdotal discussions with growers suggest that they have incurred a greater cost in terms of energy use

UNDERSTANDING THE JD7760 ROUND MODULE PICKER IMPACTS

when tilling post JD7760 use. Hence, it will be important to continue to understand management considerations and strategies to minimise the risks of soil compaction. Current investigations through the CRDC NEC1301 project include the use of a single wheel on the front of the JD7760, planning plant date for a drier pick, changing compaction depth via manipulating tyre and inflation characteristics, later defoliation to dry down profile, as well as the ability to use existing soil models to predict soil compaction in Australian Vertosols as a decision aide for growers.

Conclusion

With the rapid adoption of the JD7760 picking system has come a series of supply chain impacts, as well as some more latent impacts associated with the soil resource and ability to offset the investment cost. The initial perception of financial savings by changing systems motivated about 50% of the industry to adopt the JD7760 system, but industry feedback suggests this saving is not real. The bulk of operational considerations were machine related, which, while understandable, masked consideration of how the soil resource might be impacted. It was also apparent that the decision to purchase the JD7760 was primarily an on-farm decision. Hence, there will be value in continuing to synthesise the information currently available and to further investigate and quantify soil resource impacts to generate some guideline prompts for consideration prior to adoption of other significant machinery.

Acknowledgements

We wish to acknowledge the growers who have participated in the work through the survey, focus groups and field trials; also the funders, CRDC, for supporting the work.

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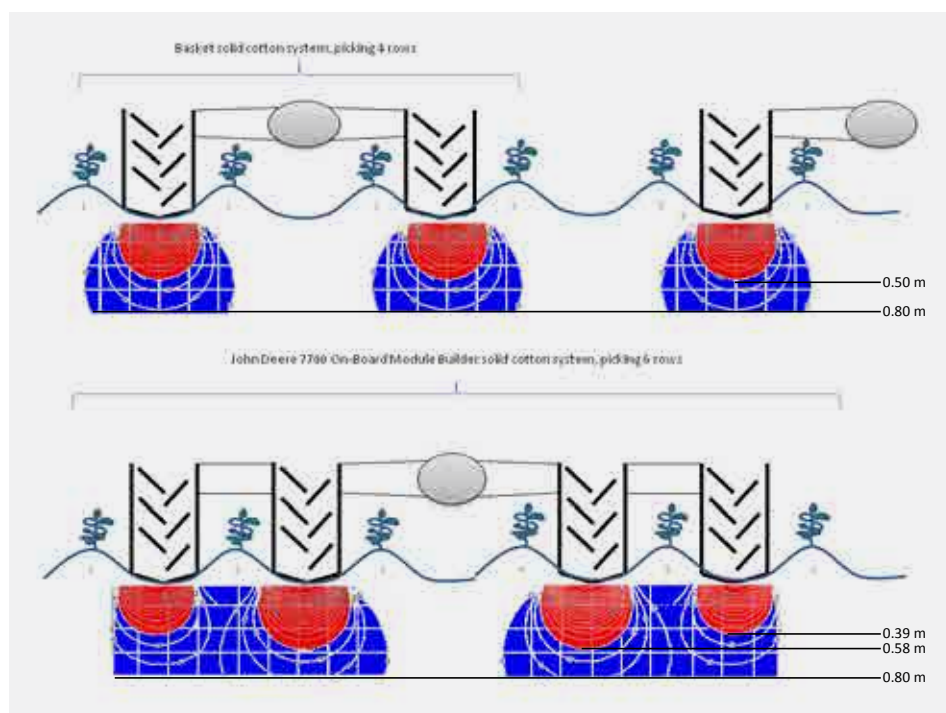


FIGURE 2. Diagrammatic representation of compaction potential under four row basket and six row JD7760 picking systems for a set of six rows. Red represents stress propagation greater than the pre-consolidation stress (irreversible), while blue represents stress propagation less than the pre-consolidation stress (somewhat reversible). Maximum depth shown is 0.8 m and propagation stress <25 kPa is not shown. Propagation stress diagrams are to relative scale, while the depiction of the rows, crop and machines are not. The pre-consolidation stress used is 99 kPa for a moisture content of 32% with uniform moisture content throughout the full soil profile assumed.

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REVISED METHODS FOR MONITORING RESISTANCE TO CONVENTIONAL INSECTICIDES

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17th **australian COTTON** conference
Our Fibre. Our Focus. Our Future

Summary

Standard techniques for monitoring conventional insecticide resistance in *Helicoverpa armigera* originally developed for broad-spectrum contact insecticides involved topical bioassays of insects in the F_0 generation. However, limitations are associated with these techniques for monitoring resistance to newer selective products. This paper describes revised protocols for monitoring resistance to emamectin benzoate, chloranthraniliprole and indoxacarb including using F_2 screens to identify non-dominant genes that may enhance survival. Additionally, the introduction of bioassay methods appropriate for products active by ingestion is also described. These protocols will increase capacity for isolating low frequency resistance which is difficult to detect using traditional monitoring techniques.

Introduction

Since the early 1980s a resistance monitoring program has been in place for detecting changes in resistance frequencies in *Helicoverpa armigera* (Forrester et al. 1993) and is part of a broader pre-emptive insecticide resistance management strategy (IRMS) used by the Australian Cotton Industry to formulate responses to emerging resistance issues. Methods for monitoring resistance originally developed for broad-spectrum contact insecticides involved topical testing of insects in the F_0 generation. However, these methods may be less effective for determining resistance to selective insecticides because:

- i) Selective insecticides are primarily active by ingestion.
- ii) F_0 screening may underestimate frequency of non-dominant alleles.

The objectives of this study were to increase capacity to detect resistance to selective products by:

1. developing a feeding bioassay to determine toxicity of emamectin benzoate, chloranthraniliprole, and indoxacarb to *H. armigera*, and evaluate this method as an alternative to topical bioassays,
2. accumulating baseline susceptibility data to determine the full range of intra-specific tolerance in field populations of *H. armigera* to these insecticides,
4. determining diagnostic doses for use in resistance monitoring, and

5. utilizing diagnostic doses in an F_2 screening method to detect enhanced survival to insecticides.

Materials and Methods

Insect Strains

The laboratory *H. armigera* strain was sourced during the mid-1980s from cotton fields in the Namoi Valley and tested at 4 to 6 week intervals to check for consistency of bioassay. Field strains were sourced from major cropping areas across NSW and QLD with populations established from insects collected from cotton, coarse grains and pulses between September 2012 and March 2013. All strains were tested within 3 generations of establishment in the laboratory. A minimum of 50 field collected individuals constituted any one geographically distinct strain.

Bioassays

The response of *H. armigera* populations was measured by performing bioassays on artificial diet into which formulated insecticide was incorporated. Formulated insecticides were diluted in distilled water producing two-fold serial insecticide dilutions spanning 6 or 7 insecticide concentrations expected to induce from 1 to 99% mortality. Serial dilutions were incorporated into diet and dispensed into bioassay trays. The ratio of diet to toxin determined the concentration calculated as μg of insecticide/ml of diet.

Insects used in bioassays were reared on untreated diet and introduced to insecticide-incorporated diet as late 2nd

or early 3rd instar larvae. Each bioassay was performed in triplicate with individual treatments (insecticide concentrations) in replicates consisting of a minimum of 20 individuals; untreated diet was used as the control. Bioassays were assessed for mortality at 7 days. Bioassays were performed on a minimum of four non-synchronous cohorts of the laboratory strain between November 2012 and May 2013. The results were pooled in the final analysis because there were no significant differences between cohorts.

The dose responses to insecticides were corrected for control mortality (Abbott 1925). Slope, LC_{50} and $LC_{99.9}$ estimates, and associated 95% fiducial limits (FLs) were calculated by probit analysis using the POLO-PC software (LeOra Software, Berkeley, CA). Toxicity ratio of insecticides was calculated by dividing the LC_{50} value of each field population by the LC_{50} value of the laboratory strain.

F₂ screening procedure

F₂ tests generate isofemale lines that in the second generation produce a proportion of individuals that are homozygous for each allele present in the two field-derived parents (Andow and Alstad 1998). This method involves (1) collection of eggs from host plants, (2) rearing F₀ eggs to moths, (3) mating single-pairs of moths, (4) rearing the F₁ larvae, (5) sib-mating the F₁ families, (6) collecting F₂ eggs, (7) screening late 2nd/early 3rd instar larvae with a pre-determined diagnostic concentration of insecticide. Assuming that resistance is non-dominant we would expect at least 6.25% (1 in 16) of larvae to survive on diet incorporated with insecticide.

Results and Discussion

1. Development of feeding bioassays

Management of *H. armigera* is becoming increasingly reliant on selective insecticides due to high compatibility with integrated pest management (IPM) programs. However, selective products intoxicate insects via both contact and ingestion, with the later considered the primary route whereby insects accumulate a lethal dose

Insecticide	Insect strain	n ^a	LC ₅₀	LC _{99.9}	Slope ± se	Toxicity Ratio ^b	Diagnostic Dose [µg /ml diet]
			[µg /ml diet] (95% FL)	[µg /ml diet]			
Emamectin Benzoate	Lab		7.4 (6.0-9.0)	30.0	5.1 ± 1.00		
	Field	20	10.2 (9.5-11.0)	79.0	3.5 ± 0.19	2.4	195
Chlorantraniliprole	Lab		14.3 (12.9-15.9)	106.4	3.5 ± 0.30		
	Field	21	25.0 (23.2-26.8)	453.9	2.5 ± 0.10	1.7	500
Indoxacarb	Lab		147.2 (136.6-158.5)	1272.2	3.4 ± 0.19		
	Field	22	291.3 (269.7-314.3)	6812.4	2.3 ± 0.10	2.0	12000

^a number of field strains tested
^b Toxicity ratio = LC_{50} of population/ LC_{50} of lab strain (average of four non-synchronous cohorts of lab strain)

TABLE 1. Bioassay of field and laboratory strains of *H. armigera* tested as late 2nd/early 3rd instars on diet incorporated insecticide and assessed for mortality at 7 days.

Insecticide	Number of isofemale lines tested	Total positives	Total alleles	Proportion R
Indoxacarb (Steward)	519	7	1038	0.007
Chlorantraniliprole (Altacor)	497	0	994	0.000
Emamectin Benzoate (Affirm)	472	0	944	0.000

TABLE 2. The number of strains in the F2 screen that scored positive for a resistance allele to emamectin benzoate, chlorantraniliprole or indoxacarb.

of insecticide (Wing et al. 2004, Lasota and Dybas 1991, Temple et al. 2009). Results from this study demonstrate that high slope values are associated with the dose-response regressions from feeding bioassays of emamectin benzoate, chlorantraniliprole and indoxacarb (Table 1). This suggests delivery by ingestion is highly effective for assessing toxicity of these products and would be an appropriate method for monitoring resistance in *H. armigera*.

2. Baseline susceptibility determined in feeding bioassays

The response of laboratory and field populations to insecticides is shown in Table 1. Toxicity of insecticides was highest for the laboratory strain. Field strains were also generally susceptible to insecticides demonstrated by low toxicity ratios of 1.4, 1.7 and 2.0 for emamectin benzoate, chlorantraniliprole and indoxacarb, respectively (Table 1).

3. Determination of a diagnostic dose of insecticides for resistance monitoring

This is an empirical compromise based firstly on the limits of tolerance, and secondly on a dose of insecticide that kills most (99.9%) of susceptible individuals. Critically, diagnostic doses should be high enough to effectively discriminate between resistant and susceptible phenotypes without detecting false positives, while not so high as to mask resistance. In this study, determination of diagnostic doses of insecticides is based on a theoretical estimate of the highest $LC_{99.9}$ value, taking into account empirical mortality observed at the upper limits of the dose response curve (Robertson et al. 2007). Based on these criteria diagnostic doses for insecticides are shown in Table 1.

4. Detection of enhanced survival using an F₂ screening procedure

Combined data from all regions (Table 2) shows that none of the isofemale lines examined for resistance to emamectin benzoate or chlorantraniliprole scored positive against the diagnostic dose of insecticide. In contrast, 7 of the 519 isofemale lines tested for indoxacarb resistance scored positive. Based on these data and assuming non-dominant resistance, the estimated *R* frequency for alleles conferring resistance to indoxacarb is 0.007.

Conclusions

- Low intra-specific tolerance, high slope values and goodness-of-fit to a probit binomial model suggest a feeding bioassay using diet incorporated insecticide is an effective laboratory method for measuring dose-responses of emamectin benzoate, chlorantraniliprole and indoxacarb in *H. armigera*.
- Discriminating concentrations of 195, 1000, and 12,000 µg of insecticide/ml of diet for emamectin benzoate, chlorantraniliprole and indoxacarb, respectively are recommended for monitoring resistance to these insecticides.
- An F₂ screening procedure may be an effective method for detecting non-dominant resistance to emamectin benzoate, chlorantraniliprole and indoxacarb in *H. armigera*.

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MANAGING FLEABANE IN THE COTTON SYSTEM

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17th **australian**
COTTON conference
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Summary

Fleabane has become increasingly problematic in the farming system due to its prolific seeding rate, ability to emerge in different seasons and tolerance to glyphosate. It is a major weed of rotations crops, fallows, channels, roads and even cotton.

Diuron has become the herbicide of choice for controlling fleabane in the cotton system, but it is only a matter of time before resistance to diuron develops.

A long term, whole farm integrated approach is needed to manage fleabane, effectively controlling it in all parts of the farming system with a range of tactics, not just relying on one herbicide.

Introduction

Flaxleaf fleabane (*Conyza bonariensis*) is an introduced weed from South America and has been a minor weed of cultivation and pastures for many years. However, more recently it has become increasingly problematic in the farming system due to:

- Its prolific seeding rate. A single plant can produce more than 100 000 seeds,
- Its seed dispersal mechanism, producing small, hairy-topped seeds that can spread kilometres in strong winds,
- Its ability to emerge in different seasons, with emergence most commonly from autumn through spring, but plants can emerge over summer,
- Its ability to germinate from the soil surface, making it ideally suited to zero-tillage situations, and

- Its tolerance to glyphosate. Most fleabane plants in cultivation appear to be around 10 times more tolerant of glyphosate than populations not previously exposed to glyphosate.

Interestingly, there are two other fleabane species commonly found around the cropping areas, Canadian fleabane (*C. canadensis*) and tall fleabane (*C. sumatrensis*). Neither of these species is an important weed in the farming system at present even though Canadian fleabane is a major weed that has developed herbicide resistance in North America (including glyphosate resistance).

Fleabane in the farming system

Fleabane seedlings most commonly emerge in autumn and spring, forming



FLEABANE is increasingly becoming an issue in cotton crops. Mature plants are difficult to control with cultivation or chipping – the secret is to control them while they are still young.

small rosette plants that develop deep tap roots. Plant rapidly enter the reproductive phase as temperatures increase in spring and summer, producing masses of seed as they progressively grow in size.

Fleabane plants often go largely unnoticed until they elongate during the reproductive phase. However, they are difficult to control with most herbicides once they enter the reproductive stage and their deep taproot makes them difficult to control with light cultivation. Fleabane plants should never be ignored in a cereal crop as they will be very difficult to control with herbicides post-harvest.

It is essential that fleabane plants are also managed in the other parts of the farming system, including fallows, roadsides, channels and waste areas as these are a ready source of seed to reinfest farmed areas.

Managing fleabane

The key focus for managing fleabane must be to control plants while they are still small. Herbicide options for managing fleabane are discussed in “*Managing fleabane in cotton*” in **WEEDpak** on the internet. Just type “**WEEDpak**” and “**Fleabane**” into Google (or another) and follow the links.

Tactics for controlling fleabane should include ensuring that:

- No fleabane seedlings are present when a crop is planted. This can be done by either a complete cultivation pass at planting or using knock-down herbicides prior to planting.
- A residual herbicide should also be included in the system if heavy infestations of fleabane are expected, provided a residual can be selected which will not cause plant-back issues for following crops.

Additionally, in fallows:

- Glyphosate alone will not be enough to control fleabane, even fleabane seedlings, so plan to use a double knock tactic of either two herbicides or a herbicide followed by a cultivation, and
- Don't hesitate to use cultivation as



FLEABANE is well adapted to minimum tillage and stubble retention situations. Small fleabane plants can produce masses of seed that infest crops, ditches, roadways and fallows.

required, it is probably the cheapest herbicide resistance management tool in the tool box.

In cereal crops:

- Seedlings that emerge over winter and spring are controlled with a broad-leaf herbicide before they become reproductive (before harvest).

In summer rotations (sorghum or maize):

- Use a double-knock with a shielded sprayer or inter-row cultivation to remove fleabane seedlings that emerge after the crop,

In cotton:

- Use a residual herbicide before planting, at planting, or as an early lay-by if heavy infestations of fleabane are expected,
- Use a double-knock with a shielded sprayer or inter-row cultivation to remove fleabane seedlings that emerge

after the cotton,

- Use chipping or spot spraying to remove escapes, and
- Use a layby at canopy closure to prevent fleabane establishing later in the season .

It is unwise to plant other broadleaf crops such as chickpeas or faba beans in fields where heavy populations of fleabane are expected as it will be very difficult to control fleabane in these crops.

Avoiding the next round of resistance

Fleabane seedlings can be managed fairly easily by using either contact herbicides, residual herbicides or cultivation. However, as with most glyphosate resistant weeds, the trap of using an alternative herbicide to control fleabane is to ensure that control doesn't rely too heavily on a single herbicide or herbicide group.

Diuron has become the herbicide of choice for many growers for controlling fleabane in the cotton system. It is effective, is relatively inexpensive and can be applied prior to crop planting, at-planting or post-planting. However, unless diuron is used as part of an integrated weed management system (including other tactics such as other residuals, knock down herbicides, cultivation and chipping) it is only a matter of time before resistance to diuron develops.

This is the trap that many farmers have fallen into in the US and elsewhere. They used a glyphosate-only approach to weed control until glyphosate resistance became a huge problem. They then changed to the next best herbicide, and found resistance developed to the new herbicide in only a few years. They then move on to another new herbicide to which resistance again developed, and so on until they ended up with weeds resistant to 4 or 6 or more modes of action that can only be effectively controlled with huge inputs of herbicide, cultivation and chipping. This situation is likely to evolve very quickly with wind dispersed weeds such as fleabane and sowthistle, where the rapid and widespread seed movement means that even if diuron (for example) has not previously been used in a field, the chances are that some fleabane plants in the field have blown in from another field or property where there is a history of diuron use and resistance may already have developed.

So, while diuron or atrazine (for example) may be valuable tools for managing glyphosate resistant fleabane, resistance to these herbicides is likely to develop within only a few years unless these weeds are managed in an integrated approach including multiple tactics such as residual and contact herbicides, cultivation and chipping or spot-spraying of escapes.

Conclusion

Fleabane has already developed resistance to glyphosate and is likely to develop resistance to other modes of herbicidal action within the next few

years. To manage fleabane, it is essential that a whole farm integrated approach is developed, targeting fleabane seedlings and effectively controlling fleabane in all parts of the farming system with a range of tactics, not just relying on one herbicide or one mode of herbicidal action group.



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THE SEPARATION & UTILIZATION OF POLYESTER/COTTON BLENDS

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Summary

Textiles are commonly made from intimate blends of polyester and cotton, which makes recycling of such textiles very difficult through mechanical means. We report the use of ionic liquid in the separation of polyester cotton blends. By selective dissolution of the cotton component, the polyester component can be separated and recovered in high yield. This finding presents as an environmentally benign approach to recycling textile blend waste.

Introduction

Improving the recycling of textiles has become an issue for the 21st century. Annually approximately 1 trillion tons of textile waste is discarded to Australian landfill (TTNA aims to recycle fibre waste from landfills 2010). The recycling of textiles is complicated by the issue that the majority of textile products are blended materials. For example the majority of clothing is manufactured from a polyester/cotton yarn (Zou et al. 2011; Kalliala and Nousiainen 1999). Separation of polyester and cotton into its individual components is difficult; mechanical separation is not possible and chemical separation requires harsh processing parameters (Zou et al. 2011; Wakelyn et al. 2007). We report a new environmentally friendly and convenient approach to separate and subsequently utilize polyester/cotton blends using ionic liquids (ILs). We have selected cellulose dissolving 1-allyl-3-methylimidazolium chloride (AMIMCl) (De Silva et al. 2013; Zhang et al. 2005). The polyester/cotton blend can be separated by selectively dissolving the cotton component, with the benefit that the IL can be recycled and reused (De Silva et al. 2013; Cao et al. 2009). The polyester, a non-renewable petroleum resource was recovered in high yield of more than 98%. The benefit of using ILs in this process is the ease with which the polyester and cotton can be separated. This technology reported here shows a facile route to the recycling of clothing in the form of polyester/cotton blends. We measure the material properties of the recovered polyester and cotton and show that no significant differences can be seen between

the recovered polymers and the as received 100% polymers.

Materials and methods

To determine the solubility of polyester, 100% polyester as received was submerged in the 1-Allyl-3-methylimidazolium chloride at 80 °C and monitored using polarizing optical microscopy. Over a 48 hour period, no dissolution was observed. Then the 50:50 polyester/cotton blend yarns were added to the ionic liquid at 80 °C. After 6 hours, the undissolved component was removed, rinsed with water and weighed. The IL was able to be recovered and recycled as previously reported as water was used as the coagulating solvent to regenerate cotton (Cao et al. 2009).

Results and discussion

FIGURE 1 shows the general scheme for the separation of the cotton/polyester blend using AMIMCl. The IL was able to be recovered and recycled as previously reported as water is the coagulating solution (Cao et al. 2009; De Silva et al. 2013).

FIGURE 2a shows scanning electron image of the polyester cotton blend; prior to separation both cotton and polyester fibres can be observed.

FIGURE 2 b shows the recovered polyester, only polyester fibres are observed. We also characterized the structure of the recovered polyester, using a combination of DSC, TGA, NMR and FTIR shown in FIGURE 3a-d. For comparison we include the as received 100% polyester. It can be seen that no change in the melt temperature of the

THE SEPARATION & UTILIZATION OF POLYESTER/COTTON BLENDS

polyester is measured (endothermic peak around 252 °C), which is important since polyester can be recycled by melting the polyester and reshaping the polyester into the desired form (fibres, bottles, etc). The ^{13}C NMR spectrum and FTIR do indicate that some small amount (less than 2%) of cotton may remain with the recovered polyester as evidenced by the additional peaks observed at 60 and 110 ppm (Zhang et al. 2005), and the presence of the hydroxyl peak at 3300 cm^{-1} (Fan et al. 2012) in the FTIR spectrum.

We now turn our attention to the recovered cotton. It is shown that fibres and/or films can easily be prepared from the cotton/AMIMCI solution. FIGURE 4a-c shows a series of material characterization experiments performed on the recovered cotton from the blend compared with as received cotton dissolved and regenerated from the same IL, AMIMCI. As can be seen no difference in the tensile properties are observed between the two regenerated cotton samples. Similarly the thermal degradation temperature and FTIR show no appreciable differences.

Conclusion

Here we described the facile and efficient separation of polyester/cotton blends into their individual components. This was achieved by selective dissolution of the cotton component using the ionic liquid AMIMCI. We showed that the cotton could be regenerated using water as the coagulated solvent. Regenerated cotton is a material finding increased use in the textiles industry, in the carbon fibre industry as low cost precursor materials (Dumanli and Windle 2012) and as the starting material for bioethanol (Zhu et al. 2006). Current work is in progress to develop a new regenerated textile fibre using the cotton recovered from the textile blend waste.

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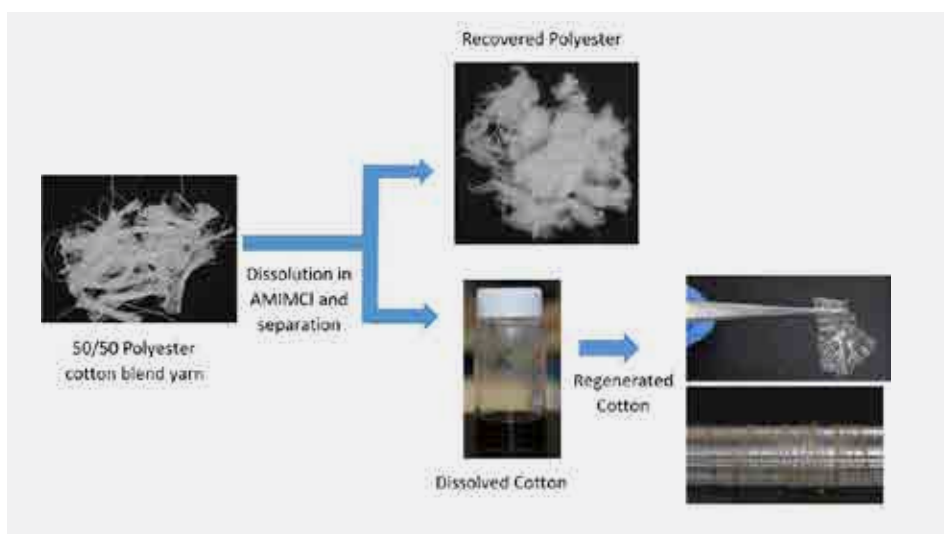


FIGURE 1. Separation and utilization of polyester/cotton blends using AMIMCI

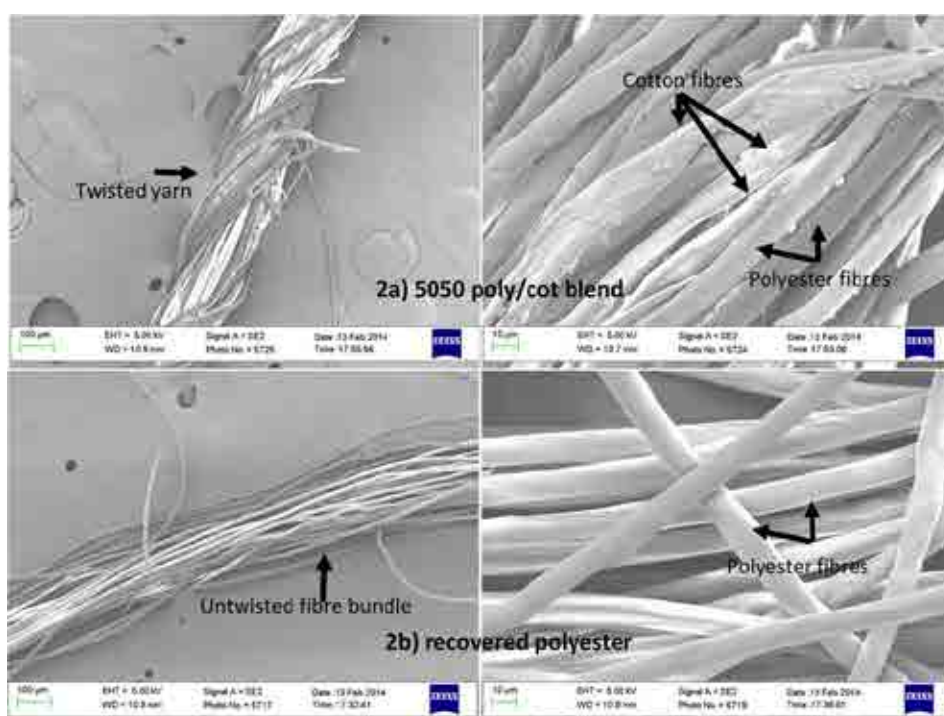


FIGURE 2. (2a)-SEM of polyester/cotton blend; (2b)-SEM of recovered polyester

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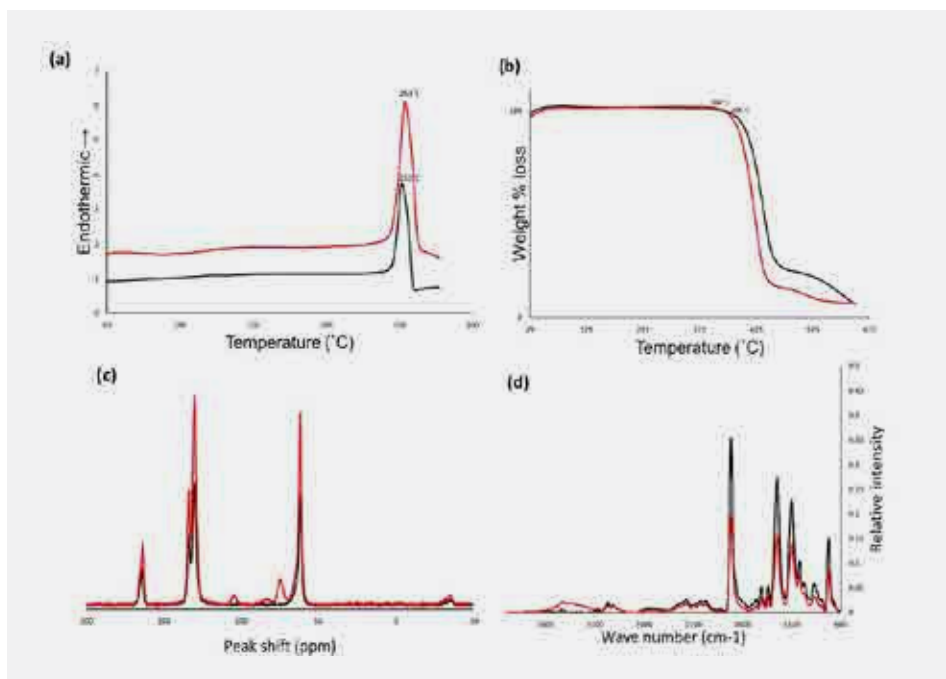


FIGURE 3A-D. Characterization of the recovered polyester (red curve) compared with the as received polyester (black curve) a) DSC curves b) TGA curves, c) ¹³C-CP-NMR and d) FTIR, all show little to no difference between the two polyester samples.

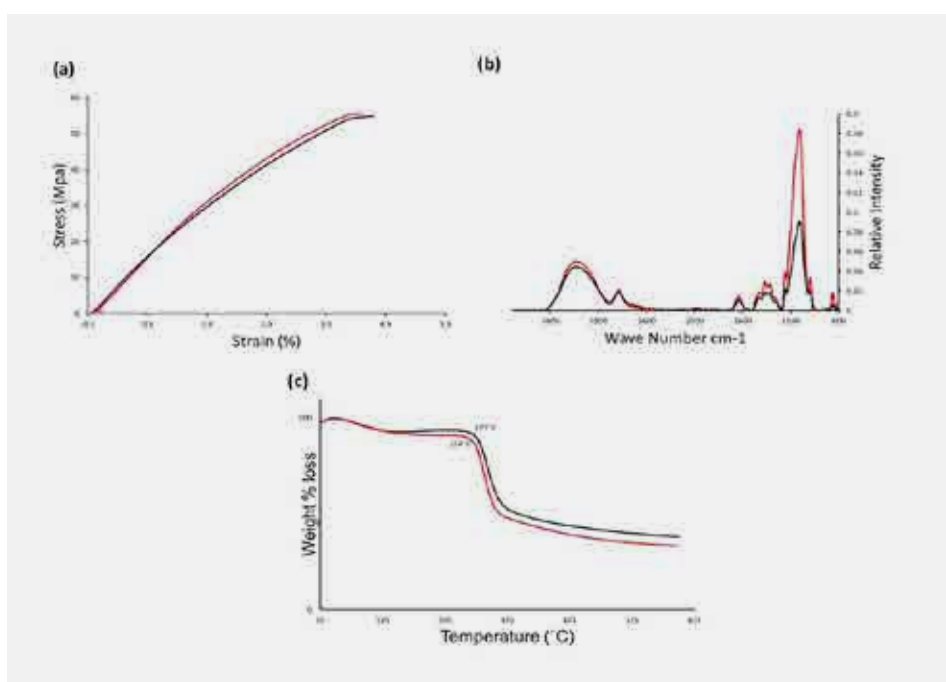


FIGURE 4a-c. Characterization of the recovered cotton (red curve) compared with as received cotton (black curve) a) DMA curves b) TGA curves, c) FTIR, all show little to no difference between the two cotton samples. Both samples are regenerated cotton.

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RESISTANCE MANAGEMENT OF COTTON APHID, TWO-SPOTTED MITE AND MIRIDS

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Summary

In 2010-2011 some 96% of the strains tested showed some level of neonicotinoid resistance (ie Actara®-Cruiser® or Shield®) but that had fallen to 29% of cotton strains in season 2011-2012 and a similar 33% of cotton aphid strains in season 2012-2013. It is possible that neonicotinoid resistance will plateau at approximately 30% of populations tested. For the 2013-2014 season cotton aphid was particularly difficult to find although eight strains were eventually collected. This season cotton aphid will be additionally tested against sulfoxaflor (Transform®) and spirotetramat (Movento®) for resistance.

During 2012-2013 two-spotted mite (TSM) was susceptible to diafenthiuron (Pegasus®) only with all strains showing some degree of bifenthrin (Talstar®) resistance and half the strains indicating some abamectin (Agrimec®) resistance. The detection of propargite (Comite®) resistance in 1 of the 4

strains tested is of concern because it is a mainstay product for mite control. TSM made resurgence during 2013-2014 with some thirteen strains collected (normally ca. 5). Despite ubiquitous and large thrips numbers reddened two-spotted mite hotspots were evident in some fields with mites requiring targeted sprays.

Work has continued preparing for possible resistance in mirids and these past two seasons' baseline data was generated against clothianidin (Shield®) and fipronil (Regent®) and discriminating doses for resistance detection interpolated. For season 2013-2014 some growers thought fipronil (Regent®) may not be working as reliably as before so samples were collected and for the first time are to be evaluated using molecular methodology for a fipronil (Regent®) resistance causing gene.

Introduction

With the introduction of transgenic cotton in Australia, a reduction in chemical insecticide usage has occurred. Subsequently, sucking insect pests, such as green mirids and green vegetable bugs, which were formerly controlled by sprays against *Helicoverpa* spp. have emerged as important early and mid season pests. Control of these emergent pests with broad-spectrum insecticides depletes beneficial insect populations in the mid-season and often leads to later outbreaks of mites and aphids, which

when controlled inevitably selects for insecticide resistant strains. Dealing with the likelihood of resistance requires on-going monitoring for resistance to key insecticides if future control problems are to be averted.

Cotton aphid is resistant to a range of insecticides in many crops and countries. Some ten years ago high-level resistance to organophosphates (omethoate and dimethoate) and some carbamates (pirimicarb) developed in Australian cotton aphid strains causing control failures (Herron *et al.* 2001) but in recent seasons the efficacy of both products has been recovered. More recently neonicotinoid resistance was detected in cotton aphid and this increased in both level and abundance to levels causing control failure (Herron and Wilson 2011). There is now an increase in sprays specifically targeted against green mirids, with high reliance on Regent® (fipronil), which accounts for about 70% of sprays and organophosphates (omethoate and dimethoate) which account for about 20% of sprays. Overseas data indicate that similar sucking bug pests, such as *Lygus lineolaris* in the south eastern USA, can quickly develop resistance to organophosphates and pyrethroids (Scott and Sondgrass 2000). Two-spotted mite (TSM) is notorious world-wide for developing insecticide resistance including in Australia. TSM insecticide resistance continues to evolve in cotton and most recently caused chlorfenapyr (Intrepid®) resistance (Herron *et al.* 2004). Although TSM remains resistant to many of the chemicals used for its control it is

less common and may be being displaced by other mite species.

Two-spotted mite (TSM)

Once both bean spider mite (BSM) and TSM were collected and tested for resistance but from about 1980 bean spider mite was only sporadically found in Australian cotton so collection of that species ceased. The decline in BSM was probably because it remained susceptible to insecticides whereas TSM developed resistance. Over the last 4-5 years BSM and another species, strawberry spider mite (SSM) have become more abundant and TSM less abundant, probably reflecting the reduction in spraying since the advent of Bollgard II. This may be partially because in unsprayed conditions BSM tends to out-compete TSM. Nevertheless, last season (2012-2013) TSM was found with bifenthrin (Talstar®), abamectin (Agrimec®) and propargite (Comite®) resistance. In 2013-2014 TSM made resurgence with some thirteen strains collected. TSM abundance caused typical reddened TSM hotspots in some fields with mites requiring targeted control despite ubiquitous and large thrips numbers. Testing of the 2013-2014 TSM strains is still being done, however, we consider it unlikely the resurgence seen in TSM abundance relates to a dramatic shift in resistance to that evident in season 2012-2013 (Table 1) and more that it is due to subtle changes in the cotton agro-ecosystem.

Mirids

Mirids are very fragile and easily damaged but testing them against insecticides is not particularly difficult; in fact Cornford and Simpson (Undated) has already tested field collected green mirid from Australian cotton. Similarly, we collected green mirid from unsprayed lucerne during 2012-2013 and evaluated them against the neonicotinoid clothianidin (Shield®) and produced a discriminating dose estimate of 0.03 g/L for resistance monitoring (Figure 1). This current season we did the same with fipronil (Regent®) and established a 0.004 g/L discriminating dose for resistance monitoring (Figure 1). Our ultimate concern

Strain	Notes	Bifenthrin (Talstar®)	Abamectin (Agrimec®)	Propargite (Comite®)	Diafenthiuron (Pegasus® CGA140408)
Bud 12		96	100	100	100
Clark	Bifenthrin March	79	93	100	100
East		97	94	99	100
Paddock 6		98	100	100	100

TABLE 1. Percent mortality at the discriminating dose (ie percent susceptible) for various strains of two-spotted mite collected during season 2012-2013 and evaluated for resistance against bifenthrin (Talstar®), abamectin (Agrimec®), propargite (Comite®) and diafenthiuron (Pegasus® (CGA-140408))

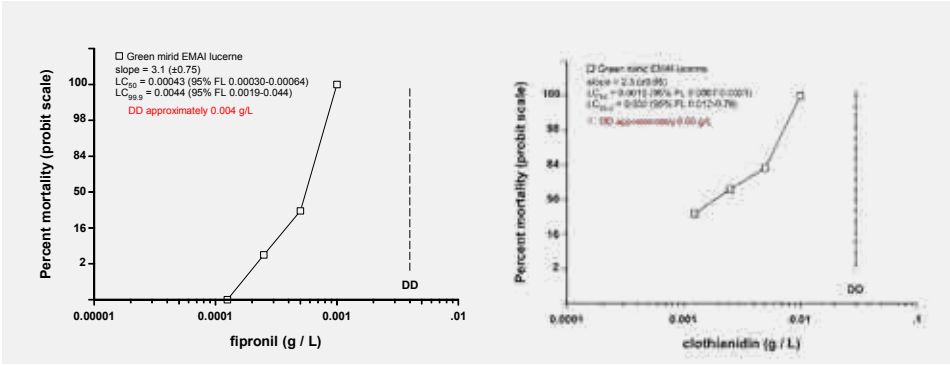


FIGURE 1. Dose response for green mirid collected from unsprayed EMAI lucerne and tested against fipronil (Regent®) and clothianidin (Shield®) to yield tentative discriminating doses of 0.004 and 0.03 g/L respectively.

with mirids remains the difficulty of reliably establishing suspect resistant insects into culture and maintaining them prior to resistance testing. Mirids do not travel well and in our experience most will die in transit. Those that do establish into culture will be slow and time consuming to breed and resistance may revert before it can be diagnosed. Consequently we consider mirids are a species that will benefit from molecular based testing methodology and for the first time during season 2013-2014 green mirids will be evaluated for a fipronil (Regent®) resistance gene using such methodology. To this end mirids were collected from cotton and pigeon pea refuges, put immediately into 100% alcohol and then returned to the laboratory for molecular processing. As with the TSM above the process is still in its initial phase as we write with the outcome unknown.

Cotton aphid

As for mirids and TSM above, testing of the 2013-2014 strains is started but not complete. Although aphids were

particularly hard to find eight strains were collected and for the first time they will be screened against sulfoxaflor (Transform®) and spirotetramat (Movento®) for resistance. It will be interesting to see what this current season testing reveals against these new chemistries but with much testing yet to be done we will have to look back to previous seasons to speculate what may be revealed this season. In the 2007-2008 season neonicotinoid resistance was detected and then increased in both level and abundance during the following seasons, peaking at 96% of strains tested for season 2010-2011 (Figure 2). However, for season 2011-2012 neonicotinoid resistance in cotton aphid dramatically reduced to 29% of cotton aphid strains collected and in the following 2012-2013 season 33% of cotton aphid strains again showed some resistance. This reduction in the neonicotinoid resistance frequency in aphids collected off cotton from a high of 96% happened despite the amount of thiamethoxam containing seed dressing used in Australian cotton likely increasing

RESISTANCE MANAGEMENT OF COTTON APHID, TWO-SPOTTED MITE AND MIRIDS

rather than decreasing and a higher rate 'Extreme' product also being available. Possibly it was the interaction of the foliar sprays and seed treatments that pushed neonicotinoid resistance to such extreme levels. Once resistance was identified as an issue growers then tend to avoid the foliar neonicotinoid sprays for cotton aphid control if practical. For this reason neonicotinoid resistance detected in 2011-2012 2012-2013 seasons may relate more to background selection from seed dressings only that may settle around a 30% resistance frequency. If eventually shown to be a trend it would mean that 70% of the time foliar neonicotinoids can be used without immediate resistance consequences. However, 30% of the aphid populations could still suffer a neonicotinoid control failure after a single application. It will be interesting to see if the 2013-2014 resistance data shows such speculation to be true.

Acknowledgments

The many researchers, CRC Regional Extension Officers, consultants and growers who collected aphids and mites are thanked. This study is funded by the CRDC (DAN1203 and related PhD DAN1201).

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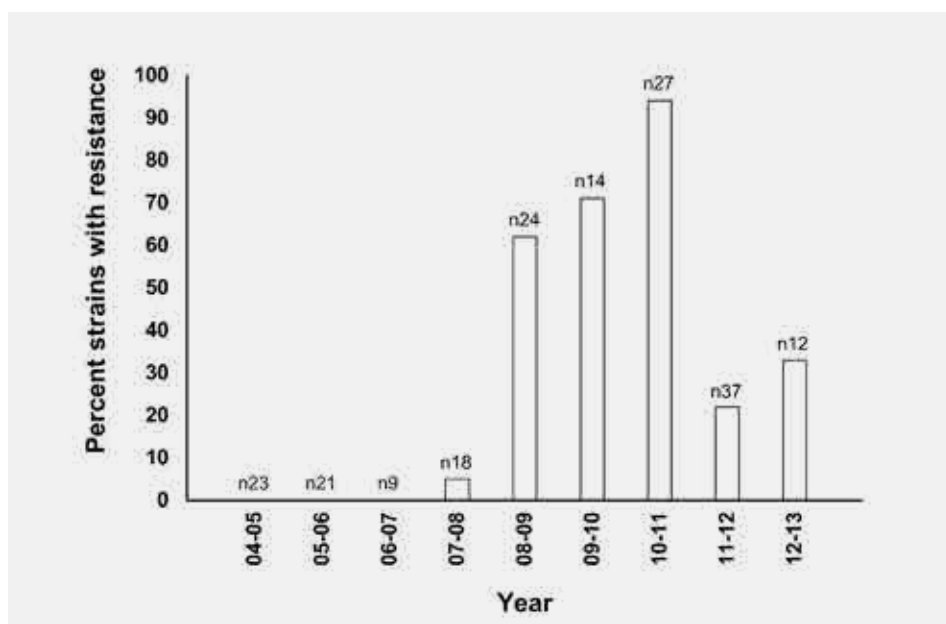


FIGURE 2. Percent cotton aphid strains collected from 2004-2005 to 2012-2013 showing some degree of neonicotinoid (clothianidin, thiamethoxam or acetamiprid) resistance (n = number of strains tested)

Glover (Aphididae: Hemiptera) from Australian cotton. *Australian Journal of Entomology* 50: 93-98.



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SOLENOPSIS MEALYBUG DAMAGE AT DIFFERENT DEVELOPMENT STAGES OF BOLLGARD® II COTTON- IMPLICATIONS FOR MANAGEMENT

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Summary

Solenopsis mealybug establishment onto cotton and the damage they inflicted at different plant development stages was studied in a glasshouse trial and through field observations. The plant growth stages that were studied included; 4-5 leaf, squaring, early boll, late boll and mature. Results from these studies indicate that the earlier mealybug establish on cotton, the more damage they cause. Solenopsis mealybug establishment at 4-5 leaf stage caused 100% yield loss while infestation at squaring and early boll stage caused 90 and 65% yield loss respectively when compared to the control plants with no mealybug. Establishment of solenopsis mealybug on mature plants caused little or no yield loss.

Introduction

Solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae), is a sucking pest of a wide variety of field and horticultural crops, including cotton. They were first reported as a pest of cotton in Texas, USA in 1990 (Fuchs *et al.* 1991). In more recent times severe outbreaks of Solenopsis mealybug have been reported in Pakistan (Zaka *et al.* 2006) and India (Hodgson *et al.* 2008; Nagrare . 2009). In 2007, 40% of cotton crops were damaged by solenopsis mealybug in Punjab (Muhammad 2007) and caused an estimated US\$500,000 damage in one season alone (Nagrare *et al.* 2009). Solenopsis was first detected in Australia during the 2009-10 season on cotton in the Emerald and the Burdekin regions. Since then solenopsis mealybug outbreaks have occurred in Byee (2011), Dalby (2013 and 2014), Condamine (2014) and St George (2014).

Solenopsis mealybug overwinters as adults and nymphs and utilise a wide variety of alternative plant hosts. During the winter months they move into the soil and live in the root zone of the host (Khan *et al.* 2012). When temperatures increase in September and October they move out of the soil and colonise ratoon or volunteer cotton as well as available weed hosts such as pig weed (*Portulaca oleracea*), stagger weed (*Stachys arvensis*) and parthenium (*Parthenium hysterophorus*). When cotton is planted, the insects will move to this preferred host plant. Solenopsis mealybug needs to be well established on plants to cause significant damage. This is unlike some other sucking pests such as mirids

which cause immediate damage. Yield loss from Solenopsis mealybug is therefore likely dependent on crop growth stage at the time of establishment. The objectives of this study were to (1) assess damage caused by solenopsis mealybug on cotton and (2) identify crop stages on which establishment of solenopsis mealybug caused maximum damage.

Methodology

One glasshouse trial and one observational data collection from an infested field, were undertaken to get a better understanding of solenopsis mealybug impact on cotton development and yield.

Glasshouse Trial

Cotton plants used in this trial consisted of the following development stages; 4-5 leaf, squaring, early boll setting, late boll setting and mature (near cut out) boll stage. Single plants (variety Sicot 71BRF) were grown in 25cm diameter pots until the required growth stage. Solenopsis mealybug (from a laboratory culture) were then transferred with a fine paint brush onto the larger, flat top leaves and allowed to establish. Forty five mealybugs (10 adults, 15 small and 20 large nymphs) were released onto each of 6 plants of each stage and allowed to feed and breed until harvest. Four control plants of each stage were kept mealybug free. The plants were closely monitored for damage and all damage symptoms were described. When the cotton plants matured, the number of mealybug and the number of harvestable bolls on each plant were recorded. Bolls were harvested individually but harvesting

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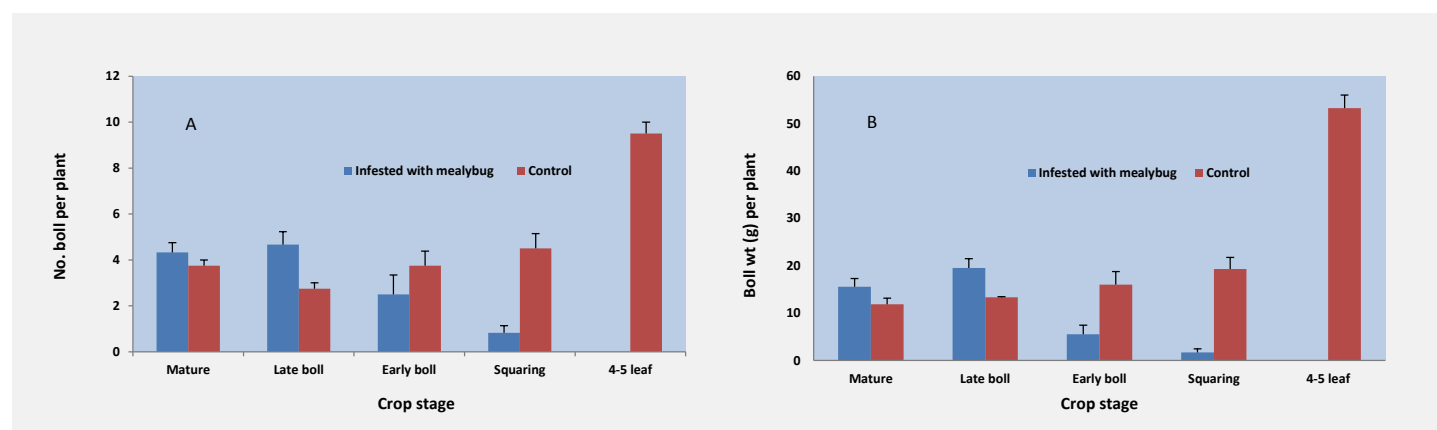


FIGURE 1. Boll number (A) and weight (g) (B) per plant at harvest for different crop stages in the glasshouse. Error bars indicate standard error of means.

was staggered due to plants maturing at different times.

Field Trial

This observational field trial was located near St George (cotton variety Sicot 74BRF). No treatments were applied in this trial but a yield assessment was made from plants with different levels of mealybug infestation. Solenopsis mealybug was first detected when the crop was already mature. The field was also sprayed three times throughout the season with abamectin (@ 600 mL/ha) and fipronil (@ 63 mL/ha), fipronil (@ 40 mL/ha) plus salt and pix and pyriproxyfen (@ 500 mL/ha) to control mites, mirids and whitefly. These insecticides are unlikely to have a direct effect on solenopsis mealybug. However, they will have an adverse impact on those beneficials that can keep solenopsis mealybug populations under control.

Mealybug damage in this field ranged from no damage (no mealybug present) to severe damage (dead plants). Five levels of damage were categorised. 'Severe' damage - dead plants, no leaves, few remaining bolls and no remaining pests. 'High' damage - plants dying, top 8/9 nodal leaves and bolls had dropped and more than 500 mealybug per plant. 'Medium' damage - plants were normal with tip and 1st and 2nd nodal leaves yellowing, top most bolls had dropped and 200-300 solenopsis mealybug per plant. 'Low' damage - plants were normal with less than 100 solenopsis mealybug per plant, mainly on the top of the plants. 'No damage' - there was no evidence of solenopsis mealybug on plants.

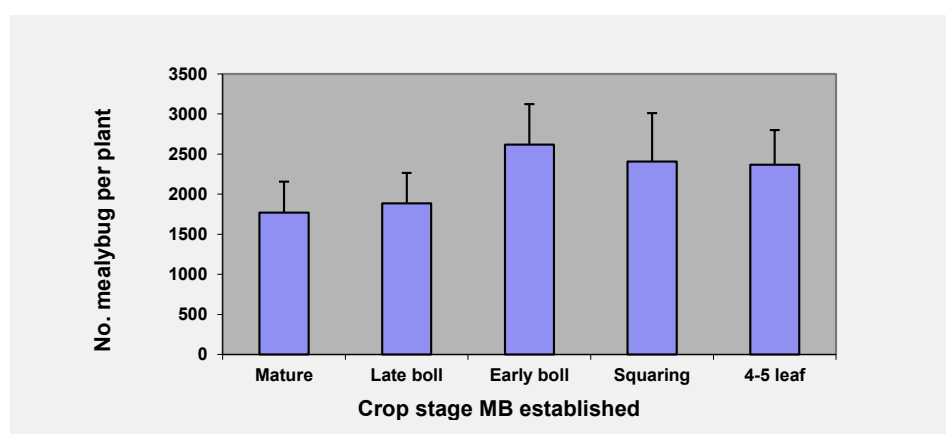


FIGURE 2. Number of mealybug per plant at harvest that established at different crop stages in the glasshouse. Error bars indicate standard error of means.

In each damage category, 5 x 1m areas were hand harvested to determine yield.

Data for both trials was analysed using analysis of variance. Means were compared using Tukey's test. Data from the glasshouse trial was subjected to a paired T-test between plants with and without solenopsis mealybug for each crop stage

Results

Glasshouse Trial

When released onto cotton plants, mealybug initially moved to the underside of leaves and later dispersed onto other parts of the plant. Throughout the trial period they predominantly congregated on the underside of leaves and inside bracts of squares and bolls. Under leaves, they were primarily found on the leaf base (junction of the petiole and leaf blade) and later dispersed all over the leaves. Initial damage symptoms included brownish

areas on the lower surface of the leaf base and reddening on the upper surface. As the population increased the whole leaf turned yellow, then brown and eventually dropped. Feeding inside the bracts led to bracts with a brown and papery appearance. Small squares and bolls also turned brown and dropped. When most of the leaves and some squares and bolls had dropped, mealybugs crowded onto the upper stem and tips.

Plants that were infested with solenopsis mealybug on 4 – 5 leaf, squaring and early boll stages, produced a significantly lower numbers of bolls ($p < 0.05$) compared to infestation at other crop stages (Figure 1A). Yield was also significantly less ($p < 0.05$) in these plants than older plants (1B). At harvest solenopsis mealybug numbers were higher on younger plants than on older plants (Figure 2). Establishment of solenopsis mealybug at 4 - 5 leaf stage resulted in plants that failed to produce bolls and all squares dropped before

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the boll setting stage. Analysis using the paired T-test revealed that yields at 4-5 leaf, squaring and early boll stages were significantly less ($p < 0.05$) in treated plants than control plants. However, this difference was not significant ($p > 0.05$) at the late boll and mature stages. Compared to the control plants solenopsis mealybug caused 65, 90 and 100% yield loss at early boll, squaring and 4-5 leaf stage respectively.

Field Trial

The highest lint yield achieved in the field trial was 6 bales per hectare in the solenopsis mealybug free areas of the crop (Figure 3). This low yield may be attributed to the fact that the field had one less irrigation than required. Lint yield in the mealybug infested areas of the field, where there were medium, high and severe levels of damage was significantly lower ($p < 0.05$) than in the control. However, there was no significant difference ($p > 0.05$) between a low level of damage and the control. When compared to the control, lint yield was 16.7, 35, 66.7 and 93.3% lower for low, medium, high and severe levels of damage respectively.

Discussion and conclusions

From the glasshouse trial, and observations in fields in different locations, the severe damage described here is only possible if solenopsis mealybug establish on plants at or before the squaring stage. The level of damage found in the field was similar to damage found in the crop stages used in the glasshouse trial. The percent yield losses for severe and high damage in the field trial match yield losses for squaring and early boll stage in the glasshouse trial. These results confirm that in order to reach the severe, high, medium and low damage levels, solenopsis mealybug would have established at squaring, early boll, late boll and mature stages in the field.

Furthermore, solenopsis mealybug needs to establish early on cotton to have an impact on plant growth and yield. The earlier they establish the more damage they cause. In our trials the younger plants suffered more damage than older plants as mealybug had the opportunity to feed and breed longer and produced at

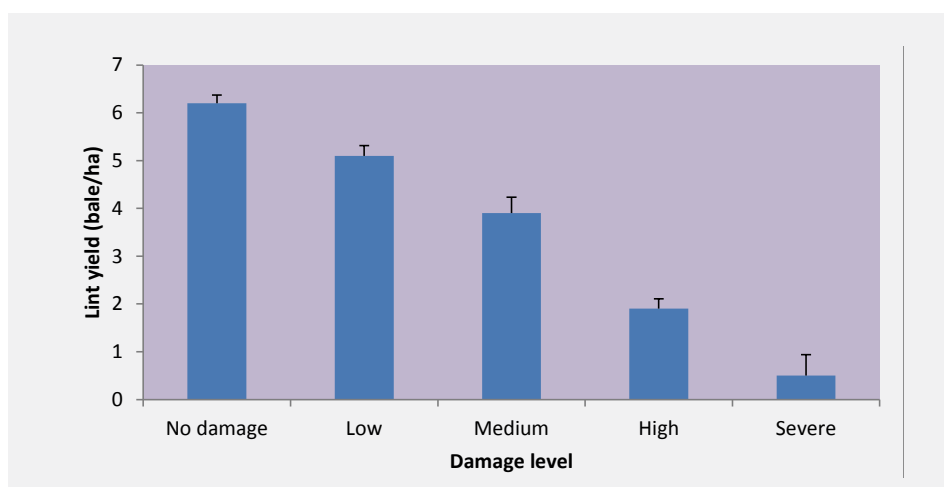


FIGURE 3. Lint yield (bale/ha) for different damage levels in the field, St George. Error bars indicate standard error of means.

least one more generation than on other plants. Trial results also indicated that establishment of solenopsis mealybug up to the boll setting stage caused significant yield loss. Therefore early detection in the field is vital for successful management. Cotton fields with a previous history of solenopsis mealybug are more likely to be infested early and can therefore suffer significant damage. As early infestation usually occurs from ratoon/volunteer cotton and from other overwintering host plants, it is important that farms be kept free of overwintering hosts, particularly ratoon and volunteer cotton. This practice will minimise the early establishment of solenopsis mealybug.

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PHOSPHORUS, POTASSIUM AND COTTON: WHERE ARE WE UP TO?

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Abstract

Cotton continues to be a tricky plant to get a consistent understanding on its responses to phosphorus and potassium fertilisers. Methodologies used successfully in broadacre annual cereal and pulse crop research haven't necessarily translated to similar benefits in the cotton crop. Biomass and tissue concentration differences are being measured with phosphorus and potassium application in early growth stages, but not necessarily at maturity or in yield. Some observations on what is happening, why and where research is heading are offered and explored.

Results and Discussion

Nutrition research in cotton either under irrigation or dryland farming systems, continues to provide a contrasting set of outcomes in comparison with our experiences in broadacre grain and pulse crop research. In general with grain and pulse crops, above ground biomass growth increases associated with phosphorus (P) or potassium (K)

application during the vegetative stages continue through the reproductive phase, translating into a bigger plant at maturity and hence a higher yield. A sorghum trial at Yelarbon in 2013-14 demonstrates this principal. Early dry matter samples collected at 37 days after sowing (DAS) (Fig. 1a) show the almost doubling of biomass from a combination of starter phosphorus with the seed, and 20 kg P/ha applied 20 cm deep when compared to district farmer reference (FR) practice. At physiological maturity (100 DAS) (Fig. 1b), the 20 kg P/ha deep treatment was still 30% above FR and harvested grain yields (Fig. 1c) 20% or 500 kg/ha increase.

Phosphorus research

The lack of consistent maturity biomass or yield responses in experiments examining either factorial PKS combinations or phosphorus placement over the previous three seasons (acknowledging some challenging seasonal conditions) prompted a change of focus for 2013-14 season. Rather than looking solely at the total biomass and nutrient uptake at physiological maturity, measurements

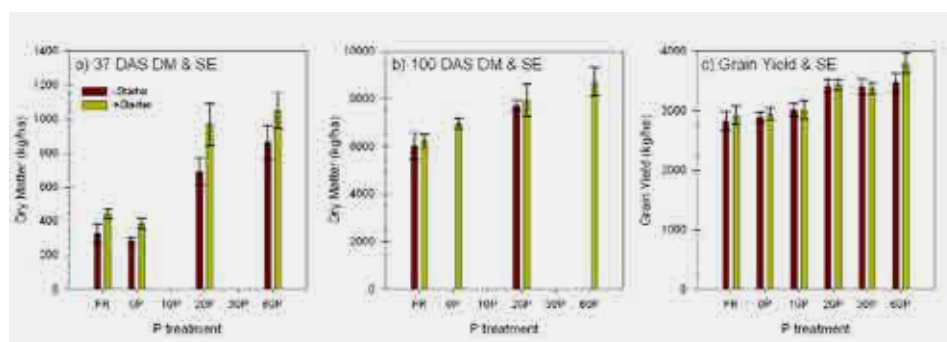


FIGURE 1. Sorghum dry matter at (a) 37 DAS, (b) 100 DAS and (c) grain yields from Yelarbon Qld in 2013-14.

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were also taken throughout the growing season to examine the plant nutrient uptake dynamic. A glasshouse experiment conducted using large pots suggested that during early growth (up to early boll fill) cotton preferred P that was well mixed through the profile as opposed to a banded placement (McLaren et al. 2013), although a dryland field experiment comparing band placement (row spacing x depth) suggest band applications can still produce growth responses (McLaren et al. unpublished data).

Two trial approaches were taken in the 13-14 season, with irrigated cotton at Goondiwindi focussed on assessing biomass growth and phosphorus uptake from a placement x rate experiment, whilst a dryland trial at Moree was directed towards assessing rate responses. Compared to the control, applying P increased biomass at first flowering by roughly 30% in both experiments (irrigated trial shown below) (Fig. 2a). The tissue P concentration was also increased in the plus P treatments and the combination of increased dry matter and tissue concentration put another 1 kg P/ha into the crop (equivalent to a 45-50% increase in uptake at that stage).

However by first open boll any growth differences had been eliminated, while the samples collected at maturity (Fig. 2b), just before defoliation commenced, also showed no P effect on growth. However, note the substantially larger amounts of dry matter present — from 1000 kg/ha at first white flower to 20 000 kg/ha at defoliation. With an expected total crop P uptake of 35-40 kg P/ha, the extra 1 kg/ha taken up at first white flower is no longer significant or even detectable. This is consistent with other experiments examining P rate x placement, where no effect of application rate or placement method altered biomass, tissue concentration or uptake.

Raw cotton yields (Fig. 2c) are presented as ginning hasn't been completed. While they suggest a trend of higher values with P application, the variability around each mean suggest statistically significant differences are unlikely.

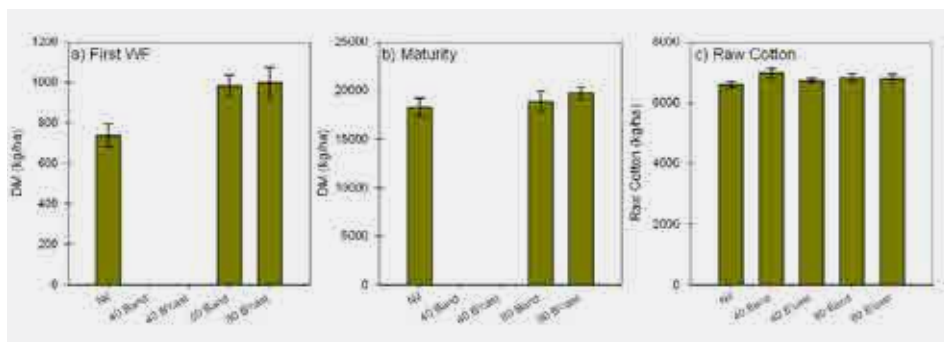


FIGURE 2. Dry matter at (a) first white flower, (b) maturity and (c) raw cotton yields from a P placement by P rate irrigated trial at Goondiwindi in 2013-14.

So, why are there good early responses with P application but the older crop doesn't indicate any effect? Has the early response been then limited by another factor, or how has the nil P treatment overcome the slow start to pull level?

Good questions for future exploration, but there are hints about the process in some literature. Several references suggest that as cotton boll loading and filling starts, the earliest established roots (in the shallow soil layers) begin to be shed by the plant. If this is the case, the plant may be limiting its ability to acquire phosphorus from the fertilised parts of the soil profile just as it enters the period of its most rapid growth. Whether this root loss is an evolutionary mechanism (to exploit deep moisture reserves) or is a response to environmental conditions (i.e. fluctuating moisture conditions in the topsoil/hill) is uncertain and are topics for further investigation. However the apparent reliance on subsoil P for a large proportion of crop P uptake and the continual depletion of subsoil reserves present real challenges to sustainable P management in cotton systems.

Subject to a bit more literature research, the management options we're considering initially pursuing are (i) to place P even deeper in the profile (e.g. below, rather than in the hill in irrigated systems) where more roots may be active during the rapid growth phase; and (ii) attempt to supplement P nutrition through the foliage after first white flower. Our aim at this stage is to have a look at the foliar effects in

an irrigated site this coming season.

Potassium research

Our field research is firming up some likely critical values using soil and plant tissue testing. Crops grown on upland slope Vertosols and on Ferrosols are demonstrating increases in biomass and yield associated with increasing plant available K supply. We think that predicting responses on these soils may be slightly easier as the soil K supply characteristics may not be as variable as in soils from alluvial deposition. Also, these soils don't tend to have the potential influences of magnesium or sodium on structure or cation activity. However these same factors may limit the application of these results to other soils as the impact of a given K rate on K in the soil solution, and hence the rate of crop K uptake, will change with ion activity ratios and soil cation exchange capacity (Al-Azawi 2010; Bell *et al.* 2009). Similarly, varying amounts of sodium and magnesium, which impact soil structure and diffusive supply processes so important in K (and P) supply to plants, will affect the efficiency of crop recovery of applied fertiliser, and thus effectiveness in overcoming a K limitation. These issues also require more investigation.

We established a deep placed K rate experiment SE of Moree that grew cotton in 2013-14. Exchangeable potassium levels were 0.37 cmol/kg for 0-10 cm and 0.20 cmol/kg for 10-30 and 30-60 cm depths. Exchangeable sodium percentages did not exceed 3% in these layers. Biomass

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samples collected at first white flower indicated a growth response to 100 kg K/ha rate when P was also applied (Fig. 3a), but the tissue K concentrations (Fig. 3b) segregate the treatments into those not receiving potassium (FR, 0K -P and 0K +P) versus the 100 kg K/ha rates. Whilst the results are from only one site and one year, it suggests at least the potential for further identification of a critical whole plant tissue concentration at this growth stage, rather than just a leaf or petiole sample on its own. However our hope that seed K concentration could be used as a diagnostic indicator of crop K status now seems unlikely. Despite some very significant plant growth and yield increases, the seed K concentration does not appear to vary in response to K supply.

These early season responses did carry through to significant yield (raw cotton) increases in a very drought affected crop (Fig. 4a-c). Further processing of maturity dry matter samples for this year is currently underway, and we are continuing to investigate sites for future K field research.

There is a note of caution with these K results. The yield responses may be related to the low overall K requirement of such a small crop, allowing a significant impact of small additional amounts of K uptake (~10 kg K/ha – Fig. 3c) in a season where growth was seriously limited by lack of water. Previous studies in irrigated sites showed similar early growth responses and K uptake benefits, but like the observations with P, these disappeared later in the growing season and represented a relatively insignificant amount of overall crop K uptake by maturity.

Next Steps

We need to get further into the dynamics of plant P and K supply and demand from flowering onwards, and relate these demand characteristics to root activity and nutrient acquisition in different parts of the soil profile. Our research has established that good early growth responses to P and K can

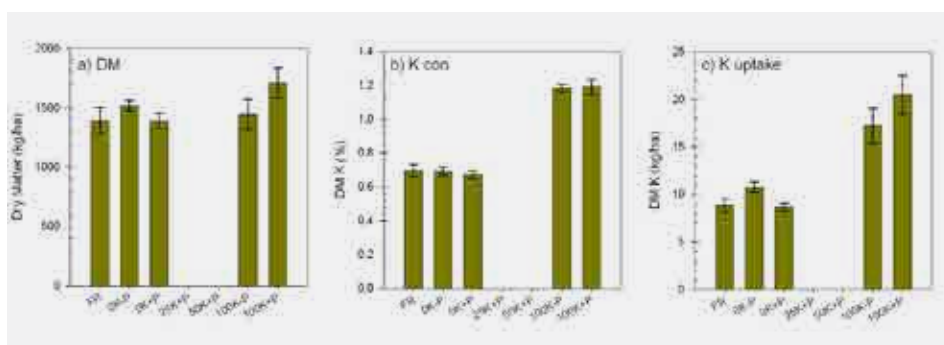


FIGURE 3. Data from a dryland K rate experiment at Moree 2013-14 showing (a) above ground dry matter at first white flower (b), tissue potassium concentration and (c) plant potassium uptake.

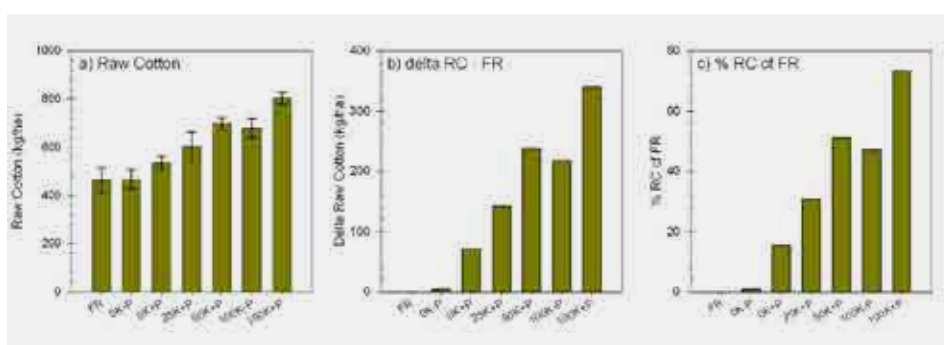


FIGURE 4. Yields from a dryland K rate experiment at Moree 2013-14 showing (a) raw cotton yield (b) the absolute and (c) the relative difference from the untreated control treatment.

be achieved, but it's what happens later in the growing season that determines whether these early growth benefits deliver more lint at harvest.

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COTTON FARM HEALTH AND SAFETY PROFILE - 2014 UPDATE

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Aim

To provide the cotton industry with an update of the rates of work related serious injury and fatality to ensure that the most current and complete data possible is made available so that any priorities for and/or actions to improve cotton farm health and safety, can be based on up to date, comprehensive evidence.

Method

Information was derived from several sources, including:

1. National Coroners Information System 2001 - 2013
2. National Workers' Compensation Data 2008 - 2012
3. Injury Self-Reports, and
4. Near-miss incidents

The paper reports on components (1), (2) and (4) above. For comparison, cotton growing was compared to the grain growing sector.

Results and Discussion

National Coroners Information System

Data from 2001-2013 were accessed and analysed using several different strategies as the industry coding on the data is unreliable. From this process cases were classified as definitely occurring within cotton production or possibly occurring in cotton production. Where it was clear the fatality involved another sector (e.g. cattle or grains), these cases were deleted from the analysis.

Cotton Related - seven cases were identified with mechanisms involving the following: aeroplane, cotton picker, dam drowning (child), farm ute, module builder (x2), water pump). Further data on the costs associated with the cotton related fatal incidents is being compiled.

Potentially Cotton Related - a further 28 possible cases involved properties where cotton is also grown were identified, with mechanisms being: dams, earth moving

equipment, firearms, forklifts, fuel store, motorcycles, quads, tractors, utes and being hit by objects (trees / equipment / structures).

Workers Compensation Data

Workers Compensation data were accessed for the four year period 2008/09 to 2011/12. Data for 2011/12 is provisional and it is expected that further cases will be added in time.

Number of Claims

- Cotton had a similar number of short term injury claims (0-4 days) as grain production (approx 30/year).
- Cotton had approximately half the number of serious (5+ days) claims (35/year) when compared to grain production.
- There is around 2,000 claims (0-4 days) and 3,000 (5+ days) per year across all Australian agriculture. Cotton represents less than 0.02% of all claims in agriculture for injuries less than 4 days and 5+ days.

Claims by Nature of injury

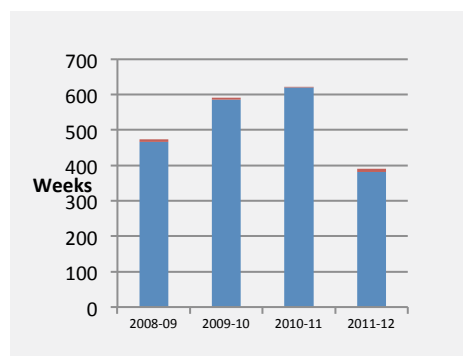
- Sprains and strains accounted for around one-third of both short term (0-4 days) and serious (5+ days) injury claims.
- Open wounds (without amputation), followed by contusions, foreign bodies and fractures were common in claims of 0-4 days duration.
- For the more serious injuries (5+ days), apart from sprains and strains, fractures, open wounds and contusions were most common.

COTTON FARM HEALTH AND SAFETY PROFILE - 2014 UPDATE

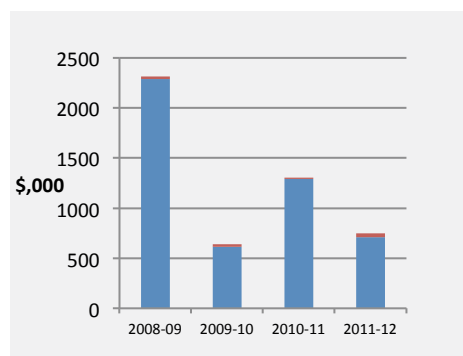
Claims by Mechanism of injury

- Being hit by moving objects, hitting stationary objects, falls and muscular stress (not carrying) were the major causes of short term (0-4 days) injury claims.
- A broader number of causal factors were involved in the more serious claims (5+ days) - falls from height (n=19), muscular stress (lifting), muscular stress (not carrying), hitting stationary objects, being hit by moving objects, vehicles and falls on same level.

Claims by Time Lost and Cost



TIME LOST - Serious and Total



CLAIMS COST - Serious and Total

- Almost 2,100 weeks of work time were compensated in the cotton sector costing over \$5 million. This compared to 182,000 weeks across all Australian Agriculture, costing \$296 million.
- The relevant proportion of time lost and related compensation costs within the cotton sector represented approximately 0.1% of all time lost and costs in Australian agriculture.
- The median time (weeks) off for injuries in the cotton sector (1.35 weeks) was around one-third of that for the grains

sector and less than half that of all agriculture.

- The median cost of all injuries was around \$2,150 in the cotton sector, which was significantly lower than the median for the grains sector (\$4,275) and all Australian agriculture (\$7,100).
- The serious injury claims comprised between 97.8-99.4% of all time lost and 94.6-99.03% of all compensation costs in these years. Not surprisingly, this clearly indicates that the major burden associated with injuries is those that are more severe in nature. Consequently, these should be prioritised for attention as key risks or hazards.

Injury Self-Report

A series of cotton farm safety workshops were conducted with growers throughout the last six months of 2013. Workshop venues included - Boggabri, Bourke, Brookstead, Carroll, Dalby, Gunnedah, Moree, Mungindi, Narromine, St George (x2) and Theodore. In total approximately 80 growers attended these farm safety workshops. At these workshops, growers were asked what have been the major types of injury on their properties in recent years. This information is:

TABLE 2 Reported Serious injury / Near Miss Incidents

Agent/ Injury	No
Quad	
Quad rollover	6
Head Injury	1
Chest Injury ribs	1
Broken leg	1
Quad crash graze/ bruise	11
Quad crash loss of control	common*
Motor Vehicle	
Crash/Collision	9
Run in channel	7
Truck in channel	1
Drowning	2
Serious head injury	2
Pickers	
Fall from ladder	2
Fall from basket	1
Hand infection/ injury	1
Picker fire destroyed picker	1
Picker fires	common
Overhead power line	1
Module Builder	
Injury lower leg	2
Crush injury	3
Fall back injury	2
Fall from ladder	1
Fall tarping module	3
Hit by rear door	1
Hydraulic oil injury	1
Module fire burn arm	1
Module fire	common
Power line strike	2
Anhydrous Ammonia	
Nurse tank roll into channel	1
Gas escape/ burns	2
Tractors	
Collision with irrigation gates	2
Run over vehicle	1
Run into channel	1
Hand injury hitching implements	1
Fire tractor/ slasher	1
Spray Rigs	
Power line contact	2
Aircraft	
Power line strike	1
Engine failure spraying	1
Workshop	
Hand injury	5
Burns	1
Welding flash	4
Eye injury	3
Excavator/ Grader	
Roll/ slide into channel	2
No Serious Incidents Reported	27

Summary

Workers' Compensation Injury Data alone does not identify and provide detailed information on the mechanism and cause of injury compared to data from the National Coronial Database.

To more accurately provide the cotton growing industry with better health and safety information and strategies to further reduce the cost of serious injury; better apportioning of Workers' Compensation injury claims to industry sectors (i.e. mixed farming operations) is required.

Better information is also required from cotton growers, to provide more detail about how serious injury and near-miss incidents occur. This would increase the rate of health and safety improvement, especially to obtain a significant reduction in serious injury, Workers' Compensation costs and claims.



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NITROGEN LOSSES FROM SOIL AND IRRIGATION WATER

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Summary

Several recent experiments at ACRI, Narrabri have illustrated the fate of N fertiliser in irrigated cotton cropping. During the cotton growing season of 2011-2012, nitrous oxide (N₂O) emissions totalled 0.51, 0.95, 0.78 and 10.62 kg N₂O /ha, for the four N fertiliser rates (0, 120, 200, or 320 kg N/ha). Further measurements have indicated that about 12 kg N/ha was lost to deep drainage and 10-15 kg N/ha was lost in the tail water following irrigation. Shallow fertiliser placement resulted in N moving out of the hills and lost via denitrification in the irrigation network.

Introduction

Cotton is a high value commodity and crops normally require N fertiliser to optimise lint production. Growers cannot afford to under-fertilize with N (or other nutrients) and tend to manage risk by ensuring their cotton crop yields are not limited by N deficiency. Cotton-growing soils are typically medium to heavy clays and are prone to waterlogging following furrow irrigation or heavy rain (Scheer et al., 2008, Scheer et al., 2013, Han et al., 2014). Losses of 50-100 kg N/ha can occur during the growth of a cotton crop through denitrification and leaching (Rochester 2003), resulting in inefficient use of N fertiliser. Periodic waterlogging and drying drives soil the denitrification processes which leads to the production of nitrous oxide (N₂O) and nitrogen (N₂) gases. Measured losses from the fertilised hills in furrow irrigated systems are typically below 3% of the applied fertiliser (Rochester 2003, Mahmood et al. 2008, Scheer et al. 2013). In cotton production systems emissions of N₂O from the furrows can be greater than the hills when urea is water-run down the furrows (Grace et al., 2010). Grace et al (2010) also indicated there was substantial movement of nitrate-N from the mounds into the furrows. In furrow systems which are over-irrigated, up to 18.6 kg N/ha can be lost into the irrigation network (McHugh et al., 2008). Once the nitrate enters the tail water it is lost from the field and may undergo denitrification to N₂O and N₂ in water storages. Harrison and Matson (2003) have shown in furrow irrigated wheat production in Mexico that N₂O losses can

be large, averaging 40 N₂O-N g/ha/day. This paper seeks to identify key nitrogen loss pathways in Australian cotton production systems.

Methods

Land surface N₂O Measurements and N₂ estimate

Emissions from the soil and crop were measured using chambers (see Scheer et al. 2013) connected to a fully automated system that enabled N₂O emissions from each of the four fertiliser treatments. The N₂O concentrations were measured with gas chromatography. N₂O was measured during all phases of a 2-year cotton-faba bean-fallow rotation. N₂ emission was estimate from the N₂O:N₂ mole relationship determined by Rochester (2003).

Dissolved nitrate, organic nitrogen and nitrous oxide in the irrigation network

Filtered (0.45 µm) water samples were collected for the determination of nitrate, total ammonia nitrogen (TAN), and total dissolved nitrogen (TDN). Total nitrogen (TN) was determined on unfiltered samples. Collected samples were placed in an insulated box and stored at 4°C, returned and analysed in the laboratory within 7 days. Nitrate and TAN were measured using the cadmium reduction method (Method 4500 Nitrate F; Rice et al., 2012) and automated phenate method (Method 4500 Ammonia G; Rice et al., 2012). The TN and TDN samples were digested using the persulphate method (Method 4500-N; Rice et al., 2012) and the nitrate concentration in the digest

was measured using the cadmium reduction method. Dissolved nitrous oxide concentration was determined using the headspace equilibrium technique (Weiss and Price, 1980).

Estimations of N₂O flux

Nitrous oxide flux was estimated from dissolved nitrous oxide concentrations using the following equation:

flux = k_{total} * (N₂O_(water) - N₂O_(eq))

Where N₂O_(water) is the measured concentration of N₂O in the water, N₂O_(eq) is the concentration the water would have if it were in equilibrium with the atmosphere and *k* is the gas transfer coefficient (m.s⁻¹) (Clough et al., 2007; Cole & Caraco, 2001).

The gas transfer coefficient, *k_{total}*, was calculated as the sum of the transfer velocities attribute to wind (*k_{wind}*) and water (*k_{water}*) speed; and were calculated using the following equations (Clough et al., 2007; Wanninkhof, 1992).

k_{wind} = 0.31u₁₀² (Sc/660)^{0.5} and k_{water} = √(DU/h)

where u₁₀ = the windspeed at 10m above the height of the water body, Sc is the Schmidt number for N₂O, *D* is the diffusion coefficient of N₂O in water, *U* is the velocity of water (m.s⁻¹) and *h* is the average depth of the water body (m). Where water speed was unavailable, *k_{wind}* was used instead of *k_{total}*.

The wind speed at 10m height was calculated using the logarithmic wind profile law:

U₁ / U₂ = ln (Z₁ / Z₂) ÷ ln (Z₀)

where Z₀ is the ‘effective roughness height’, here assumed to be 0.001m, and U₁ and U₂ are the respective wind speeds at heights Z₁ and Z₂, respectively (Kubik et al., 2011). Sc and *D* were calculated in R, using the package ‘marelac’ (Soeraert et al., 2010; R Core Team, 2014).

TABLE 1. The flux of nitrate and DON+TAN from each field and its potential contribution to N₂O emissions (per irrigation per ha).

Irrigation Network Component	Nitrate Pool		DON+TAN Pool	
	kg N	g N ₂ O-N#	kg N	g N ₂ O-N!
Tail Drain D4	1.1 (0.9)*	102 (87)*	2.7 (5.8)	80 (23)
Return	0.4 (0.0)*	34 (0)*	2.8 (56.1)	85 (224)
Tail Drain F3	2.4*	215(NA)*	7.9	711 (NA)
Tail Drain F7	2.3*	206 (NA)*	1.8	157(NA)
Storage	108 (0.7)^	5771 (4649)^	73	1290 (NA)

#Conversion from NO₃ to N₂O based on Seitzinger and Kroeze 1998 method ;!
Conversion from DON based on Kyoto Protocol estimates for waste water;
*Assuming 1 ML/ha irrigation at 75% efficiency; ^Assuming 33 ML irrigation water in storage

Measurements of deep drainage loss of nitrogen

Water samples were analysed for dissolved N from the drainage lysimeter at the ACRI and used to estimate nitrogen loss from the upper profile.

Results and Discussion

Nitrous oxide emissions from the land surface

Overall for the 0, 120 and 200 kg N /ha fertiliser applications, 40-50% of the N₂O was emitted from the cotton phase, 5-10% from the faba bean phase and 30% from the fallow. For the over-fertilised 320 kg N/ha treatment, 80% of the N₂O was emitted from the cotton phase, 6% from the faba bean phase and 14% from the fallow. The N₂O-N emission factor corrected for the background for the 320 kg N/ha treatment was 3.2% compared with <0.9 % for the other measured rates It is evident that during the measurement period that to minimise N₂O production and maintain yield the fertiliser rate should not have exceeded 200 kg N/ha.

Dissolved nitrate, organic nitrogen and nitrous oxide in the irrigation network

The water chemistry of the irrigation waters shows that the DON+TAN fraction is as large as the NOx fraction (Table 1) and should be considered for nitrogen budgeting. Further, it was observed that there was significant variation in the water

nitrogen concentration during irrigation and between irrigations. The soil physical and moisture characteristics also vary within each row and hill and as a result the irrigation water and dissolved nitrogen compounds will transit through the soil at different rates.

The NOx and DON+TAN concentration in the water increases during its transit down the field. The NOx and DON+TAN appear to be sourced from the adjacent hill and are collected as the irrigation water seeps through into the next furrow. It was observed during one irrigation that the irrigation furrow was less saline than the non-irrigated furrow. This indicates that irrigation water is removing salts from the furrow and adjacent hills and transporting them into the tail drain and return channel. As expected, concentrations of N₂O within the irrigation network were small in comparison to other forms of N, with concentrations ranging from 162ng/L to 6530ng/L (e.g. Cole & Caraco, 2001; Harrison & Matson, 2003). Throughout the sampling period, flux of N₂O from the irrigation network ranged from 9.76 to 7795.90 g N₂O-N ha⁻¹ d⁻¹, averaging 222.54 g N₂O-N ha⁻¹.d⁻¹.

Deep drainage loss of nitrogen

During the 2008-2009 cotton season we measured nitrogen leaching from the surface down to 2 meters depth. About 10 kg of N/ha was lost by deep drainage during that cotton season which equated to 6% of the applied fertiliser (160 kg N/ha).



FIGURE 1. Partitioning the estimated nitrogen losses from the application of 200 kg N/ha. The remainder is either stored in the soil or was consumed by plant and soil microbial uptake.

Conclusions

Our measurements estimate that ~40% of the applied urea-N was lost from the field (Figure 1) into the atmosphere and into the subsoil and removed in run-off irrigation water, including water storages. The surface water and nitrogen gas components represent the greatest loss pathways. In the systems we studied, urea was drilled into the hill to a depth of 20 cm prior to sowing and irrigation was applied to alternate furrows that resulted in N leaching from the hills. It is evident that N_2O emissions from the tail water can increase the GHG footprint of the irrigated system. Mitigation strategies include reducing irrigation volumes, placing the N fertiliser deeper in the soil, and strategically use N-rich tail water in adjacent fields.

Acknowledgements

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NEONICOTINOID RESISTANCE IN COTTON APHID FROM AUSTRALIA

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Summary

We have shown that target site insensitivity in Australian *Aphis gossypii* via the R81T mutation is not the causal mechanism of neonicotinoid resistance despite overseas studies implicating such. Instead we propose metabolic detoxification as the likely causal mechanism for resistance in Australian *A. gossypii* and we are currently trying to validate that hypothesis via transcriptome analysis. It is not clear why the R81T mutation is absent but the difference may relate to limited imidacloprid use in Australian cotton and the progressive nature of the cotton industry itself.

Introduction

In Australia, cotton aphid, *Aphis gossypii* Glover is a destructive pest of cotton and cucurbits and is frequently targeted with chemical sprays for its control. Resistance to the organophosphates, carbamates, pyrethroids and more recently the neonicotinoids has been detected in *A. gossypii* in Australian cotton (Herron et al. 2001; Herron & Wilson 2011; Marshall et al. 2012). Insecticide resistance in *A. gossypii* has two primary routes; target site insensitivity and metabolic detoxification. Target site insensitivity is caused from modification/s in the gene of the target site which prevents binding of the insecticide and renders the chemical ineffective. In metabolic detoxification, enzymes which metabolize the insecticide may be over produced (gene amplification) or up-regulated (gene expression), in each case allowing the insect to metabolize the toxin to a level suitable for survival. Alternatively, enzymes may have a greater affinity for binding to the insecticide, allowing it to be slowly sequestered over time. Detoxification and/or sequestration are not mutually exclusive and often occur together in insects whereby metabolic detoxification is the primary mechanism of resistance.

For the three chemical classes; organophosphates, carbamates and pyrethroids, the mechanisms by which *A. gossypii* confers resistance have been elucidated as either target site insensitivity and/or metabolic detoxification. Against the more recent chemical class, the neonicotinoids, the causal mechanism of resistance has not yet been revealed.

Overseas, imidacloprid (a neonicotinoid) resistance in *A. gossypii* has been linked to target site insensitivity via a modification in the predicted binding site of neonicotinoid insecticides in the nicotinic acetylcholine receptor (nAChR) (Koo et al. 2014; Shi et al. 2012). This mutation, termed R81T results in an arginine (AGA) to threonine (ACA) base substitution at amino acid position 81 in the loop D region of the $\beta 1$ subunit of the nAChR.

To ascertain whether target site insensitivity was responsible for the confirmed resistance in Australian *A. gossypii*, we amplified the mutation site within the loop D region of the $\beta 1$ subunit through PCR and compared the DNA sequence of a thiamethoxam resistant *A. gossypii* strain (Carrington) from Australia against a reference imidacloprid resistant *A. gossypii* strain (GenBank Accession number: JQ627836) from China (Shi et al. 2012). Additionally, the cDNA sequences of a neonicotinoid susceptible strain (F 96) and an additional thiamethoxam resistant strain (Glentown) from Australia were included for sequence analysis.

Methods

1. Bioassay

Insecticide susceptible (strain F 96) and thiamethoxam resistant (strains Carrington and Glentown, both collected off commercial cotton) were bioassayed against the neonicotinoid insecticide thiamethoxam (Actara®). Briefly, aphids in batches of thirty were placed onto an excised cotton leaf discs fixed in agar in

a petri dish and sprayed using a Potter spray tower with serial dilutions of the insecticide prepared with distilled water (Herron et al. 2001). Each strain was tested against five serial concentrations, selected to achieve $0 < x < 100\%$ mortality. After spraying, each petri dish was covered with cling wrap with tiny perforations to reduce condensation and placed in an incubator at 25°C for 24 hours. After this period aphids were assessed as dead or alive with the aid of a stereo microscope.

2. Data Analysis

Bioassay data was analysed using a stand-alone probit program developed by Barchia (2001), which ensures that variability between replicates is taken into account. Dose response probit regressions were corrected for control mortality (Abbott 1925) and the LC_{50} and $LC_{99.9}$ plus their 95% fiducial-limits were calculated by applying the method of Finney (1971). Resistance factors were calculated by dividing the LC_{50} of the field-collected population by the value of the susceptible strain.

3. PCR Amplification

DNA was extracted from a pooled sample of 200 aphids of strain Carrington and used as a template in a polymerase chain reaction (PCR) protocol using primers (Forward primer: CTGTCCAGAACATGACCGAA and Reverse primer: GTGGTAACCTGAGCACCTGT) designed to amplify the mutation site within the loop D region of the $\beta 1$ subunit of the nAChR. The amplified DNA was purified and sequenced by the Australian Genomic Research Facility (AGRF). Using the sequencing software program CodonCode Aligner® the sequencing data of strain Carrington was aligned to the reference imidacloprid resistant *A. gossypii* strain (GenBank accession number: JQ627836) for comparison.

Additionally, cDNA sequences were produced for susceptible strain F 96 and thiamethoxam resistant strains Carrington, and Glentown for further analysis.

Results

Bioassay Results

Strain	LC ₅₀ (95% FL ^a) (g/L)	Slope± SE ^b	RF ^c (95% CI ^d)
Susceptible	0.00038(0.00031-0.00046)	2.4±0.24	-
Carrington	0.03(0.027-0.039)	2.2±0.19	85.00(65.29-110.66)
Glentown	0.02(0.01-0.03)	1.2±0.20	51.3(30.5-86.2)

^afiducial limits; ^bstandard error; ^cresistance factor; ^dconfidence interval.

TABLE 1. Full log dose probit regression summary of neonicotinoid susceptible strain F 96 and thiamethoxam resistant strains Carrington and Glentown against thiamethoxam

Sequencing Results

Sequence alignment between susceptible strain F 96, thiamethoxam resistant strains Carrington and Glentown and the reference imidacloprid resistant *A. gossypii* strain (Genbank accession number: JQ627836) confirmed that the region amplified were the loop D region of the $\beta 1$ subunit. Comparative sequence analysis identified that all strains sequenced from Australia possessed a nucleotide G at base position 242 in the consensus region of DNA (AGA), whilst the reference imidacloprid resistant *A. gossypii* strain (Genbank accession number: JQ627836) possessed the nucleotide C (ACA), the later resulting in a corresponding codon change at position 81 from arginine to threonine (R81T) (Fig.1).



FIGURE 1. Comparative sequence analysis of Aphis gossypii strains susceptible F 96, Carrington (cDNA and gDNA), Glentown and imidacloprid resistant (Genbank accession number JQ627836). (Note: mutation site R81T boxed in red)

Discussion

Through comparative sequence analysis, our results have illustrated that in Australian *A. gossypii* the causal mechanism of neonicotinoid resistance is not a target site insensitivity via the *R81T* mutation (Fig. 1). Studies overseas which have found the *R81T* mutation in *A. gossypii*, have described it firstly as the putative mechanism for imidacloprid resistance, and secondly as a cross resistance mechanism to other neonicotinoid insecticides (Koo et al. 2014; Shi et al. 2012). Interestingly, our strains display resistance to thiamethoxam (Table 1) but recent bioassay data has shown they are susceptible to imidacloprid (unpubl.data). Although there is confirmed cross resistance between members of the neonicotinoid mode of action group 4A (Shi et al. 2011; Wang et al. 2007) the spectrum of resistance displayed may be dependent on exposure to each chemical. Infrequent use of imidacloprid in Australian cotton may have increased the susceptibility of *A. gossypii* to this chemical. Additionally, in Australia the majority of cotton seed planted is coated with thiamethoxam as a pre germination seed treatment for the control of all early season insect pests. If the *R81T* mutation develops in response to imidacloprid, *A. gossypii* in Australian cotton may not have had enough exposure to develop the *R81T* mutation. Alternatively, we consider in the absence of imidacloprid a metabolic resistance developed via detoxification to the secondary analogs of imidacloprid and in particular to thiamethoxam. Research to validate a metabolic detoxification theory as the primary mechanism of neonicotinoid resistance in Australian *A. gossypii* from cotton is underway.

Conclusion

The mutation responsible for imidacloprid resistance (*R81T*) in *A. gossypii* strains overseas is not present in Australia. Thiamethoxam is used widely in Australian cotton as a pre germination seed treatment whilst imidacloprid use is limited. This could explain the reason

why the causal mechanism of resistance to neonicotinoids in Australia, in particular to thiamethoxam may develop from a different origin.

Acknowledgements

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SOCIAL-COGNITIVE MODELLING OF GROWER AND EMPLOYEE MOTIVATION

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17th **australian**
COTTON conference
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Summary

Research suggests that farmers' economic behaviour and productivity is predicted by their personality traits (Austin, Deary, & Willock, 2001; Willock et al., 1999). Given cotton is a "high-risk" crop, the implications of this research are significant; yet, there is no body of research that discerns the key motivational factors of a cotton growers and farm employees. Knowledge of the motivational factors is needed to inform the development of a workforce strategy for cotton and to develop interventions that support growers. Toward that end, this paper provides an outline of a social cognitive model of cotton grower and employee motivations (McIlveen et al., 2014; Wunsch, McDonald, & McIlveen, 2014).

Introduction

The *Edinburgh Study of Farmers* (Austin et al., 2001; Willock et al., 1999) is a striking example of psychological research that describes the economic, productivity-related behaviour of farmers—both crop and cattle. The key findings of the Edinburgh Study highlight the role of personality traits in farmers' motivation and productivity. These traits are: Extroversion, Openness to Experience, and Conscientiousness. In this paper, we report on progress toward a new conceptual model of grower and employee motivation that extends beyond the Edinburgh Study's focus on personality traits. The model identifies other *adaptive attitudes and behaviours* that have additional potential to predict work behaviours that is associated with cotton growers' and farm employees' productivity, satisfaction, and engagement in work. The findings of the research project will inform farm-management theory and practices, including the recruitment and selection of cotton farm employees, and the ongoing professional career development of growers.

Many industries have taken up the empirical research and technologies produced by applied psychology, most notably in human resources management, occupational health and safety, and marketing. For example, psychometric screening of future employees is now commonplace as a method to (a) reduce the time, cost, and risk of staff recruitment, (b) enhance the likelihood of selecting staff that "fit" in a workplace. Yet, apart from the Edinburgh Study, there has been little research into the vocational psychology of agriculture since the 1970s (e.g., Richards

Jr, 1973) and, as a consequence, agriculture has not benefited from the advancements in research in the specialised fields of psychometrics and vocational psychology that predict career satisfaction and workplace productivity. There is a pressing need to determine the factors that attract and retain personnel in the cotton industry, and psychological approaches to understanding the factors that contribute to attraction and retention will go a long way to closing the knowledge gap.

We conceptualise cotton grower and employee behaviour within a social cognitive framework (Bandura, 2001). This framework accounts for the influences of the real world, including on-farm factors (e.g., personnel, finances) and off-farm factors (e.g., industry trends, suppliers). Following the Edinburgh Study, a cotton growers' personality (e.g., Conscientiousness) leads the grower to a work ethic to the best of available resources.

To a cotton grower, it seems obvious that his or her Conscientiousness is key to success as a grower, and equally important is the Conscientiousness of those employees who are solid and reliable. It makes sense: being diligent, dependable, organised, and aiming for success, drive one to engage in behaviours that ultimately produce a good year. What is not known, however, are those adaptive attitudes and behaviours that boost the effects of Conscientiousness. We also suspect that other personality traits, such as Grit, will influence how growers and employees engage with their work. A gritty grower knows how to hang in there for the long-term. Again, what is not known is how best

to enhance the effect of Grit by training other adaptive attitudes and behaviours. Within the frame of our social cognitive model, the aim of our research is to discern those attitudes and behaviours. Central to the model's predictive relationships are self-efficacy and outcome expectations.

Methodology

The research project will use develop authentic measurements of the key motivational factors, using exploratory and confirmatory factor analysis. Structural equation modelling will test the social cognitive model to determine if the predicted relationships between adaptive attitudes and behaviours have potential impact on engagement and satisfaction.

Results

Preliminary research using interviews with growers affirmed the content validity of the psychometric measurement instruments. Parallel modelling using data on other occupations has affirmed the model's validity. The interview research will continue in 2014 and will be widened to include farm employees. A large-scale survey, using a battery of psychometric measurement instruments, will be rolled out in 2015.

Conclusion

The final and fully tested models of grower and employee engagement and satisfaction will be used to design supportive initiatives for growers and employees, so that they can get the most out of their career and commitment to farming. Furthermore, the outcomes of this research project will inform on-farm management practices and workforce strategies that aim to attract and retain talent in the industry.

Acknowledgements

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A PILOT STUDY- COTTON GIN TRASH TO ETHANOL

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Abstract

Cotton gin trash (CGT) collected from Australian cotton gins was evaluated for bioethanol production. A detailed compositional profiling of CGT reveals variation between ginning samples and a unique profile consisting of elevated extractive fractions (26-28%), lignins (17-22%) and holocellulose (41-51%). Process conditions for converting CGT to fermentable sugars were experimentally optimised using multifactorial experimental designs. Process optimisation revealed CGT fibre required pretreatment at 180 °C in 0.8% H₂SO₄ for 12 min to maximise glucose recoveries by enzymatic cellulose hydrolysis. The highest ethanol productivity by yeast fermentations yielded 147 L ethanol/ metric tonne.

Introduction

Australia's self-sufficiency in crude oil and refined petroleum products is forecast to drop from 48% in 2011 to <20% by 2020. In 2011, this corresponded to trade deficit of \$18 billion which is predicted to rise (BP Energy Review, 2012). Ethanol from renewable feedstocks is regarded as an ideal supplement and credible replacement fuel. However, Australia's current ethanol production of 350ML only contributes to < 0.2% of petrol consumption. By 2015, ethanol production capacity is forecast to double to >890ML due to growing demand. Expansion in ethanol currently produced from starches and sugars (1st generation ethanol) is seen as unsustainable because it competes with food and fibre production and does not significantly reduce GHG emissions associated with transport. These shortcomings can be addressed in part by producing 2nd generation ethanol from lignocellulose feedstocks, such as residues/ wastes from agricultural and forestry activities.

Significant research in emerging lignocellulosic technologies is underway in many countries (USA, Brazil, Europe, China & India) in anticipation of approaching commercial reality. These ethanol technologies are principally designed for resident biomass feedstocks at hand (principally sugarcane bagasse, corn and rice trash). Only two small scale commercial ventures, narrowly focusing on sugarcane bagasse and ethanol are being developed in Australia. A viable biobased industry in Australia needs to

consider other feedstocks including local agricultural and forestry residues.

Agro-based industries including cotton production generate several million tonnes of waste and for most handling, storage and disposal options add considerable cost to production. Cotton gin trash (CGT) from the ginning process is a centrally stockpiled resource with unique compositional attributes making it ideal as a low-cost biomass feedstock for regional biorefineries. By converting this waste into fuels (ethanol) and higher valued products the cotton industry is positioned to gain benefit in cost reductions associated with disposal practices (including GHG emissions) in addition to gaining access to new markets and opportunities along the cotton processing value chain.

The aim of this study is to investigate the use of CGT as a bioproducts feedstock in order to eliminate traditional disposal management issues in addition to adding value to industry by-products. Specifically, the project aims to provide technical insight and an assessment of the process associated in the conversion of CGT into sugars and subsequently into biofuels (ethanol) via fermentation.

Methodology

The aim of this project is to determine the effectiveness of biochemical pretreatment options for processing CGT into sugars and subsequently fermenting resulting sugar streams into ethanol. Specifically, the research will focus on critical processing stages 2, 3 and 4 (described in Figure 1) and identify key conversion parameters

and their relationship to each other throughout the processing stages. The investigation is best summarised by the following objectives:

1. Describe a complete compositional profile of CGT
2. Determining the role of critical processing parameters (acid strength, temperature, residence time and enzyme concentration) and optimise the recovery of sugars.
3. Evaluate fermentation potential of recovered CGT sugar hydrolysates;

Results

Composition of cotton gin trash.

In the first stage of processing it is essential to identify the composition of the CGT biomass. This is crucial to understanding the overall utility of CGT and for specifically tailoring the bioprocessing strategies.

Outcomes:

- CGT is uniquely different in composition to most other agricultural residues in that it consists of a heterogeneous mixture of different plant components mainly, cotton stems, leaves, motes, burrs, lint and seeds. The proportion of these may vary substantially and affect its overall utility.
- The composition of CGT reveals a relatively high extractive content at 26 to 28% compared to other herbaceous crops like wheat straw (18%) and corn stover (10%) (McIntosh et al (2011)). Likewise, the acid-insoluble lignin content (17.9- 22.8%) are more comparable to hardwoods like eucalyptus (McIntosh et al. 2012)). The total carbohydrate content ranged from 41 to 51% with glucan representing about 24 to 36% and correlated well with total cotton fibre content. These compositional estimates reveal that CGT is unique to other biomass feedstocks in that its characteristics are between those of herbaceous crop residues (like cereal straws) and woody type feedstocks.



FIGURE 1. Lignocellulose to ethanol conversion steps. (1) Biomass harvesting and delivery. (2) Thermal and/or chemical pretreatment separates cellulose from lignin seal and exposes it to enzymatic digestion. (3) Enzyme mix is added to digest cellulose into simple sugars. (4) Microbes produce ethanol by fermenting recovered sugars. (5) Ethanol is distilled and concentrated. Graphics by U.S. DEG Programs (<http://genomics.energy.gov>).



FIGURE 2. Bioprocessing CGT to sugars and ethanol. Panels from L-R are: Raw CGT; Pretreated CGT; Recovered sugar hydrolysate; Post fermentation beer.

Bioprocessing CGT to sugars and ethanol

The critical stages in bioprocessing CGT feedstocks are in the recovery of sugars (mainly glucose) and fermentation to ethanol (process streams are shown in Figure 2). To recover composite sugars the CGT must be fractionated by processes of pretreatment followed by further digestion using enzymes. Using dilute acid at elevated temperature is a well documented pretreatment method for fractionating lignocellulosic substrates. Previous processing studies of agroforestry biomass have established that pretreatment variables such as temperature, acid concentration and residence time play a critical role in dictating the efficiency of enzymatic digestion and recovery of fermentable sugars. Furthermore, optimised process conditions must also minimise degradation reactions and production of undesirable toxic

compounds. These compounds generally lead to an unfavourable environment for microbial growth resulting in low ethanol titres and productivities, and potentially require removal via an expensive detoxification step.

Outcomes:

- According to the model, the optimal pretreatment conditions are comprised of 0.8% H₂SO₄ at 180°C with a holding time of 12 min.
- A maximum glucose release of 273 mg/g was achieved represents a glucose yield of ~ 60%.
- Further improvements in process configuration and optimisation of enzymatic digestion increased glucose recoveries to about 88% of the theoretical maximum.
- Glucose produced under optimised conditions was rapidly fermented by industrial yeast in about 6-8h with an ethanol yield of approximately 147 L / metric tonne CGT.

- This also demonstrates that the levels of toxic compounds produced during the optimised pretreatment phase are within the yeast's tolerance level and that no expensive detoxification processing steps are required.



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Conclusion

Outcomes from this study demonstrate that CGT is a viable resource for producing low cost sugars and subsequently bioethanol. However, further research is required to explore the full potential of CGT and demonstrate the technical and economic viability of commercial scale bioprocessing. The use of CGT as a bioproducts feedstock will eliminate traditional industry issues surrounding disposal costs and potential pollution problems associated with landfilling and composting. Likewise, the development of new processing technologies and establishing new value along the cotton process chain will improve the competitiveness, sustainability and profitability of Australia cotton farming systems.

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A NEW SEMIOCHEMICAL BIOPESTICIDE FOR COTTON PEST MANAGEMENT: DISCOVERY AND DEVELOPMENT

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Summary

Australian cotton is now dominated by transgenic (Bt) varieties, which provides a strong platform for Integrated Pest Management (IPM) of key pests such as *Helicoverpa* spp. This now means though that new selective IPM products are required to manage the development of resistance in *Helicoverpa* spp. to transgenic cotton and the control of emerging and secondary pests, especially sucking insects. A 10 year study looking at organ surfaces of plants identified *Clitoria ternatea* plants as having compounds that deter feeding, oviposition which are toxic and do not support the development of *Helicoverpa* spp. and other sucking pests on cotton plants. In collaboration with Innovate Agriculture Pty Ltd, these compounds have been developed into a product (Sero X®) that is effective on *Helicoverpa* spp., *Bemisia tabaci* (silverleaf whiteflies) and *Creontiades dilutus* (green mirids) with minimal impact on beneficial insects, and is in the advanced stages of commercialisation for use in the cotton industry.

Introduction

With the commercial release of transgenic Bt (Bollgard II®) cotton, insecticide use to control *Helicoverpa* spp. has declined. However, prior to the uptake of Bollgard II®, early season applications of synthetic insecticides against *Helicoverpa* also suppressed the populations of sucking pests such as *Creontiades dilutus* (green mirids), *Nezara viridula* (green vegetable bugs), *Bemisia tabaci* (silverleaf whiteflies) and *Aphis gossypii* (cotton aphid). This reduction in insecticide applications and the ineffectiveness of the Bt toxin against sucking pests has resulted in a greater incidence of sucking pest populations as well as an increase in use of insecticides aimed at controlling these pests. Issues of insecticide resistance, disruption of beneficial species, high production costs and environmental impacts now require the development of alternative strategies for managing and controlling sucking pests (Gregg and Wilson 2008).

Behaviour modifying chemicals, which improve control and management of sucking pests and *Helicoverpa* spp. on cotton, are some of the novel non-chemical and natural chemical pest control tools that are required to complement beneficial insect activity against cotton pests and thus support IPM programs in cotton.

In the search to develop a new semiochemical product, affecting insect behaviour, our intention was not to focus just on compounds of known structure (including sugars, amino acids, gossypol, and tannins) (Tukey, 1971) unless these

emerged as particularly effective during bioassays and chemical identification studies or if there were differences in their presence (e.g. in various plants or plant parts) which indicated that they could have significant behavioural determinants. Analysis of known compounds is a comparatively trivial exercise which logically precludes the discovery of novel compounds. Although bioactivity-guided fractionation of plant extracts would not necessarily lead to detection of novel compounds it was rationalized that the probability would be increased in the case of plants that have received little or no previous attention.

Specifically, the aims of the study were to: (1) isolate and identify plants that may contain natural plant chemicals having stimulant or deterrent/repellent activity towards *Helicoverpa* spp. and other pests on cotton, (2) undertake bioactivity-guided fractionation of extracts of the plant materials, and to identify fractions efficacious against *Helicoverpa* spp. oviposition and larval survival; and (3) develop a semiochemical product from *C. ternatea* bioactive fractionated mixture into a commercial product and determine the impact of the product on cotton pests and beneficial insects.

Materials and methods

The working hypothesis for the screening and identification of plants, potentially having insect behaviour-modifying properties, was based on the evolution of oviposition behaviour among female insects which tend to select plant species that will maximize survival of their larvae

(Rausher, 1982; Thompson & Pellmyr, 1991). For example, *Helicoverpa* spp. adults that do not feed on the cotton plant but have to select a host plant which will support larval survival and performance, the cues received from plant surfaces play a major role in the decision to oviposit or not (Schultz, 1988).

Between 2001 and 2002, *C. ternatea*, various cotton genotypes and selected refuge crops (Hall, 1985; Mensah & Khan, 1997; Mensah, 1999; Mensah et al. 2013) were planted in 12 metre row strips within commercial cotton fields and screened for behaviour modifying properties against pests (Benays & Chapman, 1994). Counts of *Helicoverpa* spp. eggs and larvae on these crops were carried out fortnightly throughout the cotton season.

The study identified *C. ternatea* as deterring insect egg lay, feeding as well as causing direct mortality to *Helicoverpa* spp. and other cotton pests. Thus the plant was thought to be containing some secondary plant compounds (SPCs) that may either kill or modify the behaviour of insect pests.

During 2003 and 2004, *C. ternatea* extracts were prepared and the most promising crude extracts (particularly non-volatiles) that demonstrated biological activity against *Helicoverpa* spp. were identified and later fractionated using a Solid Phase Extraction (SPE) technique similar to that used by Sharma et al., (2001) and Green et al., (2003). Six fractions were prepared and bioassayed for efficacy against *Helicoverpa* spp. oviposition, feeding and mortality on cotton plants.

Following the bioassay studies, the promising *C. ternatea* fractions were combined, formulated and then bioassayed for efficacy against *Helicoverpa* spp. Adult oviposition, larval feeding and mortality of *Helicoverpa* spp. was tested on potted cotton plants within a mesh house. The combined formulation was also tested in small scale field trials against *Helicoverpa* spp., *Creontiades dilutus* (green mirids) and *Bemisia tabaci* (silverleaf whitefly), and efficacy compared with commercial conventional insecticide

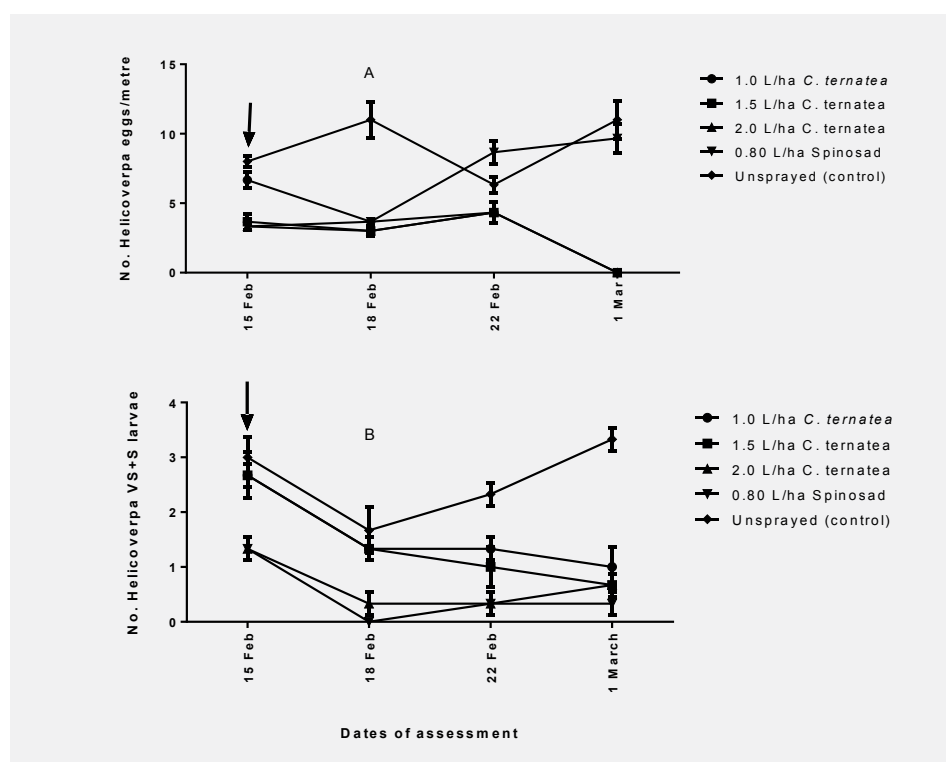


FIGURE 1. Efficacy of *C. ternatea* against *Helicoverpa* spp. eggs (A) and larvae (B) on commercial cotton crops at Norwood near Moree, 2009-2010. Arrows indicate spray application dates.

products used by growers to manage these pests on cotton in Australia.

Results

Helicoverpa spp. and other cotton pest infestations on *C. ternatea* were lower than that on cotton and the other refuge crops. The mixture of *C. ternatea* formulated fractions was found to reduce *Helicoverpa* spp. egg lay and to be efficacious against *Helicoverpa* spp. first to third instar larvae (Figure 1).

In addition to *Helicoverpa* spp., the *C. ternatea* extract was found to control *Creontiades dilutus* (green mirid) adults and nymphs (Figure 2) and *Bemisia tabaci* (silverleaf whitefly) adults and nymphs (Fig. 3) when applied to the pest populations in the cotton field. No significant difference in the number of *B. tabaci* nymphs per leaf was found among plots treated with *C. ternatea* and conventional insecticides (Fig. 3).

In the case of beneficial insects, the results showed that application of Sero-X to cotton plants did not affect the number of predatory insects such as predatory

beetles, predatory bugs, lacewings and spiders. No significant difference was found among the Sero-X treated and the unsprayed (control) plots after the first and second spray applications. However, after the first spray, plots treated with Fipronil had lower number of predatory insects than the unsprayed plots.

Discussion

The present results clearly showed that very few *Helicoverpa* spp. eggs, larvae as well as green mirids and silverleaf whiteflies occurred in areas which had been treated with *C. ternatea* fractionated products. A new biopesticide product now known as Sero X[®] has been developed from *C. ternatea*. The study found minimal impact of the *C. ternatea* product on beneficial insects, less than the commercial synthetic insecticides, indicating that the *C. ternatea* product should be compatible with IPM.

It is anticipated that the aim for Sero X[®] in cotton pest management is to be used as part of the industry's IPM program to modify the behaviour of insect pests on cotton crops by deterring pest egg lay and

A NEW SEMIOCHEMICAL BIOPESTICIDE FOR COTTON PEST MANAGEMENT: DISCOVERY AND DEVELOPMENT

feeding as well as causing mortalities to pests to reduce/suppress populations of *Helicoverpa* spp. and other sucking pests such as green mirids, silverleaf whiteflies etc. It is also anticipated that Sero X[®] might be used, in conjunction with attractants such as Magnet[®] or attractive crops, in push-pull systems that manipulate *Helicoverpa* spp. populations in cotton landscapes for the purposes of IPM and/or Bt resistance management.

In cotton cropping systems, Magnet[®] (moth attractant) and Sero X[®] (oviposition, feeding deterrents and semiochemical) can be integrated and exploited as a behavioural manipulation tool to manage *Helicoverpa* spp. (Mensah et al. 2013). The use of Sero X products will elicit some changes in pest behaviour.

Additionally, Sero X[®] used as a mixture with reduced rates of insecticides can enhance synergism while reducing the quantity of synthetic insecticide actives used on the cotton crops without sacrificing product efficacy. Thus, the Sero X product can be exploited in the context of IPM to manage pests such as *Helicoverpa* spp. and other pests in agricultural crops such as cotton.

The gap in the semiochemical research is to develop a strategy that can integrate long (Magnet) and short range (Sero X) semiochemicals on both transgenic (Bt) and non Bt cotton systems in Australia. Mensah et al. (2013) suggested several strategies for exploiting semiochemicals in managing pests especially *Helicoverpa* spp. on transgenic or conventional cotton crops. These include (1) use semiochemical lures with insecticides to attract-and-kill pests, (2) apply semiochemicals onto cotton plants to deter pest oviposition and feeding, (3) apply semiochemical lures with insecticides to stimulate oviposition and feeding on another crop, (4) apply semiochemicals directly to pests to cause direct mortality and (5) mix semiochemical with insecticides to enhance synergism (through exploitation of semiochemicals as stimulants, deterrents, attractants or repellents in conventional spray programs

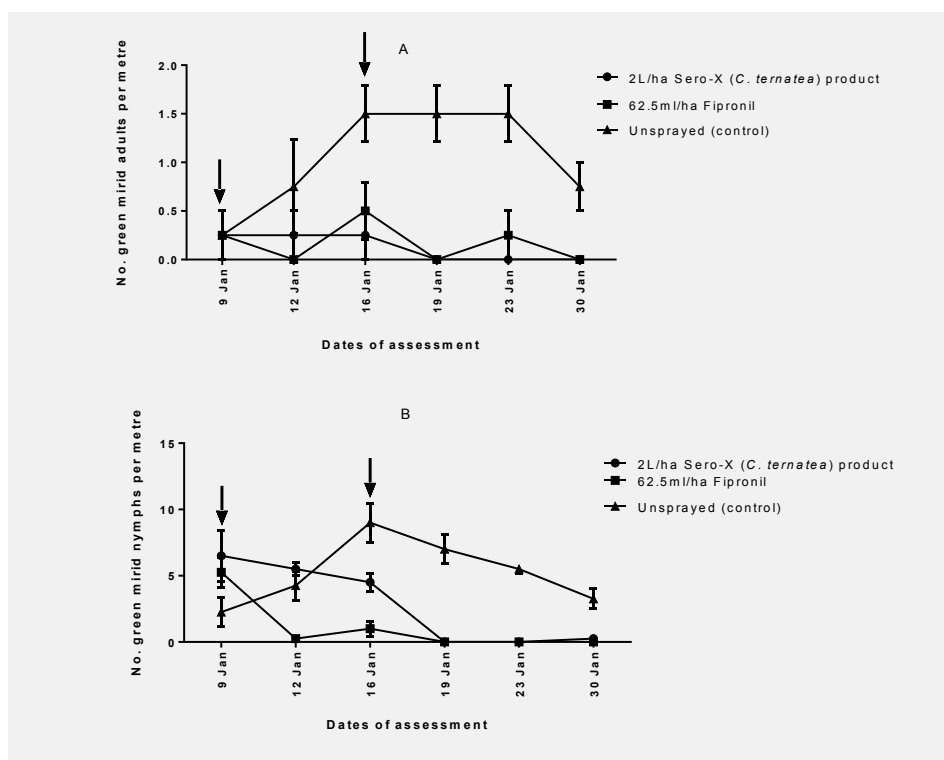


FIGURE 2. Efficacy of Sero-X (*C. ternatea*) product against green mirid adults (A) and nymphs (B) on commercial cotton crops at Cooina, St George 2013-2014. Arrows indicate spray application dates.

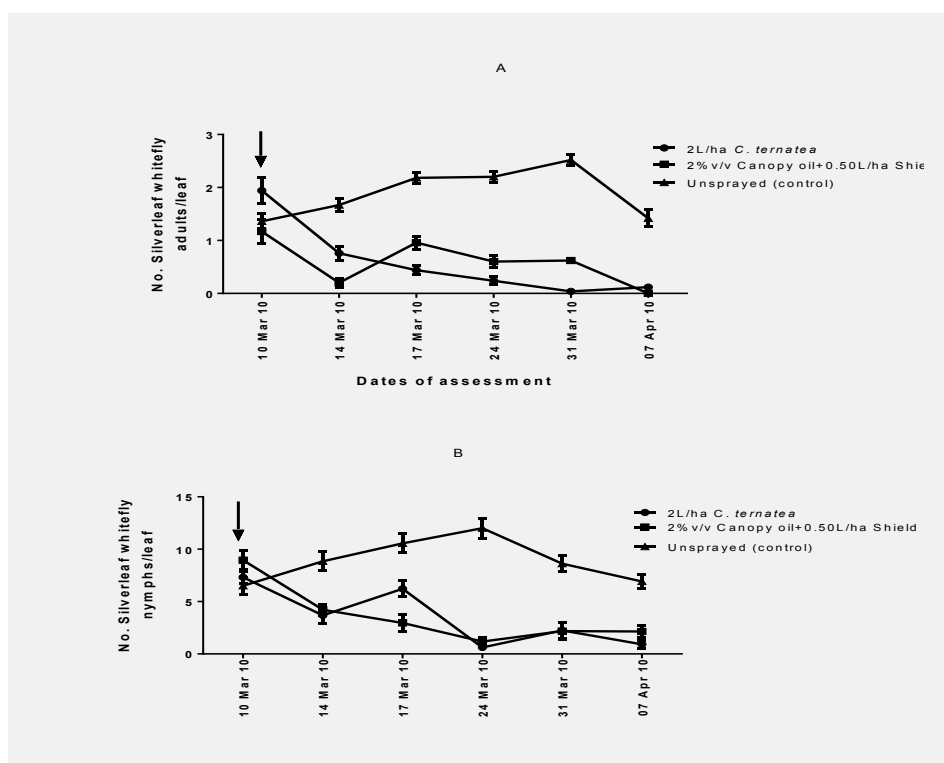


FIGURE 3. Efficacy of *C. ternatea* against silverleaf whitefly (*Bemisia tabaci*) adults (A) and nymphs (B) per leaf on commercial cotton crops at Norwood near Moree, 2009-2010. Arrows indicate spray application dates.

to manipulate the behaviour of the pest or cause direct additional mortality of the pest to protect the resource).

The studies reported here are the beginnings of a long term research plan to develop new biopesticides to explore these possibilities. The Cotton Research and Development Corporation (CRDC) have invested in the Centre for development of Biopesticides and Semiochemical products with New South Wales Department of Primary Industries, University of Western Sydney and University of New England as the initial participating research organisations.

In my opinion, research aimed at developing commercial products can often provide new insights into some fundamental questions of insect chemical ecology, which in turn open new possibilities for pest management. Hence the adoption of a strategy whereby a product such as Sero X, that contains a combination of a wide range of a plant's secondary plant compounds, can be exploited in the context of IPM to manage pests such as *Helicoverpa* spp. and other sucking pests in cotton and other agricultural crops.

Conclusion

In light of the evidence provided in this study, the use of semiochemicals such as Sero X, either alone or in combination with other biopesticides or synthetic insecticides, has the potential to manipulate the behaviour of the pest or cause direct mortality of the pest to protect the target crop.

Acknowledgements

We wish to thank all the technical staff, Ms Angela Singleton, Leah Austin, Ray Morphew, Katinka Atkins, Stacey Cunningham, Cynthia Wilson, Carolyn Palmer, Lori Nemec, Nicole Bell and Penelope Vary for providing technical assistance. Special thanks go to the commercial partners Growth Agriculture Pty. Ltd/Innovate Ag Pty Ltd and for their effort in registering the semiochemical product developed in this project. The

semiochemical projects received funding from the Australian Cotton Research & Development Corporation and Growth Agriculture Pty Ltd.

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WATER USE EFFICIENCY IN THE AUSTRALIAN COTTON INDUSTRY

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Summary

The Australian cotton industry has used values of Gross Production Water Use Index (GPWUI_{farm}) to benchmark water use efficiency since 1988/89. GPWUI_{farm} for 2006-07 and 2008-09 were 1.17 and 1.14 bales/ML, and both seasons had reduced plantings, low water availability and cotton prices. In contrast, for 2012-13, which saw record planting and full production, the GPWUI_{farm} was 1.12 bales/ML. There was no significant difference in GPWUI_{farm} between the three seasons indicating the cotton industry is performing as water efficient in years of full production. Variation in GPWUI_{farm} between farms indicates the scope for further efficiency gains.

Introduction

The Australian cotton industry gauges its water use efficiency (WUE) performance by using irrigation benchmarks. New South Wales Department of Primary Industries (NSW DPI) has measured WUE benchmarks over three recent seasons 2006-07, 2008-09 and 2012-13. Williams and Montgomery (2008) found a 40 per cent improvement in GPWUI_{farm} since the previous industry estimate conducted by Tennakoon and Milroy (2003), later confirmed by Montgomery and Bray (2010).

The 2006-07 and 2008-09 seasons were very dry, water availability was low and coupled with relatively low cotton prices the Australian irrigated cotton planting was low, at around 140,000 ha. In comparison, 2012-13 saw full storage dams, good allocations and record plantings of 365,268 ha (ABS 2014). The benchmarks measured in 2012/13 will show if Australian cotton irrigators manage water efficiently when their farms are close to full production.

Methods

Over three seasons, around 40 cotton irrigators located from Central Queensland

to Southern NSW provided information to benchmark their irrigation water use (Table 1). Each year the same farms were approached to participate in the project. Due to changes in farm ownership and/or management or irrigators choosing not to participate only thirty per cent of farms surveyed appear in more than one year. The sampled farms cover a wide cross section of the cotton industry, including family and corporate farms, managing a range of cotton areas with varying water entitlement. The majority of these farms irrigated using furrows, with only a small farm area under overhead or bankless systems (< 2 %).

The web-based benchmarking program WaterTrack Rapid™ (WTR) was used each season, to provide consistent benchmark calculations across the years.

WTR utilises agronomy and water data comprising: yield, soil type, planting, harvest and irrigation dates, rainfall, water harvested on farm, licensed water diversions, changes in soil water and on-farm storage volume over the season. It generated a Water Summary Report which displays the total available water (irrigation water, on-farm storage water,

Year	No. Farms	Area Planted (Ha)			Bales produced		
		Surveyed farms	Australian total ^a	% of Aus. Production	Surveyed farms	Australian total ^a	% of Aus. Production
2006/07	36	11,868	134,000	9	109,038	1,199,700	9
2008/09	45	16,774	141,923	12	105,881	1,416,800	7
2012/13	46	35,575	365,268	10	410,965	4,384,000	9

^aABS 2014, 2010, 2008 ^bThe Australian Cotton Grower Cotton Year Book (2007, 2009, 2013)

TABLE 1. The number of farms, area of cotton grown and bales produced from surveyed farms compared with the Australian cotton industry.

WATER USE EFFICIENCY IN THE AUSTRALIAN COTTON INDUSTRY

harvest water, rainfall and soil moisture), crop evapotranspiration (ETc) and on-farm water losses.

ETc, was computed by the WTR calculator using ETo values from SILO (Jeffery et. al 2001) with a set range of FAO56 Dual Crop Coefficients (Allen et al 1998) with effective rainfall calculated using the USDA rainfall runoff model (USDA 2004).

WTR calculated on-farm water losses as the difference between the total available water and ETc. All the on-farm water losses were combined into a single value, which included seepage and evaporation from fields, storages, supply drainage and tailwater systems and operational losses.

A number of water use performance indicators were calculated including the Gross Production Water Use Index ($GPWUI_{farm}$), Irrigation Water Use Index ($IWUI_{farm}$) and Crop Water Use Index (CWUI) and were displayed in the Performance Indicator Report.

Water use indices relate production output to a water input and are a performance indicator used to assess WUE. CWUI relates total production to the amount of water consumed by the crop (ETc). The CWUI depends mostly on agronomic factors rather than irrigation efficiencies and is useful for estimating potential crop water use and for examining crop productivity. $IWUI_{farm}$ relates total production to the amount of irrigation water supplied. It does not include rainfall or soil moisture. A more meaningful water use index for comparing WUE between seasons is $GPWUI_{farm}$, which relates total production to total available water, i.e. irrigation water + effective rainfall + soil moisture.

The WTR reports for each farm were collated to retain anonymity. Statistical analysis was conducted on each performance indicator by fitting a linear mixed model with season as a fixed effect and region as a random effect to examine if there were any significant differences in the industry benchmark figures between the three seasons. Predicted means and standard errors for each year are shown in Figures 1 and 2.

	2006–07 ^a		2008–09		2012–13	
	Mean (SD)	Min Max	Mean (SD)	Min Max	Mean (SD)	Min Max
<i>Yield (Bales/ha)</i>	10.69 (1.91)	4.07 13.19	10.63 (1.49)	8.00 13.57	11.14 (1.55)	7.18 14.37
<i>Total available water (ML/ha)</i>	9.31 (1.88)	5.12 12.79	9.66 (1.75)	5.88 13.31	10.16 (1.75)	6.61 15.47
<i>Crop evapotranspiration (ML/ha)</i>	7.36 (0.88)	5.42 9.13	7.59 (0.74)	5.60 8.61	8.48 (0.81)	6.55 9.83
<i>On-farm water losses (ML/ha)</i>	1.95 (1.94)	-1.43 6.88	2.07 (1.53)	0.01 5.24	1.64 (1.44)	0.00 6.40
<i>CWUI (bales/ML)</i>	1.46 (0.26)	0.58 1.90	1.41 (0.21)	1.01 1.92	1.31 (0.16)	0.94 1.70
<i>$IWUI_{farm}$ (bales/ML)</i>	1.4 (0.45)	0.80 2.78	1.99 (0.96)	0.82 5.75	1.41 (0.39)	0.76 3.01
<i>$GPWUI_{farm}$ (bales/ML)</i>	1.17 (0.25)	0.69 1.71	1.14 (0.27)	0.64 1.58	1.12 (0.17)	0.73 1.43

^a includes 7 farms with negative on-farm water losses, which were excluded in Williams & Montgomery 2008.

TABLE 2. Yield, water used, crop evapotranspiration, on-farm water losses and irrigation benchmarks established for 2006–07a, 2008–09 and 2012–13 cotton seasons.

Results and discussion

The most striking feature of the data is the variability of yield (bales/ha), total available water (ML/green ha), ETc (ML/green ha) and water use indices in all three irrigation seasons, 2006–07, 2008–09 and 2012–13 presented in Table 2. This variability shows there is scope for large improvement in crop water management.

No significant differences were found between the yield and on-farm water losses in the different seasons (Figure 1). However, there were significant differences in ETc and total available water from season to season. This was likely due to varying climatic conditions between the seasons, which affect the crop water requirement.

While yields in 2012–13 were comparable to the 2006–07 and 2008–09 season, ETc was significantly higher (Figure 1) resulting in a significantly lower CWUI in 2012–13 (1.31 bales/ML) (Figure 2).

The variation in $IWUI_{farm}$ between the seasons (Figure 2) is due to the variation in rainfall. Both 2006–07 and 2012–13 were very dry with little in-crop rainfall, irrigation water made up 89 and 83 per cent respectively of the total available water. Whereas in 2008–09 the average irrigation water supplied was only 65

per cent of total available water. The difference in the $IWUI_{farm}$ between the seasons illustrates the influence that rainfall has on this index.

The $GPWUI_{farm}$ for the 2012–13 season was 1.12 bales/ML (range 0.73–1.43 bales/ML). There was no significant difference in $GPWUI_{farm}$ between the seasons (Figure 2). While this suggests little change in $GPWUI_{farm}$ over this time, importantly, cotton irrigators in 2012–13 were managing larger cotton areas and handling larger volumes of water. In 2012–13 the average area planted on the participating farms was 773 ha, which was 135% higher compared with the area planted in 2006–07 (330 ha). The average amount of total available water managed on farm was 8,216 ML in 2012–13, which was 166% higher compared with the 3,082 ML available in 2006–07. Cotton irrigators were able to manage this extra water and produce on average an extra 5,600 bales of cotton at a similar $GPWUI_{farm}$ to 2007–6 and 2008–9 when water was scarce.

Conclusion

The average $GPWUI_{farm}$ for the Australian cotton industry in the 2012–13 season was 1.12 bales/ML. This was statistically similar to $GPWUI_{farm}$ in the 2006–07 and 2008–09 seasons, even though cotton irrigators

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were managing much larger cotton areas and volumes of water in 2012-13. This suggests the cotton industry uses water as efficiently in times of full availability and production as in times of water shortage. Variation in $GPWU_{farm}$ between individual farms indicates scope for further efficiency gains. Irrigation benchmarking provides performance indicators with which individual cotton growers can rank their performance within the industry and so enable continuous improvement in water use efficiency.

Acknowledgement

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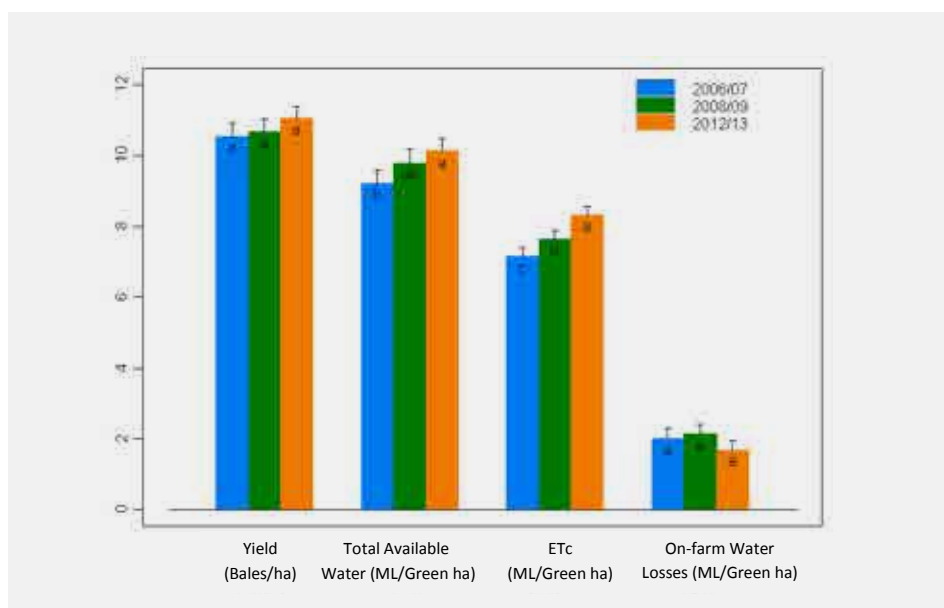


FIGURE 1. Variation in yield, total available water, ETC and on-farm water losses over three seasons. (The standard error (SE) of the predicted mean is shown a top of each bar. For each variable, bars that do not share a common letter are significantly different).

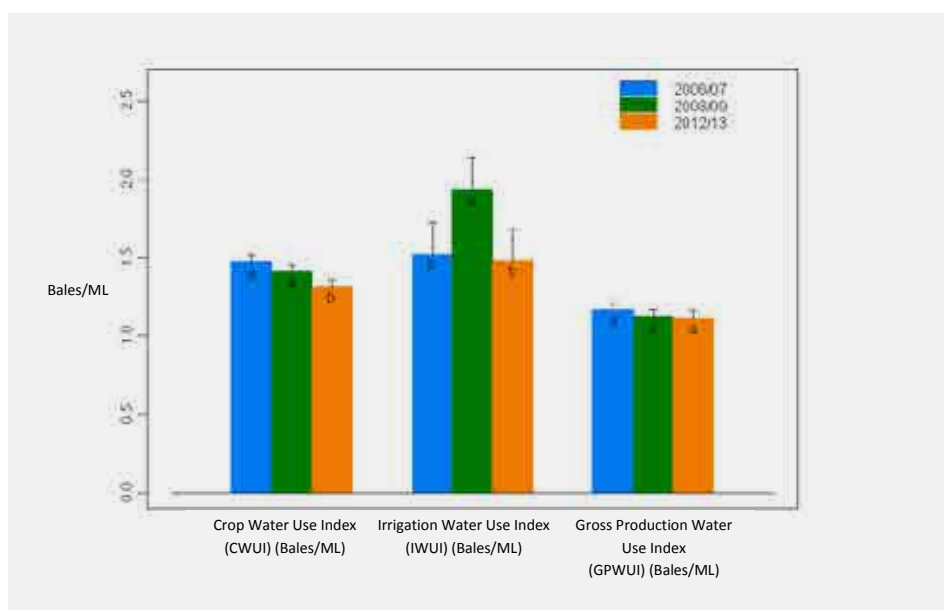


FIGURE 2. Variation in water use indices over three seasons (The standard error (SE) of the predicted mean is shown a top of each bar. For each variable, bars that do not share a common letter are significantly different).

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COTTON'S RESPONSE TO INJECTED SOIL APPLIED POTASSIUM

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Summary

The frequency and severity of potassium (K) deficiency symptoms in cotton on the highly productive clay soils in Texas have increased in recent years. Two locations with low to medium soil K levels were chosen for these trials. Four rates of injected liquid K and four rates of dry broadcast K were evaluated. Plant growth measurements, yield, and quality were recorded. Visual K deficiency symptoms were observed in the low rates of broadcast K. The injected K yields were significantly higher than the broadcast applications. Micronaire values increased with increasing injected K rates, while other fiber qualities were not impacted.

Introduction

For the past decade, Texas has continued to dominate U.S. cotton production. Much of the state's cotton is produced on clay soils in the Blacklands of Texas and Gulf Coast. Although K deficiencies have been reported in these regions in various years over the past 20 years, the frequency of reported K deficiency symptoms seems to be on the rise, and the geographic occurrence seems to be increasing as more K is mined from the soils by crops. Additionally, under deficient K levels, cotton plants are more prone to foliar diseases that can further reduce the yield potential.

Previous research has shown an 1100 kg/ha cotton crop will remove 33 kg K/ha. While a 1100 kg/ha rainfed crop is generally considered good, increased yield potential in new varieties and better pest management have pushed cotton yields to over 2,000 kg/ha, and even exceeding 2,500 kg/ha on irrigated land. As K demand by the cotton continues to increase, deep soil profile samples indicate a reduced level of plant available K in some production areas. The objective of the research was to evaluate the effect of K application rates and methods on cotton growth, development, yield, and fiber quality.

Methods

Studies were initiated at two field sites with a previous history of K deficiency, one in Williamson County in the Blacklands region and one in Wharton County in the Upper Gulf Coast region. Based



FIGURE 1. Liquid potassium fertilizer (0-0-15) being injected in 2013 trials.

on soil test results, 67 and 0 kg K₂O/ha were recommended for the Williamson and Wharton county sites, respectively, and soil test K (ammonium acetate) levels were 60 and 150 ppm for the sites. Treatments were 0, 22, 44, 88, 134, and 180 kg K₂O/ha applied using liquid 0-0-15 as KCl, and 44, 88, 134, and 130 kg K₂O/ha applied as a granular 0-0-60. The liquid K treatments were injected approximately 10 cm to the side of the row and at a 15 cm depth (Figure 1). The dry treatments were broadcast by hand and incorporated with light tillage. Both K application methods occurred 2 - 3 weeks prior to planting. In early April, cotton cv. DP 0935B2RF was planted into a Lake Charles clay loam at the Wharton site. In mid-April, cv. Phytogen 499WRF was planted into a Burleson clay at the Williamson county site. Phosphorous and nitrogen were applied according to soil test recommendations for 1100 kg/ha cotton yield goal. Both locations were non-irrigated sites and were managed for insects and with plant growth regulators according to best management practices for each region.

COTTON'S RESPONSE TO INJECTED
SOIL APPLIED POTASSIUM



FIGURE 2. Potassium deficiency symptoms and disease incidence on cotton leaves in untreated plot.

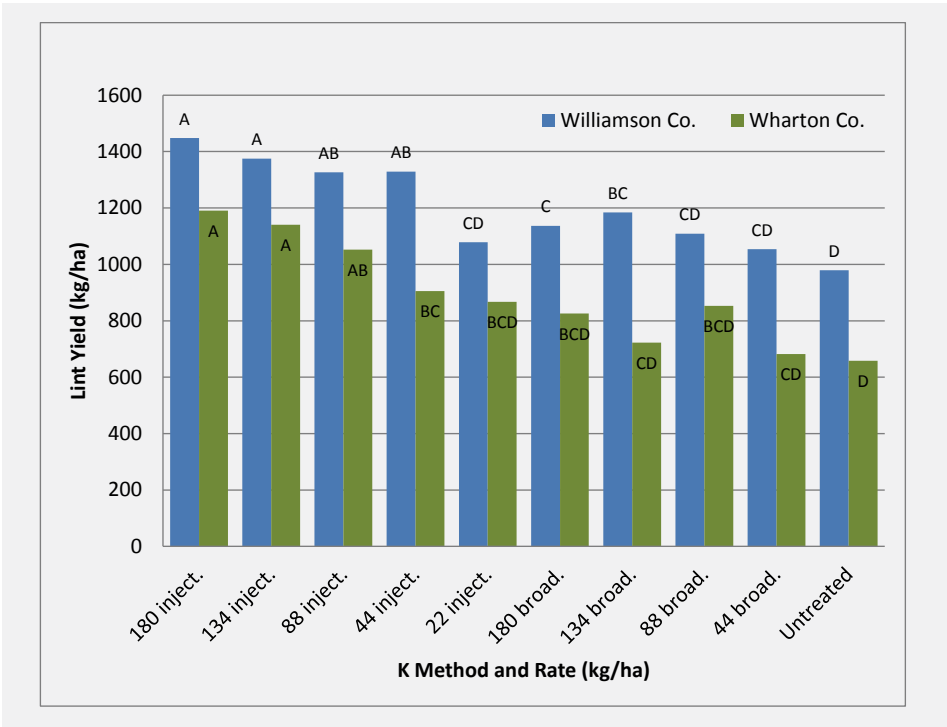


FIGURE 3. Cotton lint yield as impacted by potassium application rate and application methods (injected and broadcast incorporated) on clay soils in Texas, U.S.A.

In-season plant measurements included stand counts, plant height, nodes to first fruiting branch, and total nodes. After harvest, yield was calculated, and fiber samples sent to Cotton Inc. for HVI analysis. For return on investment calculations, a base value of 1.65 cents/kg of lint was used and then lint values calculated using the 2013 loan calculator provided by Cotton Inc. Cotton seed value was not included in the return on investment calculations. The return on investment calculations only include fertilizer costs and are presented relative to the untreated check. Fertilizer prices used were \$0.57 per kg of 0-0-60 (\$0.95/kg of K_2O) and \$0.28 per kg of 0-0-15 (\$1.88/kg of K_2O).

Discussion and Results

There was below normal in-season rainfall for most of the growing season at both locations, but good yields were obtained due to the timeliness of the rain. Visually, the biggest differences between the K treatments were the presence and severity of K deficiency symptoms in the leaves and disease incidence (Figure 2). Plots with higher rates of K, especially injected liquid K, showed few to no K deficiency symptoms. Higher rates of K had a small effect on plant height in the Wharton location but little to no effect at the Williamson location. Near the end of the season, weather conditions were conducive for some foliar disease, and disease symptoms were observed on the K deficient plants. Overall, there was a very positive response to the injected K application, on plant health and corresponding yield in the Williamson county location. The Wharton county location, with 150 ppm K, did not show foliar deficiency symptoms, but a positive yield response did occur to the injected applications. Treatments with a high rate of liquid K had higher yields compared to a similar rate of dry K at both locations (Figure 3). This is likely attributed to placement of K in the active root zone, while the dry K was less plant available due to dry soil surface conditions.

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The highest rates of injected K had a slight positive effect on lint loan price at the Wharton location, while the dry K had no significant effect. At the Williamson location, there were mixed effects on loan price due to high micronaire levels in the higher injected K treatments. When the K rate and price factors are used to calculate the net return on investment, fewer significant differences were observed for both sites (Figure 4). Despite the highest injected rates being considered unrealistic for most farmers, a significant return on investment was obtained from these rates. As with yield, the liquid treatments had a higher return on investment than the dry treatments of a similar rate.

In conclusion, applications of injected K had a positive effect on yield in soils with 150 ppm of soil K or less. Treatments with injected liquid K showed a higher K use efficiency and greater return on investment, on average, for the injected treatments versus the dry treatments. As a result of these trials, four additional trials were initiated in 2014 and the current soil test critical threshold level of 125 ppm K for Texas will likely be increased for injected applications.

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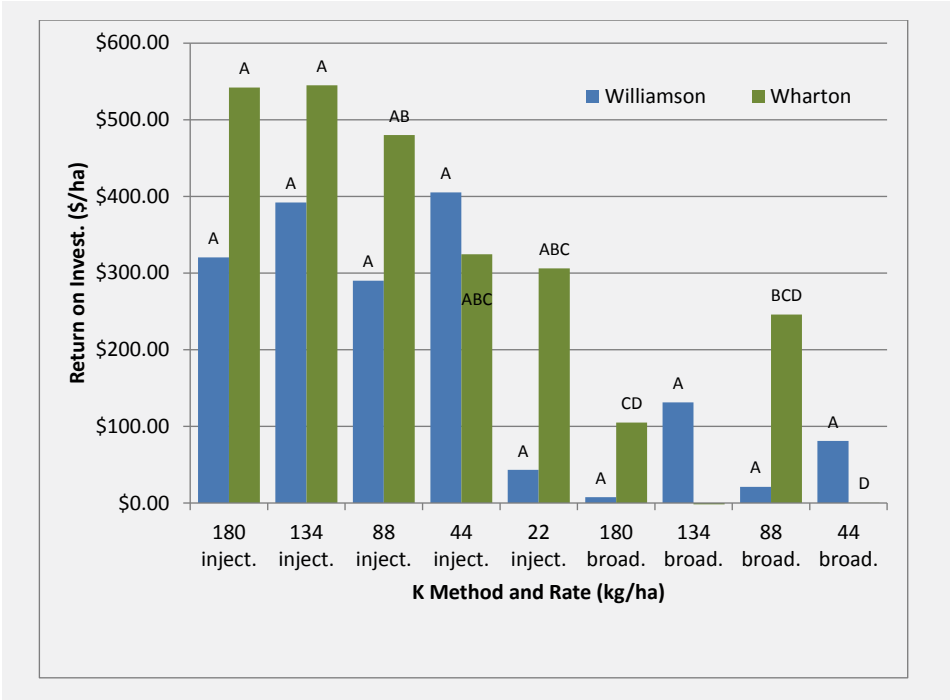


FIGURE 4. Return on investment as impacted by potassium application rate and application methods (injected and broadcast incorporated) on clay soil in Texas, U.S.A.

DEVELOPING AN INDUSTRY-WIDE STANDARD FOR LEAF HAIRINESS

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Summary

Several factors were previously believed to negatively influence the leaf grade values, including defoliation and desiccation levels. However, recent research in 2013 identified leaf hairiness as being a primary culprit in higher leaf grade values. Additionally, during these trials, discrepancies in seed company ratings for leaf hairiness and quantified trichome densities were observed. Due to these findings, widespread support exist to obtain an objective and robust method for quantifying an industry-wide standard for leaf hairiness. Leaf hairiness data were collected from existing variety trials and is being used in developing an industry-wide leaf hairiness standard.

Introduction

Cotton leaf hairiness, also known as trichome density, is highly variable between cotton varieties and can range from 0 to over 550 hairs/cm² (Bourland, et al. 2003). Previous research by Norman et al. (1994) with whiteflies and Mekala (2004) with fleahoppers has shown important impact of leaf hairiness on insect management and thus variety selection. For example, cotton varieties with a high density of leaf hairs have resulted in increased insecticide applications for white flies in the Rio Grande Valley and leaf hairiness should be a major variety selection criteria for these producers (Norman, 1994). Eder et al. (2012) and Boykin et al. (2012) demonstrated the detrimental impact of leaf hairiness on cotton leaf grade both in small plot research and commercially grown and ginned cotton.

Research at multiple locations in Arkansas and Texas identified the environmental conditions impact the leaf hair density, but has a minimal impact on the leaf hairiness ranking among varieties (Bourland et al., 2003, Norman and Sparks, 1997, Boykin, et al., 2013, and Eder, et al., 2012). Consistency of variety ranking across locations and years for leaf hairiness provides an excellent opportunity to develop an industry-wide leaf hairiness rating system that is much more objective and descriptive than the current leaf rating system.

The objectives of this project are to develop an industry-wide leaf hairiness rating system that is more objective and descriptive than the current leaf hairiness rating system and to cooperate with the

seed companies and public breeders to adopt the industry-wide leaf hairiness rating system.

Methods

In 2013, the concept of developing an industry-wide leaf hairiness rating system was proposed and discussed with the agronomists, entomologists, breeders, and ginners from universities, Cotton Incorporated, and Cotton Foundation. All provided very positive support of the industry-wide rating system, with the assumption that a robust and objective methodology can be developed. Additionally, we met with Bayer, Monsanto, and PhytoGen to seek their input on the concept of developing an industry-wide standard for leaf hairiness and obtain their input on the most appropriate procedures to obtain a robust and objective rating system. We have received favorable feedback from each of these companies, assuming the industry-wide standard will be uniformly adopted.

From existing small plot variety trials in 2013 in Palacios, TX, Lubbock, TX, Keiser, AR, and Tifton, GA, leaf trichome densities were quantified across major cotton production regions. ST 5288B2RF was planted at all locations to serve as a hairy check. A pilose genotype was included at Keiser and Palacios to serve as a second hairy check. Trichome densities were quantified using the methods described by Bourland et al. 2003. Eight varieties were in-common across all locations.

Results

DEVELOPING AN INDUSTRY-WIDE STANDARD
FOR LEAF HAIRINESS

These trials did identify a genotype by environment interaction (Figure 1). Normalizing each variety for each location with the ST 5288BRF trichome density and ranking the varieties still did not allow the locations to be combined (Figure 2). Some varieties, such as PHY 339 WRF had very stable trichome densities across locations. However, PHY 499 WRF was highly variable across locations. Discrepancies were observed between company leaf hairiness ratings and the objective trichome density ratings for some varieties. Similar trials are being continued in 2014 with additional hairy check varieties being included and additional locations. With the 2014 results, we are hopeful a fair and robust leaf hairiness rating system can be developed and adopted in the U.S.A.

Acknowledgements

The co-authors would like to extend our appreciation to Cotton Incorporated and the Cotton Foundation for financial support of this project.

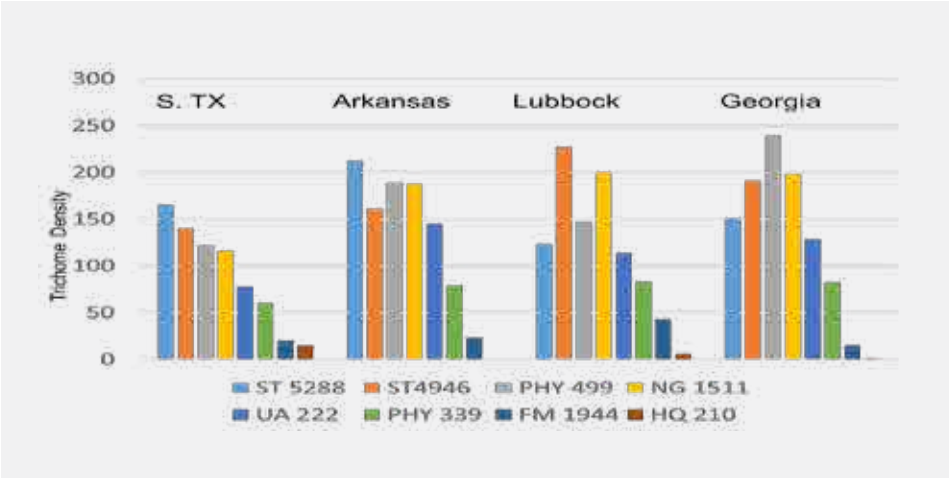


FIGURE 1. Leaf trichome density (trichomes/cm²) for 4 locations across the Cotton Belt and 8 varieties in-common across all locations.

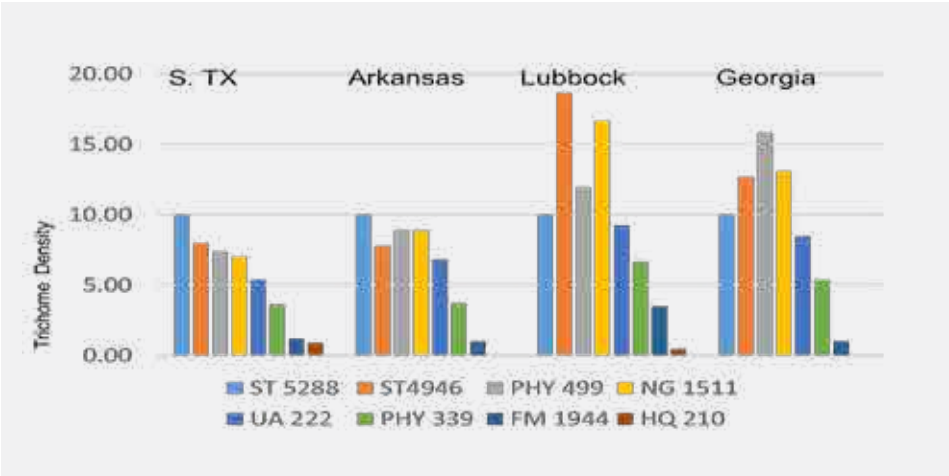


FIGURE 2. Leaf trichome density (trichomes/cm²) normalized to a standard “hairy” variety (ST 5288B2RF) for 4 locations across the Cotton Belt and 8 varieties in-common across all locations.

TRANSITIONING TO ROW CROP IN SOUTHERN NSW

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Summary

Careful management is needed if row crops are to be established after rice crops. It will take about 18 months for the soil to be suitable for row crops after the conversion of rice layouts to a row crop layout. Growing a row crop in the season after a rice crop can result in poor crop growth because of several factors – especially due to rice stubble disorder.

Introduction

There has been considerable interest in the conversion of irrigation layouts to the new bankless beds in bay layouts. This has been driven by the ease of water management and the labour savings with the new layout compared to traditional siphon layouts.

Layouts have evolved over the past 15 years and there are now a few variations appearing to suit individual paddocks and the flow capacity of individual farms.

These new layouts have a big advantage in allowing better water management during crop establishment in soils that have lower subbing capacity. The layouts also allow greater flexibility in crop choice.

Careful management needs to occur if coming out of a rice based rotation. Research during the 1970s and 80s highlighted a problem known as Rice Stubble Disorder. Muirhead (1981) indicated that phosphorus was tied up as iron came into solution when rice fields were flooded. Banklines with better growth were clearly seen in crops such as maize after rice, where most of the iron in the soil was in a crystalline form which allowed phosphorus to remain available to the plant.

A number of cotton crops in southern NSW during the 2013/14 season have had poor growth when rice was grown as the previous crop. Leaf and soil tests have confirmed low phosphorus levels in both the soil and cotton plants. Assessments of pH undertaken in the top 10 cm soil were in the range of 4.4 to 4.7 CaCl₂, and hence were not ideal for row crops. Compaction was also evident in some of these fields

which is likely to restrict root growth in row crops, consequently these fields will need deep ripping to open up compaction layers.

To grow rice, fields are selected due to the heavy impermeable nature of their soil types and in many cases have lower pH values. This is in contrast to row crops such as cotton and maize that require good drainage and have pH requirements in the range of 5.5 to 7 CaCl₂.

Other factors may also limit the growth of row crops in this situation. The alleopathic , effect of previous crop residues on the growing crop could be part of the cause and warrants further investigation. Also crops such as cotton have a high dependency on vesicular arbuscular mycorrhizal (VAM) fungi for good growth and initially coming out of the rice system VAM levels could be lower. At low levels of available phosphorus this dependence on VAM to access phosphorus is increased in cotton (Dowling 2010).. At a soil phosphorus level of 8 mg/kg, cotton depends upon VAM to meet 89 percent of its phosphorus requirements whereas when 18 mg/kg soil phosphorus, the dependency is 54 percent. Ongoing research is required to measure phosphorus, zinc and VAM levels in paddocks that are transitioning into row crops.

Conclusion

If row crops are to be successfully grown after a rice-based rotation careful management is needed. It will take about 18 months for the conversion of rice layouts to row crop layouts to be successful. The profile will need to be dried out and aerated



after rice. It is common practice to grow a cereal crop immediately after rice, and not water it fully in spring so the soil profile dries down.

After the cereal crop is harvested, landforming should be undertaken over the summer months. Soil tests will indicate if pH needs to be adjusted using the appropriate rate of lime. Common practice in past conversions is to apply high rates of poultry manure and in some cases up to double rates of phosphorus fertiliser to overcome short term Phosphorus tie up.

This timeframe allows residues to breakdown and soil biology to come back into balance.

Growers considering the conversion of fields to row cropping out of previous rice rotations should consult with a cotton crop advisor. The conversion will need to be a staged and well-managed process to get a good result with the first row crop.

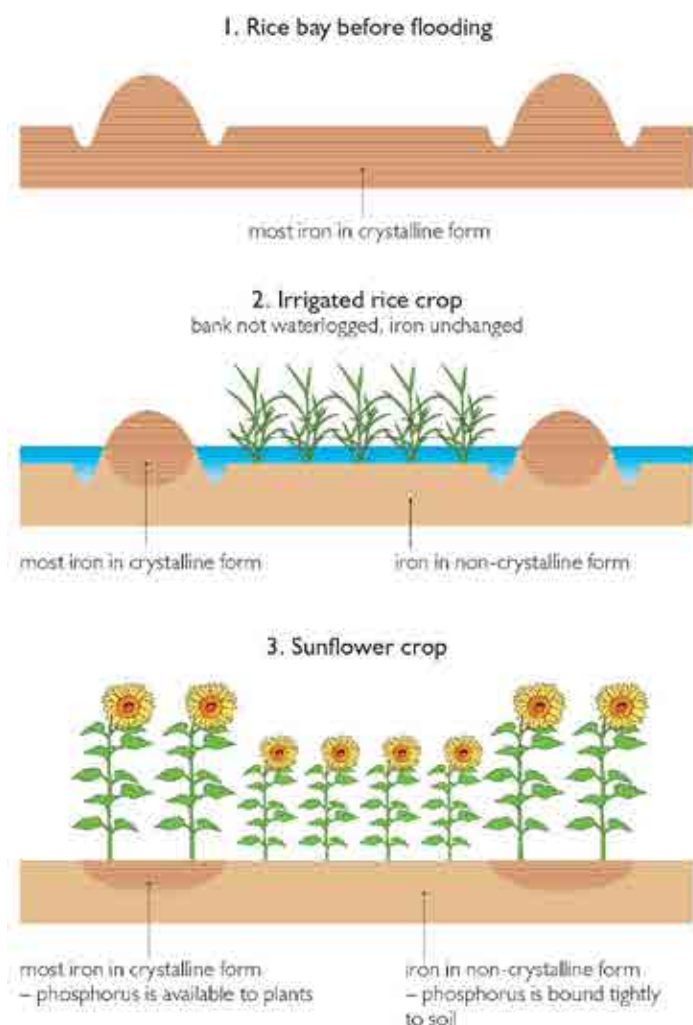
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GROWING HIGH-YIELDING NITROGEN-EFFICIENT COTTON

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17th **australian**
COTTON conference
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Summary

High-yielding cotton can be grown without causing environmental damage. Most growers aim to do this but believe high levels of inputs are required, but this is not necessarily the case. High (excessive) inputs of resources (water, fertiliser, energy) reduce profitability where these resources are not optimised. Excess N fertiliser results in increased green house gas (GHG) emissions, especially nitrous oxide, which damages the cotton industry's environmentally responsible image. Excess fertiliser and water applications promote excess crop growth and reduce yield and profits. In many cases, growers can produce higher-yielding crops and increase profits by optimising fertiliser and water applications.

Introduction

To use N fertilisers efficiently requires the grower to optimise N fertiliser inputs with respect to soil fertility, crop response to applied N and the economics of diminishing returns from increased inputs. Where N fertiliser is used in excess, emissions of the green-house gas nitrous oxide (N_2O) become significant and this contributes negatively to the carbon balance of the cotton enterprise. Where optimal amounts of N fertiliser are applied, N_2O emissions remain at the background level. Growers are able to determine the economic optimal N rate by combining soil analysis, in-crop leaf analyses and post harvest seed analyses to assess the crop's N fertiliser requirement. Several means of assessing N fertiliser use-efficiency in cotton have been developed and have been calibrated with experiments that determine the economic optimum N fertiliser rate. Several recent surveys of the cotton industry's use of N fertiliser have shown that many growers use excessive amounts of N fertiliser in relation to the lint yields afforded.

Methods

Experiments conducted at ACRI Narrabri determine the optimum N fertiliser rate and optimum time of N fertiliser application by assessing cotton response to N fertiliser application at several rates between 0 and 320 kg N/ha. The economic optimum N rate is where \$1 spent on N fertiliser returns \$1 in lint.

Results

Figure 1 shows the response to N fertiliser in 2013-14. The economic optimum N rates were 220, 135 and 153 kg N/ha for cotton following fallow, vetch or faba bean crops; cotton yielded 14.0, 12.3 and 12.8 bales/ha respectively at the optimum N rates. Soil testing (0-30 cm) for nitrate-N indicated relatively low N fertility, possibly due to the dry soil during much of the fallow prior to sampling the soil. The NutriLOGIC program predicted the cotton crops N fertiliser requirement of 250, 200 and 140 kg N/ha following fallow, vetch and faba bean crops. The predictions were on average about 15% higher than was required, due to the dry spring. Also, the flatness of the two curves describing the N fertiliser response in the cotton-legume systems (Figure 1) limits the accuracy of predicting the optimum N fertiliser rate.

These relatively high yields (12-14 b/ha) have been achieved consistently over the past three years with N fertiliser applications of less than 250 kg N/ha and with conservative water management; the 2013/4 experiment received six in-crop irrigations when soil water deficit approached 50 mm, in one of the driest seasons in memory.

Several means of measuring N use-efficiency have been devised, and require measuring crop yield, crop N uptake, or seed N concentration. However, to provide some practical information to the grower, they all need to be related to the economic optimum N fertiliser rate. It is not practical to measure crop N uptake for commercial crops, but determining seed N concentration post-harvest can give growers a sense of under or over-use of N

fertiliser. By far, the most practical method for growers to use is to simply divide their lint yield (in kg/ha) by the N fertiliser applied (also kg/ha). Figure 2 shows that to achieve the economic optimum N fertiliser rate, the yield/N fertiliser index should be between 13 and 18. If the index is greater than 18, insufficient N has been applied; if less than 13, too much N has been applied.

In 2010, seed N% was assessed as a means of indicating N fertiliser use-efficiency in commercial fields in 3 valleys, and 449 modules were sampled (Rochester 2012). Only 10% had low seed N%, 45% had ideal seed N% and 45% had high seed N%, and indicated for this group more than 80 kg N/ha may have been applied in excess of what was required. In 2009, 79% of the 82 commercial cotton crops surveyed received an average of almost 50 kg N/ha in excess of the optimum N fertiliser required (Rochester 2011).

Surveys of grower practices by Roth in 2011/2 and 2012/3 indicated that the majority of growers have used excess amounts of N fertiliser to achieve relatively moderate yields. The survey of 2011/2 (189 respondents) reported average lint yields of 9.45 b/ha and 218 kg N/ha applied. The yield/N fertiliser index for this data set was 10.9, indicating an excess of 75 kg N/ha was applied on average (Figure 2). The 2012/3 data (Roth 2014) indicate growers used 243 kg N/ha on average and produced 10.2 b/ha, indicating the yield/N fertiliser index for this data set was 9.53, indicating an excess of 110 kg N/ha was applied on average (Figure 2). Applying more N than is required to satisfy the crop's demand will not increase yield. Rather, growers need to assess their cropping system's N use-efficiency and determine if other factors are limiting their cotton production.

The timing of N fertiliser application seemed to have little bearing on crop yield in 2014 at ACRI. Urea was applied at 200 kg N/ha N, being drilled at 30 cm depth in July, September or December. There was no advantage in applying N at any particular time, the three treatments

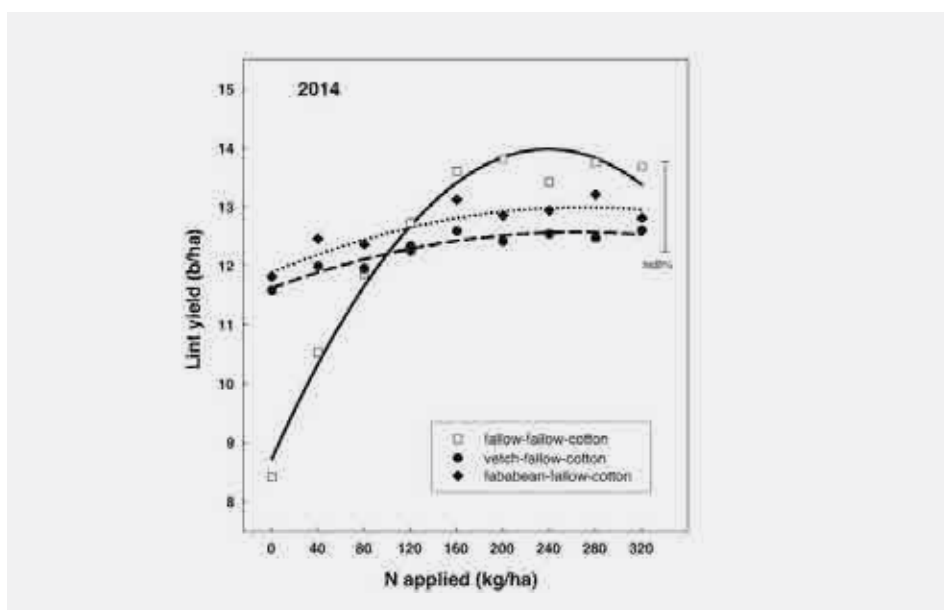


FIGURE 1. Lint yield as influenced by N fertiliser response experiments at ACRI Narrabri. The economic optimum N fertiliser rates were 220, 135 and 153 kg N/ha for cotton in the fallow, vetch and faba bean rotations.

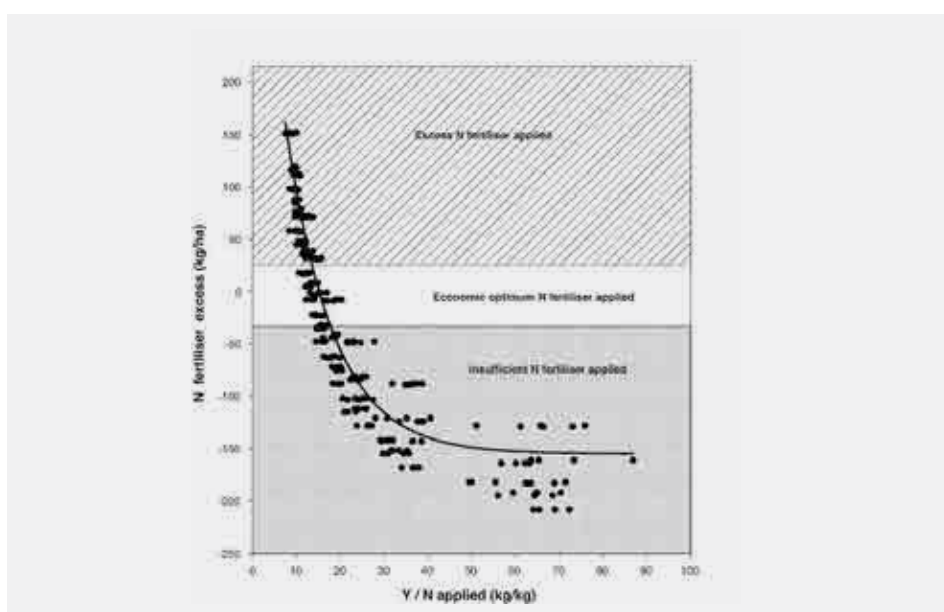


FIGURE 2. The relationship between excess N fertiliser application (relative to the economic optimum N fertiliser rate) and an index of N fertiliser use-efficiency (Lint Yield / N applied).

yielded 12.6, 12.5 and 12.1 b/ha respectively. In the December treatment, more N taken up by the crop but this provided no extra yield; it did not suffer N deficiency prior to December. Most commonly, in-crop N fertiliser is applied in irrigation water or broadcast prior to rain or irrigation - losses of N from these applications may be higher as soil and air temperatures are higher at that time of year. Where the GHG nitrous oxide (N_2O) is produced near the soil surface, there is

less opportunity for it to be reduced to less harmful nitrogen gas (N_2).

Conclusion

Experiments have confirmed that high cotton yields can be grown without excessive inputs of N fertiliser or irrigation water. Grower surveys have revealed that N fertiliser application is generally not optimised for most cotton crops. Nitrogen fertiliser can be used much more efficiently within the cotton industry

with important economic benefits and avoiding environmental damage from GHG emissions.

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NITROGEN FERTILISER USE EFFICIENCY ACROSS THE REGIONS

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17th **australian COTTON** conference
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Question/Issue being addresses?

In the Australian cotton industry nutrition is a significant cost with 75% of irrigated cotton respondents to the 2012-13 grower practice survey spending between \$300 and \$600 per hectare on nutritional inputs for their 2012-13 cotton crop (Anon, 2013). Within nutrition expenditure nitrogen (N) is the most significant input however, nitrogenous fertiliser use has increased to the point where significantly more is being applied in commercial crops than is recommended as part of industry best practice. This additional N is a significant additional cost to growers that can equate to many thousands of dollars spent that does not always result in lint yield increases. The Regional Development Officers (RDO) initiated N trials as a means of gaining an understanding of how N fertiliser management influences Nitrogen Fertiliser Use Efficiency (NFUE) as a simple tool to review crop performance.

Key results and findings

Combined data from RDO N field trials and Cotton Seed Distributor (CSD) crop management field trials highlighted a weak ($R^2 = 0.15$) although significant ($P < 0.05$) correlation between fertiliser N applied and lint yield (Figure 1). Highlighting that while fertiliser N does influence lint yield there are other factors that influence the utilisation of N in the production of lint.

Nitrogen Fertiliser Use Efficiency (NFUE) is an industry-developed measure that can provide an indication of the efficiency of N use in the production of lint by dividing lint yield (kg/ha) by N fertiliser applied (kg/ha). Rochester (2013) determined the optimum NFUE to be in the range of 13 - 18 kg lint/ha per kg of N applied/ha with efficiencies outside this range indicating that N

application has not been appropriate for the amount of lint produced. Lint production may have been limited by other factors other than applied N.

The combined data showed that only 24% of 147 irrigated sites achieved the optimum NFUE and 74% of sites were below the optimum NFUE, meaning that a reduced amount of lint was produced for the amount of N applied. The 2% of sites above the optimum NFUE are less of an issue. The use of organic amendments to supplement N supply from fertiliser is a scenario that would produce a higher than optimum result within the current parameters, unless that organic N was accounted for with the N fertiliser.

There was some separation in NFUE between fallow-cotton and back-to-back cotton. When cotton was planted

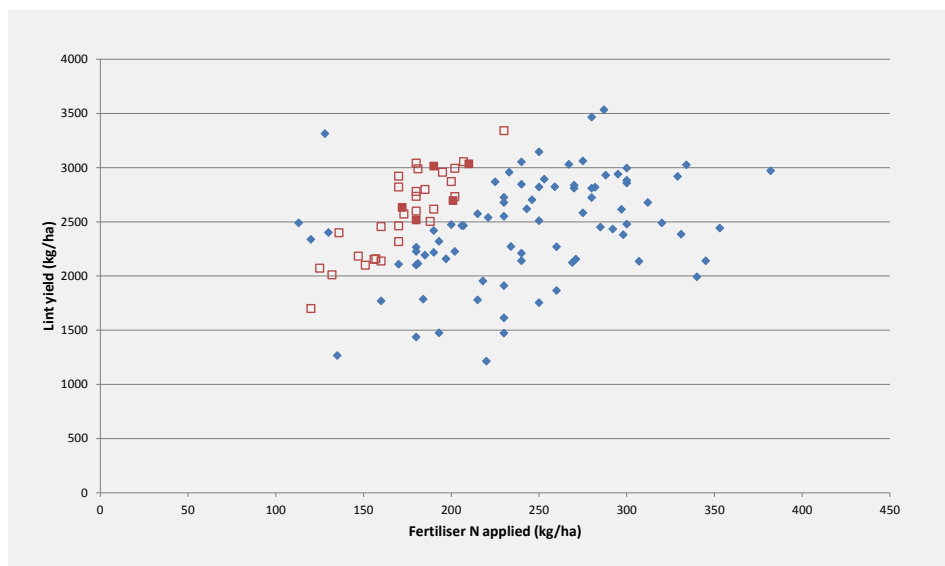


FIGURE 1. Correlation between fertiliser N applied and lint yield with crops in the NFUE optimum range highlighted in the red squares (CSD trial data). Open red squares represent crops in the optimum NFUE range planted following a fallow period.

following a fallow period 47% of those crops achieved the optimum NFUE however, only 20% of sites planted as back-to-back cotton achieved the optimum. Of all sites in the NFUE optimum range, 78% were planted following fallow period.

Within the data set, sites in the optimum NFUE range have very similar lint yield to crops outside the optimum (Figure 1).

When the correlation between fertiliser N applied and lint yield was restricted to those crops where NFUE was optimised there is a strong ($R^2 = 0.805$) and significant relationship ($P < 0.05$) between the two factors, which indicates the inherent fertility of the various sites and differing management practices among them.

What impact will this have on the Australian cotton industry?

The result of the trials clearly shows that within the majority of cases the amount of lint produced from the amount of N applied is outside the optimum, highlighting that there is opportunity for increased production with current levels of fertiliser input if the influencing factors are better understood. In addition the results also showed that there are farming systems that enable NFUE to be optimised without sacrificing lint yield.

There is a strong relationship between fertiliser N applied and lint yield when the NFUE is optimised. The variability in the complete data set highlights that there are management and/or environment factors impacting on the production of lint relative to the application of N fertiliser and thereby impacting on profitability. The predominance of crops with optimal NFUE following fallow indicates that there is something in that rotation that improves the ability to match N fertiliser requirements to plant requirements.

When NFUE is below optimum (ie consistent with the majority of sites), it is the consequence of either:

1) lint yield being restricted relative to the amount of N applied or

2) an excess of N applied relative to the lint yield achieved.

Reduced lint yield can be the result of a wide range of management and environmental factors with Maas (2013) considering successful management of cotton to be making informed decisions around diseases and disorders, irrigation, nutrition, pests and beneficials and weeds. CSD (no date) considers 13 practices, from planting and establishment through to picking, to maximise lint yield with limitations in any one of those factors restricting lint yield relative to the amount N applied.

Given the responsiveness of cotton to N, inefficient management of N can influence both sides of the equation to produce a below optimum result where excessive losses of N may reduce lint yield with consequential increases in N application carried out to try and account for any perceived losses. Within the complex N cycle, denitrification, immobilisation, volatilisation and leaching are N loss pathways that potentially impact on the amount of applied N available for crop growth and lint production. Denitrification is the dominant process contributing to loss of fertiliser N with losses commonly exceeding 50% of applied N (Freney et al, 1993 cited in Rochester and Constable, 2000).

Denitrification occurs under anaerobic, usually waterlogged conditions, where soil organisms utilise oxygen from nitrate (NO_3^-) for their metabolism and is a permanent loss of the N. The process is favoured under high soluble organic carbon, high soil water, low aeration, pH above 4.5 (water) and increases with increasing soil temperatures (Anon, 2006). Areas of compaction within soils can promote denitrification because of poor structure that restrict aeration (Rochester and Constable, 2000) exacerbated under wet soil conditions (Rochester et al, 1991).

Denitrification of applied N could occur in: waterlogged conditions experienced at any point following N application most commonly associated with irrigation especially if the irrigation followed by a

rainfall event, also related to irrigation layouts and how well paddocks drain following irrigation; compacted soil areas such as wheel tracks associated with ground operations during the production cycle, these are also exacerbated by wetter than ideal conditions when operations are being carried out.

Immobilisation of mineral N is not a permanent loss of N rather a temporary change of form resulting from the addition soluble carbon in the form of stubble. Rochester et al (1992) demonstrated immobilisation with the addition of cotton stubble and Rochester et al (1991) showed greater immobilisation of mineral N associated with low temperature and reported on work by others showing increased immobilisation in situations of high soil water content. Net immobilisation of mineral N will normally only be for a periods of days to weeks (Herridge, 2011).

Immobilisation of applied N is possible if the N is applied within the layer of freshly incorporated stubble where soil micro-organisms will utilise it as a readily available source of N to restore the C:N ratio they require. The potential impact of immobilisation relates to timing of soil tests in relation to stubble incorporation and possible underestimation of available N in the soil and subsequent over application of N fertiliser for target yields.

Volatilisation is loss of N to the atmosphere, usually ammonia gas (Anon, 2006) and is a permanent loss of the N. Loss of applied N in this way is associated with the surface application of N fertiliser (particularly urea). Significant quantities may be lost when urea or urea-containing solutions are surface-applied, without incorporation, to moist soil that is drying out or when heavy dews or light falls of rains are received providing sufficient moisture to dissolve the fertiliser but not enough to carry it into the soil (Anon, 2006). Volatilisation losses can be increased with stubble cover.

Leaching of nitrate-N is of less importance with most movement occurring in the top 30cm of the soil (Rochester et al, 1991)

maintaining it within the active root zone of cotton. Although significant leaching is possible if irrigation is used to incorporate surface applied N especially where large cracks are apparent in surface soil.

Conclusions

It is possible to achieve high yielding crops with optimum NFUE however, this is not common within the industry. This suggests that within the farming systems there are factors that are limiting lint yield relative to N fertiliser inputs. The data indicates differences in fallow and back-to-back cotton that enables better use of N fertiliser within a range of lint yields in fallow cotton. These differences are related to soil health issues and the ability of the cotton crop to use the native soil N and applied N fertiliser better. However, these differences also raise many questions as to why and where these differences occur and provide the industry with opportunity to improve production and profitability relative to current levels of N fertiliser use.

NFUE offers growers the opportunity to consider the performance of their system in terms of the amount of lint produced from the amount of N applied enabling assessment of aspects of their system that are impacting on NFUE with potential for increased production and profitability from current input levels.

Continuing the discussion of how management and environmental factors influence NFUE will be a continuing and major focus for the RDO's.

Acknowledgements

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REVIEW OF CPLM INSTALLATIONS IN THE AUSTRALIAN COTTON INDUSTRY

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Introduction

In 2001 a comprehensive review of centre pivot and lateral move (CPLM) irrigation systems in the Australian cotton industry was undertaken by Foley & Raine (2001). Interviews of 31 growers provided a detailed look at the design, management and performance of these systems. Although there is no definitive information on the total number of irrigators using CPLM in the cotton industry, it is apparent that since this study, the number of CPLM systems used within the cotton industry has significantly increased. With the accelerated adoption under infrastructure funding programs has come more questions surrounding design, operation and management.

Wigginton et al (2011), with funding from the Healthy HeadWaters Water Use Efficiency project in Qld, repeated the Foley & Raine (2001) CPLM survey across irrigators in the Queensland Murray-Darling Basin to assess changes and progress over the previous 10 years. In order to examine the changes across the whole of the Australian cotton industry, the Cotton Research and Development Corporation funded NSW DPI in 2011-12 to capture the same data for NSW cotton irrigation regions. The two data sources have been combined to provide an Australian data set to examine changes in design, operation and management of CPLM systems since the 2001 review. A full report of the findings will be published later this year.

Survey design and methodology

The surveys were designed to obtain a representative sample of cotton irrigators using CPLM systems across NSW and Southern QLD cotton regions. The survey participants were selected by the project team. The format of the two later surveys was based on that used by Foley & Raine (2001), with questions grouped under various topic headings including:

- the CPLM dimensions and configuration
- pump and water supply
- operation management and problems
- sprinkler packages
- tyres and wheels
- farming system
- crop water requirements
- application strategies
- system performance and productivity
- runoff management
- agronomic considerations
- maintenance, and
- purchase decision making.

The survey was a face-to-face interview, which took approximately two hours to complete. They were conducted on-farm with either the farm owner or irrigation manager. Fifty-eight cotton and grains irrigators were interviewed across the cotton growing regions from Southern Qld to Southern NSW. In total the survey captured information on 184 CPLM systems irrigating an area of 13,969 ha. Approximately 42 per cent of the area was irrigated by centre pivots and 58 per cent by lateral moves.

Summary of findings

The 2011-12 CPLM review provides an overview of the performance and management of these systems in the Australia cotton industry. When compared with the 2001 study, changes in design, operation and management are evident. A summary of the changes are listed below.

The 2011-12 survey data found that the proportion of centre pivot systems and lateral move systems installed on farms has shifted since the 2001 review. In 2011-12, 66 per cent of the systems were centre pivots compared to 76 per cent in 2001. Lateral moves now make up a larger proportion of machines, 34 per cent compared to 24 per cent in 2001. As lateral moves generally cover a larger area, the total area of lateral move irrigation is now 58 per cent compared with 45 per cent in 2001.

Yield and water use data collected from the survey participants suggests that CPLM systems typically produce similar yields to furrow irrigation systems whilst average water use was around 30 per cent lower for CPLM systems (see table below). The Irrigation Water Use Index (IWUI = total production in bales / Irrigation water applied in ML) has increased for both CPLM and furrow systems since 2001. The difference in IWUI between CPLM and furrow irrigation systems has narrowed. This suggests there has been considerable improvement in the management of both irrigation systems since 2001, but with greatest improvement observed in furrow systems.

Labour savings and water savings remain the top two motivations for purchasing CPLM systems. However, their order has reversed with labour saving now replacing water saving as the main driver since 2001. The proportion of survey participants that placed automation as an adoption driver for CPLM systems has declined substantially, from 58 per cent in 2001 to 24 per cent in 2011-12.

Survey participants reported a reduced labour requirement per hectare for CPLM compared to surface irrigation. For centre pivot operators, 47 per cent reported

	Furrow			CPLM		
	Average Yield (b/ha)	Average Water Applied (ML/ha)	Average IWUI (bales/ML)	Average Yield (b/ha)	Average Water Applied (ML/ha)	Average IWUI (bales/ML)
2011-12	10.4 (7.0-13.0)	6.2 (1.8-10.5)	2.0 (0.9-5.5)	10.0 (7.0-13.6)	4.2 (0.6-10.0)	2.6 (1.0-8.1)
2001			1.1 (0.6-1.6)			1.9 (1.4-2.6)

TABLE 1. Yield and water use data for furrow and CPLM systems collected from surveys

that their labour was less than ¼ of that required for furrow whilst 56 per cent of lateral move irrigators reported that their labour requirement was ¼ to ½ of that for furrow. There was little change in these labour requirements between 2001 and 2011-12 survey participants. Fifty nine per cent of the 2011-12 participants considered that a higher level of skill was required to operate CPLM compared to furrow irrigation.

Improvement in Design System Capacity is evident with 59 per cent having a capacity greater than 110 per cent of peak crop water requirement, which is a significant advance over 26 per cent in 2001. This indicates that irrigators are showing an increasing understanding of the importance of adequate system capacity for meeting crop water needs. However, in contrast to this, 55 per cent of respondents have a Managed System Capacity that cannot meet peak water demand compared to 46 per cent in 2001. Managed System Capacity is a better indicator of a system's ability to meet peak crop water demand because it allows for machine downtime and application losses. A reduction in the proportion of systems with adequate Managed System Capacity is concerning and may indicate that purchasers are underestimating the impact of their actual field operations on system performance. (Foley & Raine 2001 p.11-12)

The operating pressure at the pump is the major factor affecting energy consumption, and with the increasing cost of energy, running systems at the minimum pressure required to perform properly helps minimise operating costs.

Progress is evident in that there were no systems operating above 345 kPa (50 psi) in the 2011-12 study compared to 13 per cent in 2001. However, most systems are fitted with pressure regulators rated at 100 kPa (15 psi) or less and it is commonly recommended that the supply point pressure be no more than 100 kPa greater than the pressure regulators. This means the supply point pressure generally should be no more than about 200 kPa. However 52 per cent of systems are operating above 200 kPa so these operators may be incurring higher running costs than necessary to run their CPLM efficiently. While this was an improvement compared with 2001 when 59 per cent of systems were operating above 200 kPa, there is room for further improvement.

The potential for cost saving may be even more when the difference between operating pressure at the supply point and the rated pressure of the regulators are compared. Only a small percentage of irrigators (21 per cent) are operating their systems at the conventionally optimal pressure difference of 100 kPa (15 psi), so up to 79 per cent of irrigators have the potential to save energy costs by decreasing their supply point pressure.

A significant shift in emitter selection has occurred over the last 10 years, with moving plate sprinklers becoming the dominant emitter type. In particular, the proportion of LEPA systems reduced from 48 to 19 per cent and the proportion of moving plate sprinklers increased significantly from 4 to 54 per cent.

Eighty per cent of CPLM systems in 2011-12 used diesel powered machines compared to 65 per cent in 2001. Of the

remainder, those who used mains power were all centre pivot operators. Ninety per cent of the machines surveyed were electric drives and 10 per cent were hydraulic drive. The use of automatic control is now 40 per cent compared to 10 per cent in 2001. Most of the current automations have the ability to completely control the system by either mobile phone or the office computer.

Wheel rutting and bogging issues were experienced by 64 per cent of survey participants at some stage, an improvement since 2001 (80 per cent). These problems were mostly overcome through a combination of 'boombacks' and half-throw sprinklers to keep water away from towers and emitter system changes.

Capacitance probes were the scheduling tool most commonly used by growers. Where irrigators in 2001 generally reported that they used one scheduling tool, in 2011-12 they tended to use a combination of tools including soil moisture, weather forecasting and visual inspection. The depth of water typically applied per irrigation has altered. Fifty two per cent of growers applied 15-30 mm compared to 33 per cent in 2001. There was also a decrease in the proportion of irrigators applying more than 45 mm, 13 percent in 2001 to 6 per cent in 2011-12. Similarly there was a decrease in the proportion of irrigators applying less than 15 mm per pass, 34 percent in 2001 to 23 per cent in 2011-12.

Almost three quarters of growers applied fertiliser through their CPLM system in 2011-12 compared to less than half in 2001. All of these applied nitrogen through their CPLM. One third of growers believed that fertigation decreased total seasonal fertiliser use.

Two-thirds of all the systems in the 2011-12 study cost between \$1500 and \$3500 per hectare, with only 5 per cent costing in excess of \$4500. As a general trend, system costs decrease as the area being irrigated is increased, particularly for lateral moves. The survey found that for centre pivots, the cost for irrigating the same area could vary by a multiple of up to six times.

Monitoring a CPLM system during irrigation by looking at indicators such as pressure and flow rate is important in evaluating a system's performance. Ninety three per cent of 2011-12 survey participants had flow meters or pressure gauges for system control, and 79 per cent used pressure points as an indicator of problems within the system. Flow meters have not been fitted to most systems with only 38 per cent of growers using them to assess changes in supply or a problem of delivery to the CPLM field.

Irrigation uniformity is another important measure to evaluate how evenly the water is applied to the crop. Only 25 per cent of growers had measured their uniformity, with a range of values from 50 per cent to 100 per cent (DU of 90 per cent is recommended for CPLM machines).

Conclusion

This 2011-12 review of CPLM irrigation systems in the Australian Cotton Industry gives a snapshot of current performance and management and provides an important comparison to the Foley & Raine (2001) review.

Two important issues are evident from the survey data that may require training and raised awareness – improved understanding of system capacity and the operating pressure of CPLM irrigation systems.

The review found an improvement in Designed System Capacity which indicates that irrigators are now much more aware of its critical importance in terms of meeting crop water needs. However, around half the survey participants would still be unable to meet a crop's water requirement as the Managed System Capacity was below 90 per cent of peak crop water demand. This is a significant finding of this survey, suggesting irrigators may benefit from improved information about Managed System Capacity and the need to take into account machine downtime to ensure CPLM irrigation systems can meet peak crop water requirements.

While most growers consider the higher running costs a disadvantage of CPLM systems, around half the survey participants in 2011-12 were operating their systems above 30 psi, potentially incurring higher running costs than necessary. This is only a small improvement over 2001.

Acknowledgements

The project acknowledges the cooperation and assistance provided by participating irrigators. Queensland cotton data has been supplied by the Healthy HeadWaters Water Use Efficiency (HHWUE) Benchmarking project delivered by Qld DNRm and funded by the Australian Government. CRDC provided funding to carry out the NSW CPLM review.

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Primary Industries



CARBON NEUTRAL COTTON FARMS

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Summary

The Australian Cotton Industry is developing a carbon (C) footprint calculator for cotton farms. The calculator determines C sequestration and emissions associated with agricultural production (irrigated and dryland crops and grazing enterprises), as well as the net primary productivity (NPP) and C sequestered by native vegetation. NPP is defined as the net flux of carbon from the atmosphere into green plants per unit time (Distributed Active Archive Center, 2014). A case study illustrating the C footprint of a cotton farm near Wee Waa has been developed and is reported here. The calculator will demonstrate how growers can be carbon neutral, or even better, generate carbon credits. In addition, carbon conscious consumers need reassurance that the system used to grow the product is environmentally sustainable (Maraseni et al. 2010).

Introduction

Agricultural production inevitably leads to carbon dioxide (CO₂) and other greenhouse gas (e.g. nitrous oxide, methane) emissions to the atmosphere (ABS, 2014). These emissions are generated by clearing and cultivating land, fertilizer applications, use of diesel and other fossil fuels to power machinery, transportation of the final product and livestock grazing. These production-related emissions can be managed to some extent, and while some C sequestration occurs within cropping areas (Department of Agriculture, 2014), a holistic view of the farm, incorporating native vegetation, is required to properly reflect a farm's overall C balance. As shown in this case study, taking a holistic approach, demonstrates that it is possible to achieve a C neutral, or even better, a C positive (i.e. through the creation of C credits) enterprise.

No matter which government is in power or the price of C on world markets, it is likely that there will be a C tax or emissions trading scheme in some form in the future, and agriculture will be affected, for example a tax on inputs such as fertiliser or energy inputs (Parliament of Australia, 2014). Hence, growers should be well-informed about the sources and sinks of C on their farms. In addition, C-neutral enterprises appeal to conscious consumers and may therefore provide a product differentiation point. While most growers will not get rich by generating C credits through the Carbon Farming Initiative (CFI), the majority can minimise their ecological footprint by running C neutral enterprises.

We have been working to develop C accounting calculators to help growers manage their farms so that they can become C neutral. These tools will allow growers to make decisions about their land management, to achieve C neutrality and avoid paying C pollution taxes. The additional ecosystem service benefits for cotton growers who manage for C neutrality are huge, and include erosion mitigation, biodiversity conservation, natural pest control and filtration of pollutants that might otherwise enter waterways (Smith 2010; Reid et al. 2003).

Methods

A case study farm was chosen near Wee Waa in the Namoi Valley in northern NSW (Map 1). Farm production on the Kahl family holding 'Redbank' consists of irrigated cropping and livestock grazing (merino sheep and beef cattle). Native vegetation on 'Redbank' varied from native pastures, to mature and regenerating river red gum forest (Table 1). The soil type across the majority of the cropping and riparian areas of the farm is dominated by a heavy grey-black vertosol, while the grazing components of the property are dominated by sodic, deeply gilgaied brigalow soils that aren't desirable for cropping.

A literature review determined net primary productivity (NPP) of vegetation types commonly encountered on 'Redbank' (Table 1). The age of the vegetation (e.g. young or old tree regeneration, mature or old growth trees), density of trees (e.g. scattered trees, woodland or forest) and management history (e.g. thinning,

grazing or burning) were taken into account when selecting relevant rates of NPP on ‘Redbank’. We assumed C sequestration was equal to half of the NPP (Dwyer et al. 2009; Gifford 2000; Horner et al 2010). Where direct measurements of NPP could not be found for some vegetation communities, but the age of the vegetation was known, C storage was divided by the age of the vegetation to give average NPP over time.

The average irrigated cropping enterprise at ‘Redbank’ works on a four year rotation consisting of cotton, wheat, mung beans, fallow, cotton, fallow, maize and fallow, before starting again with cotton. The grazing enterprise utilises all non-cropping land on a rotational basis and is stocked in accordance with seasonal dry matter production, where 1000 DSE is regarded by the owner as an average production baseline. Yield estimates and crop inputs were modelled on the NSW Department of Trade and Investment gross margin budgets (NSW DPI, 2012). Emissions of farming practices in irrigated cropping have been calculated using the Cotton Carbon Management Tool (Visser et al. 2014). The Australian Farm Institute’s FarmGas calculator provided data for the 1000 dry sheep equivalent (DSE) livestock component (AFI, 2014).

Results and Discussion

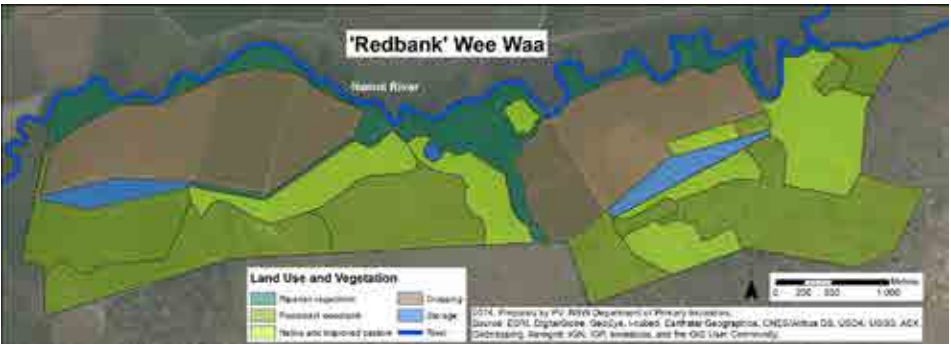
Figure 1 illustrates the environmental footprint of each component in the four year crop rotation and grazing enterprise at ‘Redbank.’ Cotton production, both irrigated and dryland, produced the highest C emissions of the components within the rotation. Corn and wheat produced approximately half the emissions of cotton, while mung beans, fallow and livestock grazing produced significantly lower emissions than cotton or wheat crops.

On a per hectare basis, cropping had the highest C emissions footprint with 2742 kg CO₂ (e) annually (Figure 2). Livestock grazing was the other source of emissions, with 280 kg CO₂ (e) annually. The three native vegetation categories represented

TABLE 1 Areas of native vegetation on ‘Redbank,’ their management and potential C-sequestration rate based on net primary productivity (NPP).

Vegetation type	Farm area (ha)	Management/land use/structure	C-seq. rate (t C ha ⁻¹ yr ⁻¹)	Total C seq. (t yr ⁻¹)	Total C seq. (t yr ⁻¹ CO ₂ (e))
River red gum riparian forest	153.5	Old-growth, mature and regenerating trees, some tree thinning	2.07 ¹	317.8	1165.0
Coolibah woodland	6.6	Old-growth, mature and regenerating trees	0.50 ²	3.3	12.1
Regenerating brigalow	114.5	Pockets of dense regeneration	0.65 ³	74.4	272.9
Mature and regenerating poplar box and brigalow	332	Multiple-stemmed poplar box with mature, open brigalow	0.60 ⁴	199.2	730.5
Tropical pasture	53	Bambatsi panic, Rhodes grass	0.40 ⁵	21.2	77.7
Native grasslands	179.5	Mix of perennial grasses	0.27 ⁶	48.5	177.7
Total Farm Veg	839.1			664.4	2436.2
Average ha ⁻¹				0.8	2.9

1. Robertson et al. 2001; 2. Burrows et al. 2002; 3. Chandler et al. 2007; 4. Moore et al. 2007; 5. Lodge and Johnson 2010; 6. Garnaut 2008.



MAP 1 Land Use and native vegetation categories represented on ‘Redbank’ Wee Waa.

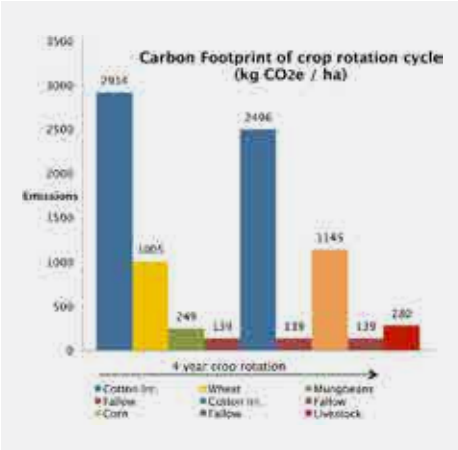


FIGURE 1 Greenhouse gas emissions from four year irrigated cropping rotation and livestock grazing native rangelands on ‘Redbank.’

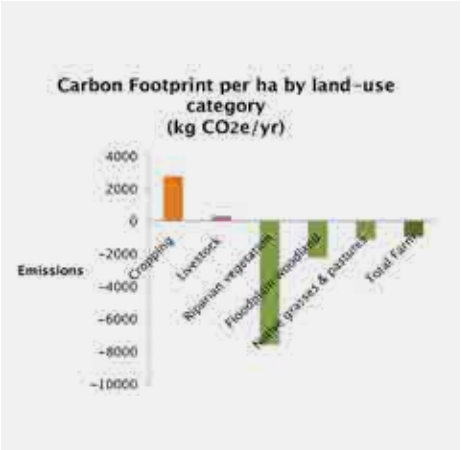


FIGURE 2 Annual greenhouse gas emissions by land use category (kg CO₂e/ha) on ‘Redbank.’

at 'Redbank' sequestered C, with riparian vegetation being the most valuable compared to floodplain woodlands and grasslands. Overall, when multiplied out according to the proportions of different land uses on 'Redbank,' the farm is C positive, i.e. it is sequestering more C annually (1185 kg CO₂e/ha) than it is emitting.

Carbon sequestration by native vegetation is variable, and depends on a variety of factors, both environmental and human induced, including: the species present and ecosystem structure (trees, shrubs, grasses, the proportions of each and competition for resources), management (e.g. grazing, burning, removal of logs), season (drought vs floods), site quality (fertility, soil type, moisture availability) and history (ringbarking or tree removal, or untouched). Riparian vegetation is the most productive on farm (Naiman et al. 2005), and therefore the most valuable for C sequestration. Woody vegetation is more valuable than grasslands in terms of C sequestration, as trees live longer and are less vulnerable to the impacts of drought, grazing and other management factors. Soils under woody vegetation are generally more C-rich due to large litter inputs and the high C:N ratio of woody litter, which decomposes slower than grass-derived litter (Swift 1979).

Younger trees have faster growth and C sequestration rates than old-growth or mature trees, and this is why revegetation and assisted regeneration are included as approved methodologies for carbon offset projects under the CFI. However, old-growth trees store more C, both in the trees themselves and in the underlying soil, than young trees. Due to the CFI regulatory 'additionality' test, the only approved activity relating to remnant woodland/forest vegetation is the protection of remnant vegetation that was previously approved for clearing (Australian Government, 2014). However, a recent paper showed the value of native vegetation (particularly river red gum woodlands) on cotton farms as a significant C sink, and put forward a case for recognition of this fact in future policy

developments (Smith and Reid 2013). In addition, many recent high impact papers have shown that old-growth remnant vegetation does sequester C, and should therefore be considered in C accounting tools (Luyssaert et al. 2008). Hence, we should not write off the value of remnant vegetation yet.

No gas flux data, e.g. respiration by plants and C released to the atmosphere during decomposition, were found for native vegetation communities relevant to this study, and data on C sequestration rates in soils under native vegetation was largely unavailable. However, this study is intended to be a conversation starter, and highlights the need for further research in this area.

Conclusion

Depending on relative land-use proportions, carbon emissions from cotton farms can be offset by native vegetation, potentially allowing cotton farmers to achieve carbon neutrality and in turn, provide an environmentally sustainable product to the global market.

Acknowledgements

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INFLUENCE OF CONTAMINATED COTTON ON YARN MANUFACTURING

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Abstract

Contamination is the major issue of concern to the ginning, and textile industry. In our study cottons with and without foreign matter were processed into yarn. The cotton was carded but the contamination was not fully firmed by the card as foreign matter often flattened in carding. The contamination tends to fibrillate and behave as coarse fibers. The contaminated cottons fiber always appears to interfere with the drafting process and the ring travelers during yarn formation resulting in increased end breaks, thus lowering the strength of contaminated yarns.

Introduction

The presence of foreign matter in ginned lint can cause cotton to be reduced its inherent characteristics and value while its grading and classification, also cause a determination in spinning quality. Contamination directly effects strength and fineness as well as on the processing quality of cotton. This study is to determine the influence of contaminated cotton on yarn manufacturing.

Experimental

The two bales of NIAB-78 upland variety of cottons were selected; one contaminated bale of medium staple 1-1/32 inch (2.62 cm) another bale of same staple variety. The selections were based on similar fiber properties and it's testing of Shirley Analyzer for non-lint content, Fibrograph length, Pressley strength, and Miconaire fineness measurements were made on two samples of ginned lint from each bale at fiber testing laboratory of the department. Shirley Analyzer non-lint content was determined on one sample of ginned lint from each bale.

Processing and testing

Both cottons were processed into yarn in the textile product lab at Mehran University of Engineering & Technology. These cottons processed by Rieter B3/4 Bale opener, B11 UNiclean, B3/3 Mixing opener, B60 UNiflex, C15 Card, D35 Draw frame, and EGM 168 Ring frame (China).

The preparatory processing specifications were 0.0330 g/cm sliver carded at 0.050 g/s, 0.0366 g/cm drawing sliver formed

at 130 cm/s, 0.0330 f/cm roving produced at 23.5 cm/s. The cotton was carded rolls loading used was 126,000 g. The cotton was spun into 0.000123 g/cm yarn with 6.27 turn/cm at 16.3 cm/s.

Statistical analysis for lint classification, fiber properties, and processing waste for contaminated cotton:

TABLE 1

Source	NIAB78 cotton	NIAB78 cotton
Grade	Grade 3	Grade 4 (contaminated)
Staple — inch	1-1/32	
(2.62 cm)	1-1/32	
(2.62 cm)		
Micronair-unit	4.3	4.7
2.5% span length, cm	2.62	2.62
1/8 in, gauge Pressley x10-7 dyne/cm ² strength	3.61	3.62
Shirley Analyzer non-lint Content, %	1.76	2.63

There is no difference in miconaire reading within the source of cotton. The number of end breaks per 96 spindles h during spinning was used to characterize processing performance. One yarn size and 5 strength measurements were made on each of 5 yarn packages made from for each test. And all yarn packages made from both cottons were tested by Uster4 for yarn evenness at 37.1 cm/s.

Testing including fiber quality evaluation, ring according to following established procedures has been made for:-

Individual spinning performance and yarn qualities for contaminated cotton:

TABLE 2

Source	NIAB78	NIAB78
Grade	Grade 3	Grade 4 (contaminated)
End down spindle, h	41.0	47.3
Strength x10 ⁻⁷ dyne/cm ²	2.00	1.98
Irregularity C.V., %	24.0	23.3

The both cottons were initially classed as normal preparations, one-grade up and one-grade reduction, but review classification the cotton containing trash were considered to be one-grade reduction. The one-grade reduction indicated that the cotton averaged 0.61% trash.

Comparison of contamination effects on spinning quality:

TABLE 3

Grade	Grade 3	Grade 4 (contaminated)
Ends Down spindle, h	34.5	45.7
Strength –x10 ⁻⁷ , dyne / cm ²	2.06	1.97
Irregularity C.V., %	23.6	23.5

The cotton that was reduced in grade because of trash exhibited a slight depression in the micronaire readings. This reduction in micronaire reading is thought to be because of the increased non-lint content of the cottons containing trash. The clean cotton was longer and stronger than the one-grade reduction. The cottons always reduced in grade because of contamination produced higher non-lint contents and processing waste than the clean cotton.



GRADE 3 cotton

Spinning performance and yarn properties

Spinning performance and yarn quality determinations are shown in Table 2. The number of ends down was higher for the cottons reduced in grade because of contamination. The strength of the yarn averaged lowest for the cottons reduced in grade. Comparisons of the grade effects are presented in Table 3. The cottons containing trash produced increased end breaks during spinning and were of lower strength than the clean cotton. The trash particles most likely interfere with twist insertion at the front roll during spinning. The trash particles are thought to upset the traveler during spinning therefore causing ends- down.

Conclusion & Result:

While comparison it revealed that the clean cotton was longer and stronger than the cotton reduced in grade because of contamination. The cotton contaminated with trash produced increased textile mill processing waste, and decreased yarn strength. The overall trend for the comparisons between cottons of normal preparation and those reduced in grade because of contamination was toward reduced spinning quality.

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GRADE 4 cotton

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DEVELOPMENT OF A PUMP EFFICIENCY MONITOR FOR USE IN COTTON IRRIGATION

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Summary

Energy costs have risen significantly over the past decade and cotton growers continue to look for ways to improve their on farm energy use efficiency. Pumping costs on irrigated cotton farms consistently account for 60 to 70% of total energy consumption on farm (Baillie and Chen 2008). The National Centre for Engineering in Agriculture (NCEA) has developed a Pump Efficiency Monitor (PEM) to assess energy consumption by the large mixed flow pumps found across the Australian Cotton industry. The ability of the Pump Efficiency Monitor (PEM) to continuously record pump station parameters provides data to assess combined motor and pump efficiency over an entire pumping event. This project highlights the importance to test each individual pumping set-up to identify the optimum operating point to achieve maximum efficiency. Significant cost savings are possible for individual growers and the industry collectively.

Background

Direct energy inputs such as diesel and electricity are major costs incurred on Australian irrigated cotton farms. Baillie and Chen (2008) conducted a series of energy audits on Australian cotton farms and found the energy used varied considerably from 3.7 to 15.2 GJ/ha, at a cost of \$80/ha to \$130/ha depending on the irrigation system used and the farming methods employed.

As energy costs continue to rise, so too does grower interest in assessing ways to improve their energy efficiency and reduce energy consumption. New techniques and equipment are required to assist irrigators in managing their energy consumption and therefore reduce operating costs and meet efficiency targets.

On Australian surface irrigated cotton farms, pumping water accounts for the largest proportion of energy use per farm (Baillie & Chen 2008), at 60 to 70% of total direct energy use. The individual efficiency of the diesel motor and mixed flow pumps typically employed by the industry, directly impacts on these results. A poorly performing pump may also affect the performance of the entire irrigation system, reducing irrigation efficiency and crop productivity. Jessen (2010) analysed the results of over 250 pump performance tests conducted in Queensland reporting the average measured pump efficiency was around 53% and highlighting need for improvement to an acceptable pump efficiency benchmark of 70%. Reynolds et al (2008) reported that optimising a mixed flow pump installation for surface irrigation

of cotton reduced energy costs to one third and provided significant irrigation management opportunities.

Conducting a pump test will verify how the pump is operating at a single point in time. The ability to record an entire pumping event will highlight trends and provide information on how to improve the efficiency of the irrigation process. The National Centre for Engineering in Agriculture (NCEA) has developed a Pump Efficiency Monitor (PEM) to conduct intensive energy audits on large diesel driven pumps in the Australian cotton industry.

Methodology

To perform an intensive energy audit across the diesel engine the fuel flow input and output are evaluated. Diesel consumption is recorded via two diesel fuel flow meters (MacNaught, MX Series) with a range of 15 to 500 L/hr that produce an electrical pulse output for every 2.5 mL of diesel measured were installed on the inflow and return fuel lines.

Another two types of instruments are also used to assess the energy consumption of the pump and motor combination. Two pressure transducers (WIKA, 0 to -100 kPa and 0 to 100 kPa, Model no. S-11) are installed at the inlet and outlet flanges of the pump to measure the pressure head component of the total dynamic head (TDH), and the elevation of their tapping points is recorded. To measure the flow of irrigation water an ultra-sonic transit time flow meter (Dalian Zerogo, Mod. No RV100) transmitting a 4 to 20 mA signal

DEVELOPMENT OF A PUMP EFFICIENCY MONITOR FOR USE IN COTTON IRRIGATION

was installed on the pipework. The pump and engine speeds are assessed using photoelectric proximity sensors. The electrical signals from these transducers are then recorded in a Campbell Scientific data logger (Mod. No. CR 850) and the captured data is then processed in a spreadsheet to determine fuel consumption per mega litre and the combined efficiency of the pump, motor, and drive-train.

A 3G modem allows remote access to the recorded data where telephone network access is available. The installation of a battery ensures an adequate power supply to the PEM and access to the data, and it is charged by the 24V electrical system on the diesel engine and a 10W solar panel.

The pump efficiency monitor was installed on a pump station on a cotton farm located west of Goondiwindi, Queensland during the 2013/14 irrigation season. The pump station consisted of a 26HBC-40 mixed flow pump driven by a Volvo Penta TWD1211P diesel engine and eight C-section belts and pulleys with a ratio of 2.82:1. This pump station is used to recirculate tail water and runoff water back into the main supply channel and on-farm water storage.

Results and Discussion

Figure 1 shows water flow rate, diesel consumption per hour, diesel consumption per megalitre and engine speed data collected with the PEM during a single pumping event conducted on the 4th and 5th of December 2013. The purpose of the pumping event was to pump tail water from irrigation fields back into the supply channel for recirculation to irrigation fields.

During such operations the requirement is to pump more than 120 ML/day at a total dynamic head (TDH) of 8 metres, a limitation imposed by the height of the distribution tank at this site.

Across this pumping event (4 to 5 Dec., 2013) the engine was operated at four different average speeds, as shown in Figure 1. This figure also illustrates the fuel consumption and pump discharge variation for the four different pump speeds. Data from two other pumping

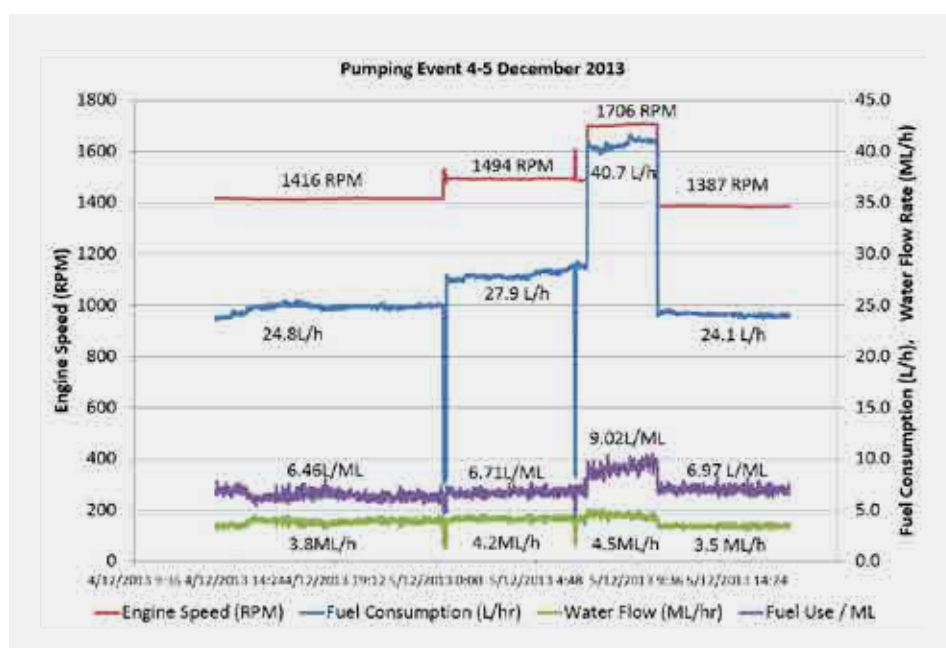


FIGURE 1. Water flow rate, fuel consumption per hour, fuel consumption per mega litre and engine speed data collected over a single pumping event (4th to 5th December 2013).

Average Engine Speed (RPM)	Water Flow Rate (ML/d (ML/h))	Fuel Consumption Rate (L/h)	Fuel Consumption per ML (L/ML)	TDH (m)	Combined Efficiency (%)
1387	84.0 (3.5)	24.1	6.97	7.78	28.4
1416	91.2 (3.8)	24.8	6.46	7.94	31.3
1494	100.8 (4.2)	27.9	6.71	7.66	29.0
1616	108.0 (4.5)	35.7	7.93	7.55	24.2
1706	108.2 (4.5)	40.7	9.02	7.83	22.1
1800	127.2 (5.3)	49.2	9.30	7.54	20.6

TABLE 1. Collation of pump discharge, diesel fuel consumption, and combined efficiency at different engine speeds from a number of PEM recorded pumping events on 26HBC-40 pumps.

events at engine speeds ranging from 1387 rpm to 1800 rpm were combined with the data from the 4 to 5 Dec. 2013 event and are collated in Table 1.

At an engine speed of 1800 rpm (Table 1) 127 ML per day was pumped using 1,180 litres of diesel over a 24 hour period at a rate of 49.2 L/h. At an engine speed of 1416 rpm it would require an additional 9 hours to pump the same volume of water (127 ML). The fuel consumed in 33 hours (24 h + 9 h) at 1416 rpm was 818 litres of diesel, at a rate of 24.8 L/h, saving 362 litres of diesel or 30% of the fuel volume. In other words a 44% increase in the fuel consumption per ML pumped occurs when altering engine speed from 1416 to 1800 rpm.

While there is a significant fuel saving when operating at the correct speed, it requires an additional nine hours to pump that 127 ML of water. This extra time may not be available for certain pumping events. Growers should make their own decision on what is appropriate for each pumping situation. Pump evaluations provide the necessary information to help with these decisions. Monitoring pump performance across various pump and engine speeds highlights that pumping 127 ML/day is not achieved efficiently for this particular pump station.

Figure 2 highlights the trend in combined (motor/drive-train/pump) efficiency and engine speed at this pumping station.

DEVELOPMENT OF A PUMP EFFICIENCY MONITOR FOR USE IN COTTON IRRIGATION

The maximum combined efficiency occurs at 1416 engine rpm, and decreases substantially with increasing speed. While it is the most efficient point, this does not correspond with maximum flow rate. Ideally when designing a pump station, maximum efficiency should correspond to the desired pump discharge.

During supplementary flow pumping events growers want to pump water at the maximum possible flow rate. It is therefore important to understand the efficiency of your pump station when operating across a wide range of speeds and duty points to minimise operating costs. This information would allow growers to make an informed decision on how to operate the pump station for various situations.

Conclusion

The ability of the PEM to continuously record various pump and engine operating parameters provides the necessary data to assess diesel engine and pump efficiency. The testing to date highlights the importance to test each individual pumping station to identify the optimum operating point to achieve maximum efficiency. Significant energy savings are possible for individual operators and the industry collectively.

Acknowledgements

We acknowledge the cooperation and assistance provided by the farm owners, the farm manager and his staff who assisted with this work. Financial support for this project was provided by the Cotton Research and Development Corporation, the National Centre for Engineering in Agriculture and the NSW Department of Primary Industries.

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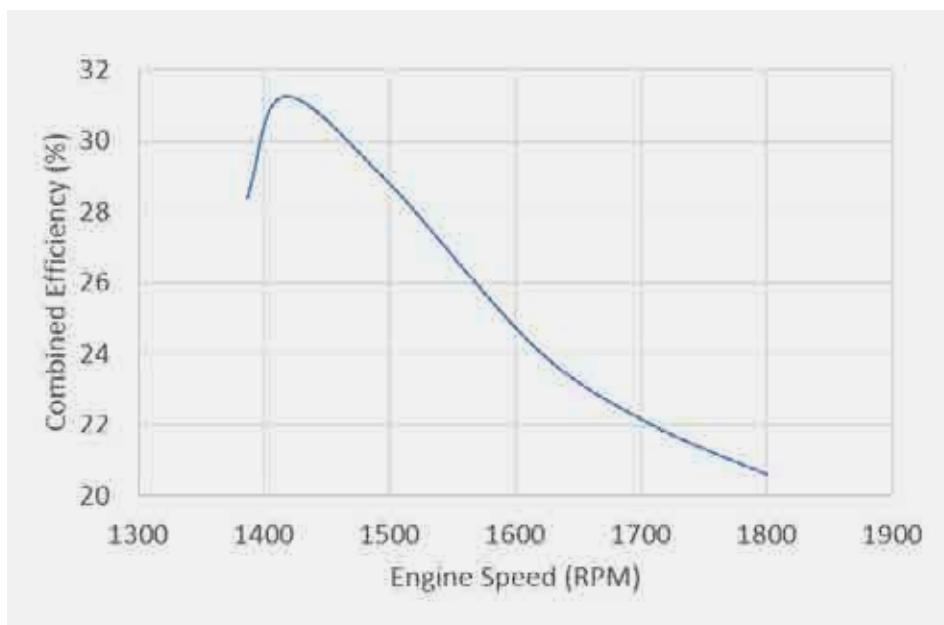


FIGURE 2. A comparison of combined efficiency and engine speed.

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ARE EVAPORATION LOSSES IN SPRINKLER IRRIGATION HIGH?

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Summary

Evaporation losses during sprinkler irrigation are perceived by the irrigation community to be high and is a major impediment to the adoption of sprinkler irrigation. Previous overseas experimental studies have reported losses up to 45% of the applied water and that a large proportion of the loss is droplet evaporation. However, a recent field experimental study conducted over a cotton crop at the University of Southern Queensland showed that the total evaporation is low (about 8%) and that droplet evaporation would be less than 1%. The additional evaporation during sprinkler irrigation would be about 4% of the applied water.

Introduction

Sprinkler irrigation is becoming a preferred method as the water available for irrigation around the world becomes increasingly scarce, especially in arid and semi-arid regions. The irrigators are still less interested to adopt this system due to the lack of accurate information regarding the losses in sprinkler irrigation often citing high evaporation losses along with high cost of operation. Previous experimental results have shown that losses may vary from 0 to 45% of the applied water and that a large proportion of the loss is droplet evaporation in the atmosphere. However, recent theoretical studies (Thompson et al., 1993, 1997) reported that the total losses should not be much more than a few percent and the droplet evaporation loss would be negligible (less than 1%). However,

due to the limitations of the available methodology these theoretical results could not be verified by field experiments in real crops. Latest studies (Uddin et al., 2013a & 2013b) showed that the advanced eddy covariance (ECV) technique can be used to measure the total evaporation during sprinkler irrigation and identification of the components of total evaporation is possible with some other additional measurements. Hence, in this study the additional evaporation during sprinkler irrigation was quantified.

Materials and Methods

The study was conducted over a cotton crop at the Agricultural Experimental Station situated at the University of Southern Queensland, Toowoomba, Australia. Eddy covariance system consisting of a 3D sonic anemometer and



FIGURE 1. Installed ECV and sap flow system at the centre of the field for continuous measurements

ARE EVAPORATION LOSSES IN SPRINKLER IRRIGATION HIGH?

infrared gas analyser (Figure and sensible heat flux (H).

Net radiation (R_n) and soil heat flux were measured by a four component net radiometer and soil heat flux plates, respectively. The temperature and relative humidity were measured using two identical temperature and relative humidity probes placed at two locations on the periphery of the irrigated plot. The measurements were done every 0.1 sec and the 5 min averages were recorded. The sap flow measurements used six dynagauge sap flow sensors and a data logger (Figure 1). The sensors were installed on six randomly-selected plants of 10 to 13 mm stem diameter. The field was irrigated using a small movable sprinkler irrigation system with low angle and low pressure impact sprinklers. The irrigation system gave an irrigated circle of 50 m diameter. The irrigations were applied for 3 hours in the middle of the day (Figure 2).

The reference ET (ET_{ref}) was calculated from the weather data using the FAO Penman-Monteith method. The latent heat flux λE was deduced from the surface energy balance over the crop surface by measurement of all major terms of the energy balance. The latent heat flux was adjusted using the Bowen Ratio method as described by Twine et al., (2000) and then converted to ET in mm hr⁻¹ using appropriate conversion factors.

Results & Discussion

The ET, sap flow (F), soil heat flux (G) and calculated ET_{ref} on a particular day are presented in Figure (3). It shows that the values of ET during irrigation increased significantly due to the direct effect of irrigation. A significant reduction of transpiration was reflected in the measurements of sap flow.

The total volume of canopy evaporation during and immediately following irrigation is the summation of:

- additional evaporation during irrigation (A) which includes canopy evaporation from the wet canopy and droplet evaporation during flight,



FIGURE 2. Evapotranspiration being measured during irrigation with the ECV system

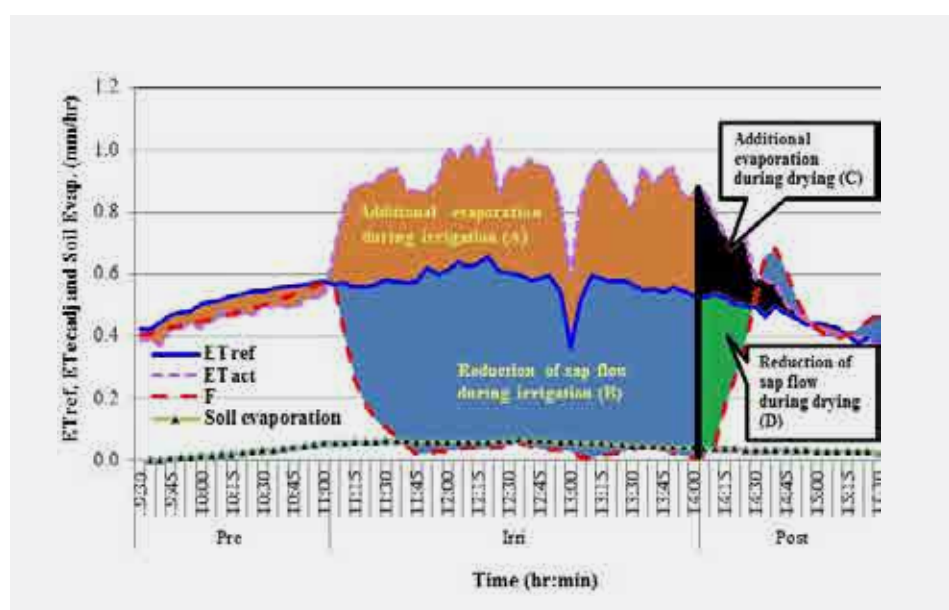


FIGURE 3. Components of total ET measured by ECV-sap flow method during sprinkler irrigation

- reduction of transpiration during irrigation in terms of sap flow (B) which would have occurred without irrigation,
- canopy interception capacity which includes the additional evaporation during irrigation (C) and reduction of transpiration in terms of sap flow during drying (D).

A negligible amount of soil evaporation was measured under closed canopy condition.

Total and additional evaporation

The total estimated depth of canopy evaporation ($A + B + C + D$) for the irrigation event on different days is presented in Table 1. The tabulated values show that total depth of canopy evaporation varied from 1.96 mm to 3.17 mm with an average 2.34 mm. On some days (e.g. DOY 102 & 104) the total evaporation was found to be significantly higher than the average due to the effect of advection during the

ARE EVAPORATION LOSSES IN SPRINKLER IRRIGATION HIGH?

irrigation. Assuming an application rate of 9 mm hr⁻¹ for the three hours irrigation, the canopy evaporation was typically about 8% of the total applied water. A slightly higher value (about 13% of applied water) was predicted by Thompson et al., (1997) while Yonts et al., 2007 measured 15% for corn. The depth of additional evaporation (A + C) in low angle impact type sprinkler irrigation was estimated to be about 1 mm which was about 4% of applied water.

Droplet evaporation

As evaporation during irrigation (Part A) includes wet canopy evaporation and droplet evaporation during irrigation, it was a strenuous task to separate these two components. However, to get an idea about the droplet evaporation during irrigation some measurements were taken over bare soil. Using the non-dimensional technique (ET_{ecadj}/ET_{ref}) to average the measurements on different days it was found that there was no discernible difference in nondimensional ET between the irrigation and post irrigation period (Figure 4) which indicates that the droplet evaporation was very small or negligible. Although the nondimensional ET was slightly lower during the pre-irrigation period, the higher nondimensional ET found during irrigation and post irrigation was most likely due to the evaporation of water from the wet soil in both periods.

Conclusions

The study shows that during the overhead sprinkler irrigation the total ET increased markedly and transpiration suppressed significantly. The total evaporation was found about 8% of the applied water. Considering the suppression of transpiration, the additional evaporation during sprinkler irrigation would only be about 4% of the applied water.

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DOY	Total applied water	Additional evap ⁿ during irrigation (A)	Reduction in trans ⁿ during irrigation (B)	Additional evap ⁿ during drying (C)	Reduction in trans ⁿ during drying (D)	Total evap ⁿ (A+B+C+D)	Additional evap ⁿ (A+C)
	mm	mm	mm	mm	mm	mm	mm
99	27 mm	0.76	0.93	0.08	0.21	1.52	0.59
102		1.43	1.10	0.14	0.20	1.98	0.84
103		0.88	1.10	0.11	0.20	2.98	1.59
104		1.65	1.09	0.19	0.20	2.50	0.99
105		0.95	0.91	0.11	0.19	3.17	1.88
114		0.58	1.09	0.08	0.21	2.33	1.23

TABLE 1. Total canopy evaporation (sum of part A, B, C, & D in figure 3)

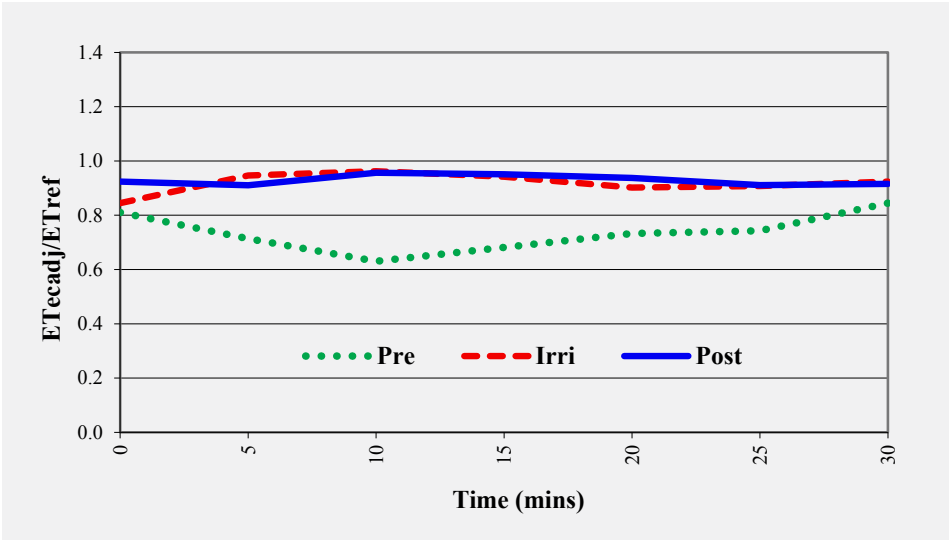


FIGURE 4. Nondimensionalised ET for bare soil before, during and after irrigation

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E-SUMMARIES

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FIELD-SCALE EVALUATION OF FURROW FERTIGATION USING LIQUID NITROGEN.

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Aim and objectives

On average about one third of applied nitrogen is lost which costs the cotton industry \$32 million each year. Fertiliser use efficiency can be improved through site-specific application of liquid nitrogen (N) in surface irrigation systems. A field-scale fertigation trial was conducted to assess: (1) the uniformity of distribution of the fertiliser applied; and (2) the agronomic performance of furrow fertigated crop based on fertiliser N recovery. The results reported in this study will aid the development of a set of practical recommendations concerning furrow fertigation in cotton to improve use efficiency of fertiliser N.

Materials and Methods

Urea ammonium nitrate (UAN, 32% N w w⁻¹) was injected into a 50 m length of gated pipe (Fig. 1) and applied with irrigation water at a rate of 43 L ha⁻¹ of fertiliser over two irrigation events conducted on 29 December 2013 and 6 February 2014, respectively. Fertiliser-treated furrows were compared with control furrows (zero-fertiliser). Uniformity of distribution of fertiliser applied was determined in water during the irrigation events and in soil before and after irrigation by sampling at three locations along the furrows (100 m, 300 m and 500 m down the 600 m

long furrows). Soil and water samples were subjected to determination of mineral N (NH₄⁺-N + NO₃⁻-N). Nitrogen recovery was determined based on Rochester (2011).

Results

Mineral N concentration in water samples ranged between 19.4 and 25.7 mg L⁻¹ of N, which suggests that distribution of fertiliser applied with irrigation water was relatively uniform along the furrows. There were significant differences (P<0.05) in soil mineral N (SMN) between fertilised and non-fertilised furrows following irrigation. Overall, SMN at the three sampling locations reported similar (P=0.08) values, which suggests that distance distribution was uniform. However, SMN determined before and after fertigation showed no differences (P>0.05), which suggests percolation of native SMN during irrigation to depths greater than 600 mm, possibly aided by preferential flow through open cracks. There was no fertigation treatment effect (P>0.05) on total N recovered in cotton seeds, which is attributed to residual fertiliser N applied prior to planting. Total N in seed showed values between 3.12% and 3.52% N for both control and treatments.



FIG. 1 Fertigation unit for injecting liquid N into gated pipe for field trial.

Conclusions

Fertigation using furrow irrigation has shown promising results and it may be used as an effective means to apply N fertiliser in cotton. This is supported by satisfactory uniformity of distribution of fertiliser applied during the irrigation events, which was achieved both at distance and depth. However, greater control over the water applied to furrows is required to reduce deep percolation of native soil N. Research is being conducted to improve the understanding of the interaction between timing of fertiliser application via fertigation and timing of irrigation, and to determine potential benefits and practicalities of pre-irrigating the soil with a small amount of water to induce reduction of infiltration rate hence deep losses of native soil N, followed by fertigation.

ASSESSMENT OF SOIL COMPACTION CAUSED BY COTTON PICKERS

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Aim

To quantify and explain patterns of soil compaction caused by cotton pickers and to develop a set of practical recommendations for minimising soil damage during harvesting operations.

Materials and Methods

Soil bulk density (SBD) and cone index (CI) measurements were determined for three different traffic treatments performed on a black Vertosol: zero-traffic (control), single pass of a JD7760 fitted with single tyres (front: 620/70-R42, rear: 520/85-R34) inflated to the manufacturer's recommended pressure and driven over previously non-wheeled soil (moisture content: $24.3 \pm 2.6\%$ w w⁻¹), and permanent (15 years old) traffic lanes representative of controlled traffic systems. Soil cores (0 to 700 mm depth range) were taken from four positions: two on the shoulders of the rut and two on either side of the centreline. Cone index was measured by pushing a cone (125 mm² base area, 30° apex) into the soil to a depth of 500 mm and digitally recording the required force at 25 mm depth increments. A higher CI infers higher resistance to penetration. Readings were taken perpendicular to the direction of travel every 100 mm spacing, and in three positions along the field at 20 m spacing. Soil bulk density and cone index measurements were

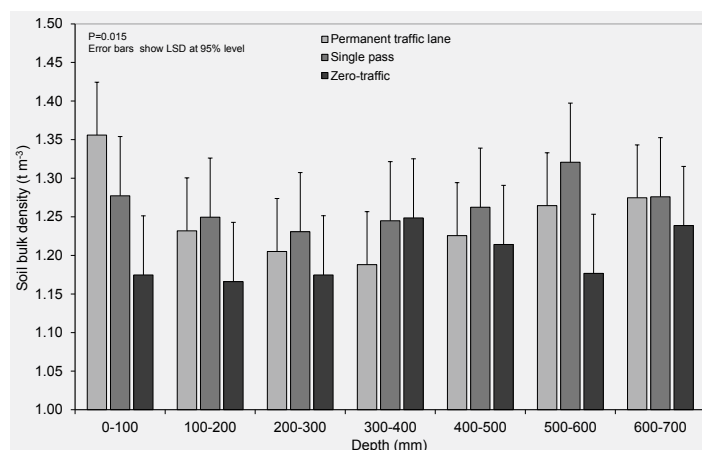


FIGURE 1. Soil bulk density observed for the three traffic treatments.

replicated three times (n=3) for all treatments.

Results and Conclusions

Figure 1 shows SBD data recorded for the three traffic treatments. Overall, there were significant differences ($P < 0.05$) in SBD between wheeled ($\approx 1.26 \text{ t m}^{-3}$) and non-wheeled ($\approx 1.20 \text{ t m}^{-3}$) soils. The single pass treatment exhibited similar ($P > 0.05$) SBD to that of the permanent traffic lane. A single pass of the picker increased SBD by about 6% on average over the measured depth compared with the non-wheeled soil. Changes in SBD on the single pass treatment were greater between 200 and 400 mm deep (range: 7.5% to 13% increase relative to non-wheeled soil). Overall, there were significant differences ($P < 0.001$) in CI between traffic treatments; the zero-traffic treatment showed lower CI ($\approx 4000 \text{ kPa}$) compared with the single pass

treatment ($\approx 4660 \text{ kPa}$), and the permanent traffic lane ($\approx 5534 \text{ kPa}$). Under the wheel, CI increased significantly ($P < 0.001$) toward the centreline of the rut, which agrees with previous studies (Antille et al., 2013). There was also a small increase ($< 10\%$) in CI recorded at locations laterally outboard of the wheeling, which is attributed to lateral soil displacement induced by traffic with the picker. These results confirm the importance of controlled traffic in minimising soil compaction. Without controlled traffic, varied equipment track widths translate into random traffic patterns which cover up to 85% of field area each time a crop is produced (Tullberg, 2010). Studies are being conducted on irrigated and dryland cotton farms in Queensland to determine soil moisture deficit thresholds for limits to trafficability with cotton pickers.

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FACTORS INFLUENCING MICRONAIRE IN COTTON CROPS

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Outline

Micronaire is a measure of fibre linear density (fineness) and maturity. Factors affecting supply and partitioning of photosynthetic assimilates to fruit affect micronaire. High micronaire occurs when there are good growing conditions and/or fruit number is low. Conversely low micronaire occurs when growing conditions are poor and/or fruit number is high. Little research has established the degree of impact of factors influencing micronaire, so field experiments were conducted to investigate effects of planting date; cultivar; canopy manipulation; and fruit number.

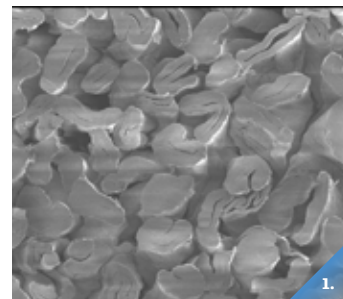
Outcomes

- Micronaire was affected by interactions of planting time, canopy manipulation (tipped out and regulated (with mepiquat chloride), and fruit load.
- Fruit removal in late planted treatments in normal and smaller canopies had similar micronaire to their earlier planted equivalents indicating compensatory mechanisms.
- Cultivar and planting time were the only consistent main effects on micronaire, with late planting time reducing micronaire.
- The ability to predict final micronaire was successful when the temperature during

boll filling, the size of the final bolls, and the leaf area at late flowering was considered together.

Industry Impact

This study has highlighted that in capturing understanding of management impacts on micronaire, the differences in cultivars, and influences of management modifying the period in which fibre thickening occurs need to be especially considered. It also reinforced opportunities to account for impacts of the effects of management by capturing the effects on boll growth directly.



1 FACTORS influencing photosynthesis influence fibre thickening and micronaire.

2 PLANTING time, cultivar, canopy size, and fruit number were varied to understand their effects on micronaire.

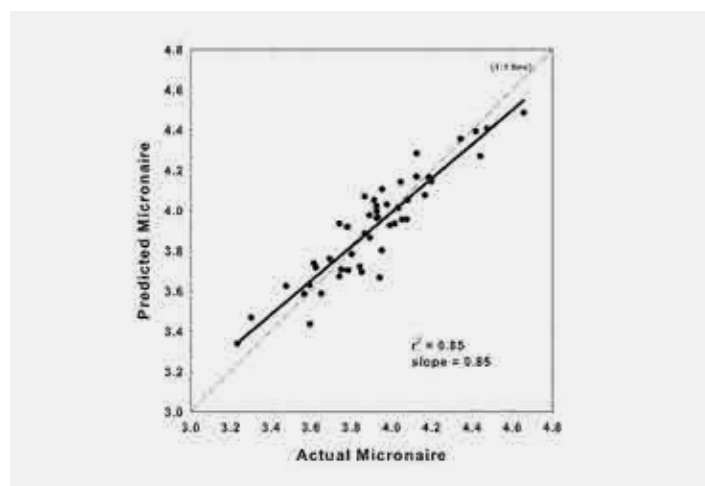


FIGURE 3. Predictions of micronaire were successful when temperature during boll filling, leaf area, and final boll size were considered together.

OXODEGRADABLE THIN PLASTIC FILM IN COTTON

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FIGURE 1. Thin film and bare plots.



FIGURE 2. Early growth: thin film and bare plots.

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Cruiser Research & Development Fund



Question/issue being addressed

Early planting poses some risk in cool regions resulting in re-planting if cold days or frost occur after emergence. So the question is, will oxodegradable thin plastic film increase soil temperature and conserve seedbed moisture potentially reducing the risk in early planting, while not compromising lint yield and fibre quality of cotton?

Key results and findings

Soil temperatures at planting depth were elevated by 2-4 °C under the film compared with the bare soil and the soil did not dry to the same extent under the film, resulting in earlier and uniform emergence under the film. Climate analysis indicated a greater risk in planting early (1st week Sept.) than the normal target date (2nd week Oct.) due to cold shock and frost days. Lint yield was not significantly different with early planting, while there was a significant difference at the later planting between the film and bare soil treatment. It is speculated that early planted seedlings were exposed to cold days which compromise development, while the later planting occurred when temperatures were increasing. All surface film had degraded by harvest.

What impact will this have on the Australian cotton industry?

Seedlings emerge earlier and seedbed moisture is conserved under thin film which may reduce the need for an early irrigation. Lint yield was not compromised by thin film.

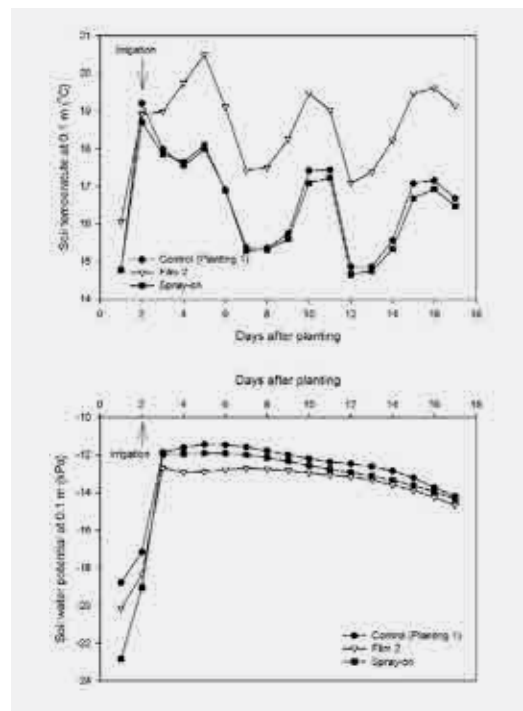


FIGURE 3. Seedbed soil temperature (°C) and water potential (kPa) at 0.1 m.

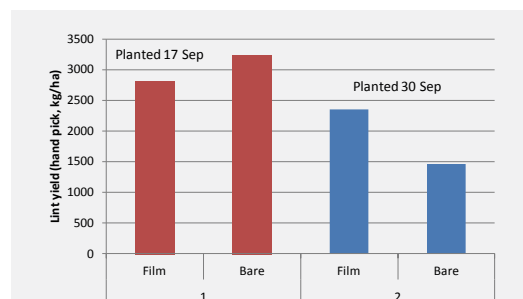


FIGURE 4. Handpicked lint yields (kg/ha).

IRRIGATION STRATEGIES IN A LIMITED WATER ENVIRONMENT

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Outline

One of the key challenges growers have when they have water for a limited number of irrigations is confidently knowing when to use this water to optimise yield, quality and water use efficiency. Irrigation timing is critical to minimise negative impacts on yield and fibre quality. New Research is underway to develop irrigation strategies for cotton in a limited water situation and with various row configurations (e.g. solid, single skip row and 2m, 80 inch, 1 in 1 out).

Results

Measuring soil water to determine irrigation timing is very difficult in these systems, we are investigating canopy temperature as a measure of crop stress and as a trigger point for irrigating in limited-water situations. A detailed field experiment at ACRI compared crop and plant stress responses, yield and quality for crops grown under different row configurations

(solid, single skip and 1 in 1 out) that were irrigated at different growth stages with staggered irrigations. Canopy temperature measurements showed that wider row configurations had fewer hrs of stress over the growing period in both fully-irrigated and partially-irrigated treatments (Figure 1).

Summary

Recent research in fully irrigated cotton has successfully applied an accumulated stress time threshold using canopy temperature for solid row configurations, these experiments and future research are evaluating the use of crop stress trigger points using canopy temperature in partially irrigated crops grown under different row configurations for optimising yield, WUE, and profit. Ultimately the outcomes of this research will identify key growth stages and crop stress 'trigger points' to get maximum benefit from a limited number of irrigations.

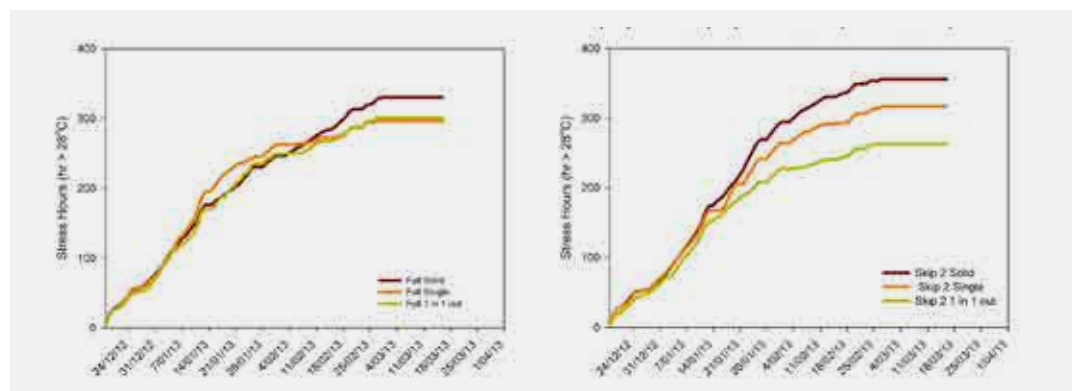


FIGURE 1. Cumulative stress hours in solid, single skip and one in one out row configurations - fully irrigated (left) and two irrigation skips at flowering (right), ACRI, Narrabri 2012-13.

EVALUATION OF INSECTICIDE AGAINST SOLENOPSIS MEALYBUG

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Outline of Research

Solenopsis mealybug (*Phenococcus solenopsis*) has been a pest of cotton in Australia since initial outbreaks in Emerald and the Burdekin in 2009. They can cause significant loss and damage to bolls via feeding and reduce lint quality due to honeydew production. With no insecticides registered for Solenopsis mealybug in Australia, this research evaluated the impact of insecticides registered for other pests of cotton. Impacts on beneficial insects was also recorded.

Outline of results and findings

Three field trials were conducted to evaluate insecticides against Solonopsis mealybug. The trials were conducted in Bollgard® II irrigated cotton at Byee (2011-12) and Emerald (2012-13 and 2013-14). Treatment details are given in Table 1. The chemicals were applied with a gas pressured hand boom sprayer (107 L/ha). Mealybug and beneficial insect numbers were assessed visually. (Figures 1. Figure 2. Figure 3.)

None of the insecticides had any significant impact on mealybug. A moderate effect with Clap® was compromised by a low overall population and further trials where greater numbers are present would be required before this chemical could be considered as a management option.

Benefits of Research

This research indicates that there is still no suitable chemical option for the control of Solenopsis mealybug. The best management options therefore remain preservation of beneficials and good farm hygiene. Removing beneficial predators causes mealybug populations to flair. Thorough cleaning of contaminated machinery and equipment and strict control of weeds and volunteer/ratoon cotton, especially in the off season, removes alternative hosts. These practices remain the most successful methods of controlling mealybug.

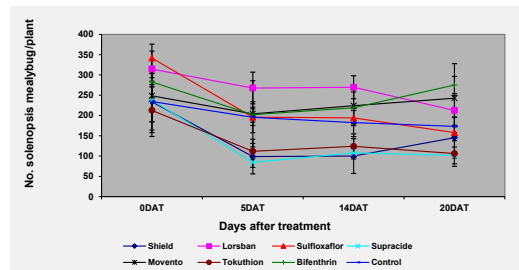


FIGURE 1. Byee 2011-12 trial results.

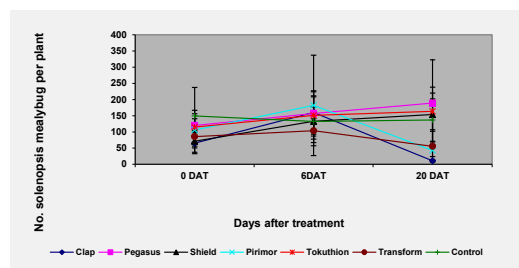


FIGURE 2. Emerald trial results 2012-13.

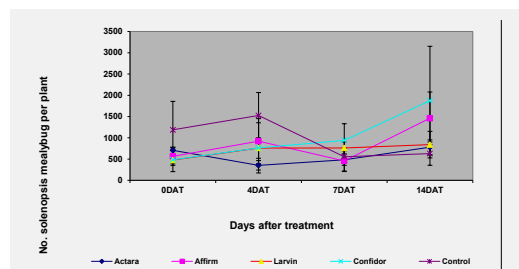


FIGURE 3. Emerald trial results 2013-14.

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(CRDC).



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Treatment	Formulation (g/L)	Rate (mL/ha)
Byee 2011-12		
Shield® + Maxx	Chlothianidin (200)	250 + 2% v/v
Lorsban®	Chlorpyrifos (500)	500
Transform®	Sulfoxaflo (240)	400
Supracide®	Methidathion (400)	1400
Movento®	Spirotetramat (240)	400
Tokuthion®	Prothiofos (500)	350
Talstar®	Bifenthrin (100)	800
Control	Untreated	-
Emerald 2012-13		
Clap®	Buprofezin (440)	1200
Pegasus®	Diafenthiuron (500)	800
Shield® + Maxx	Chlothianidin (200)	250 + 2% v/v
Pirimor®	Imidacloprid (500)	750
Tokuthion®	Prothiofos (500)	350
Transform®	Sulfoxaflo (240)	400
Control	Untreated	-
Emerald 2013-14		
Actara®	Thiamethoxam (250)	400
Affirm®	Emamectin (17)	700
Larvin®	Thiodicarb (375)	1000
Confidor®	Imidacloprid (200)	250
Control	Untreated	-

TABLE 1. Treatments and rates used in the trials.

CRY2AB RESISTANCE AND FLIGHT CAPACITY OF *H. ARMIGERA*

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Department of Primary Industries



THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Outline/Question

The effectiveness of the Bt refuge strategy relies not only on the production of susceptible moths in refuge crops, but also the movement of these moths within the Bt cotton landscape. However, as this is not a closed system, there is the potential for refuge crops to be contaminated with resistant alleles through the movement of resistant moths from Bollgard crops back into these areas. We investigated whether *Cry2Ab* resistance affects flight capacity of female Cotton Bollworm moths?

Results/Findings

Flight mill experiments were conducted to test flight capacity of susceptible and *Cry2Ab* resistant *H. armigera* female moths. Susceptible moths were heavier and flew slower than resistant moths. There was no difference in weight or flight speed between resistant moths reared as larvae on diet containing *Cry2Ab* toxin and those reared on a toxin free diet. Susceptible moths flew on average 40% longer, and 35% further than resistant moths, reared as larvae on diet containing *Cry2Ab* toxin.

Impact/Benefit to Industry

The results indicate that *Cry2Ab* resistant female moths emerging from under Bt cotton would have reduced flight capacity and this may help to limit the movement of resistance alleles into refuge areas. Results also confirm that susceptible female moths have a very high flight capacity. This could have implications for the design or refinement of the refuge strategy in Australia.

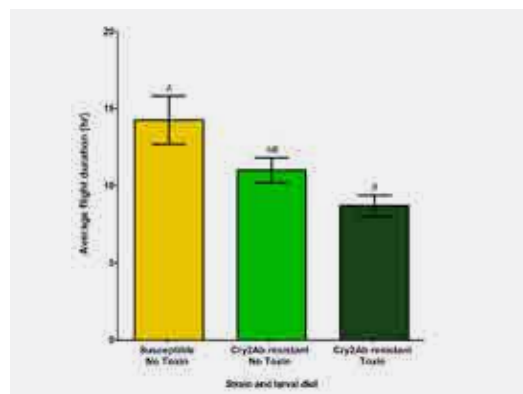


FIGURE 1 Effects of strain and larval exposure to *Cry2AB* on flight duration over five nights

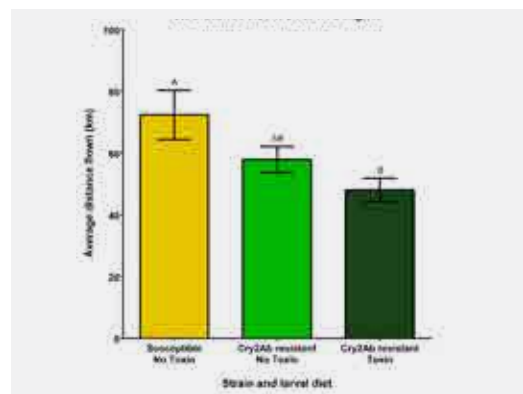


FIGURE 2 Effects of strain and larval exposure to *Cry2AB* on distance flown over five nights

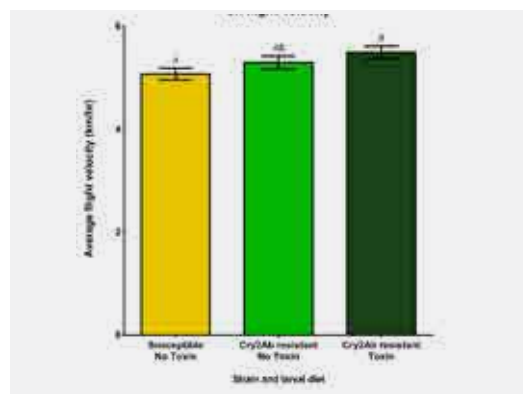


FIGURE 3 Effects of strain and larval exposure to *Cry2AB* on flight velocity



FEMALE *H. armigera* moth attached to Flight mill.

ROGUE COTTON – A PEST PATHWAY TOO YOUR PLACE

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What is the extent of Rogue Cotton in our farming areas?

With rogue cotton becoming a seemingly common sight along roadways and drainage lines a survey was conducted throughout Queensland and parts of northern New South Wales covering over 13,000km of roads and drainage ways to gauge the extent of the problem. During the survey plants were geo-tagged for future reference and subsamples taken to determine disease status and pest insect presence.

What did the Survey find?

Spilt seed cotton during module cartage was the primary source for rogue cotton plants. Densities were highest adjacent to cotton farms and near gins suggesting most seed cotton is lost soon after loading or unloading modules for transport. Sunwater drainage channels in the central Queensland and St George irrigation areas were also hot spots for plants.

Nearly half of all plants sampled across all regions were found to be positive for Cotton Bunchy Top Disease (CBTD). The high incidence of CBTD confirms the movement of aphids between these plants and potentially back into cotton fields.

The Take Home Message for the Cotton Industry

Rogue plants and volunteers are worth controlling. The high incidence of disease was the most concerning finding of this study. The prevalence of disease particularly in plants close to cotton farms suggests that there is a large reservoir of CBTD which is a potential launch pad for a disease epidemic in a high aphid activity season. On farm volunteers in fallow or rotation cropped grain fields are also likely to harbour significant levels of disease and pose the same risk.

Controlling rogue or volunteer plants where possible will greatly reduce the risk of CBTD gaining a foothold on your farm.



1.



2.



3.



4.

1. **ROGUE** cotton growing along an irrigation area drainage line.

2. **THIS** CBTD infected rogue plant is growing on a roadside adjacent to a cotton crop. This plant was 2 years old.

3. **CIVIL** Engineering structures provide protection for perennial rogue cotton plants to survive between seasons. These plants were positive for CBTD.

4. **ROAD** construction works can encourage rogue plant establishment through incorporation of seed cotton.

HAVE YOU CHECKED FOR ESTABLISHMENT PESTS BEFORE PLANTING?

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Issue being addressed

A complex of soil pests can cause crop establishment problems in newly sown cotton crops even where seed dressings are used. These occasional pests are difficult to detect prior to planting without sampling. However, as the primary control tactics for soil insects need to be applied prior to or at sowing it is important to check for soil pests that may cause problems to identify fields that may be of risk.

Damage Symptoms & Sampling

Soil pests feed on germinating seeds or young plants and cause seedling death or constricted root development resulting in a patchy plant stand.

Use bait sampling to assess soil insects as soil digging is often ineffective. The steps are:

1. Soak insecticide-free grain in water for at least two hours to initiate germination or cut a medium sized potato in half.
2. Bury a dessert-spoon full of the seed or potato bait under 1 cm of soil at each corner of a 5x5 m square at several widely spaced sites per 100 ha.
3. Mark the position of the baits to allow relocation.
4. After 5-7 days dig up the baits and count the insects.

Likely Pests

Black field earwigs (nymph pictured 1.) when in high numbers can cause extensive seedling damage.

Several species of wireworm (pictured 2.) can damage cotton. These are very difficult to detect without bait sampling.

The pest status of Symphyla (pictured 3.) is uncertain but the subject of current research. This organism is easily confused with diplurans. Symphyla are distinguished by having legs all along its body like a millipede.

Root tip grazing under some circumstances by Symphyla (4. plants on right) can cause seedling stunting and premature wilting. Symphyla are present in many fields but often cause no damage.

What is the message for the Australian Cotton Industry

Check your fields for soil pests prior to planting. Conducting basic bait sampling could make the difference between having a successful establishment or a poor plant stand and the expense of replanting. Check the latest Cotton Pest Management Guidelines for further details.

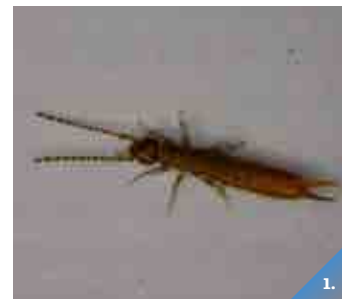


FIGURE 1. Black Field Earwigs

FIGURE 2. Wireworm

FIGURE 3. Symphyla

FIGURE 4. Root tip grazing by Symphyla

LATE WINTER SOWING FOR EARLIER BOLL FILING

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Issue being addressed

Peak summer weather in the central Highlands region can be highly variable with potential for cloudy wet monsoonal influences or high temperatures and humidity which reduces a crops capacity to keep cool. We are investigating tactics to enable substantially earlier planting and crop development to reduce crop exposure during boll filling to mid to late summer conditions. This may improve the management of climatic risk for cotton production in the Central Highlands environment and lift aggregate yield potential and lint quality.

Key Findings

A Central Highlands climate analysis identified that the October to December period is ideal for boll filling. To capitalise on this opportunity test plantings were made during August and early September with and without biodegradable films to see if early season cool temperature constraints could be overcome and enable earlier establishment, boll filling and crop maturation.

Biodegradable films raised soil temperatures by 2oC enabling more rapid establishment and earlier flowering. August sown cotton flowered during mid to late October and was physiologically mature by early January thus avoiding boll

filling during the peak summer period.

What impact will this have for the Australian Cotton Industry

The strength of the Australian Cotton Industry is underpinned by performance of each of its regions. Strategies that minimise climatic risk and improved the reliability of yield potential and lint quality for the Central Highlands would make a welcome contribution locally and for the broader Industry. This work has only recently commenced so it is too early to conclude the likely success that may accrue from earlier sowing and boll filling or the viability of late winter sowing. It is anticipated that this will become clearer over the coming seasons.



1. SLOTS in the film allow seedling emergence. The film warmed lifted the minimum soil temperatures by 2°C.

2. COTTON sown with film (right) flowered a week earlier than cotton without film (left).

3. THE film begins to degrade 6 weeks after application and is totally broken down by picking.

4. TRIALS in 2014 will deploy film on hills at a commercial scale.

FATE OF HONEYDEW ON COTTON AND IMPACTS

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The Problem

Cotton aphid and silverleaf whitefly feed on phloem sap and produce sugar rich honeydew that can contaminate open cotton bolls leading to downstream problems with processing. Despite established management strategies for these pests honeydew contaminated crops still occur. The factors that may reduce honeydew in the field include moisture (rainfall), sunlight (UV radiation) and microorganisms (sooty mould fungi). Our experiments aim to establish the importance and effectiveness of each factor in reducing honeydew to levels that are safe to harvest.

Results

Rainfall, either natural (range 8.1-21.8 mm) or simulated through overhead irrigation (range 0-60 mm, Figure 1) or micro sprinklers (range 0-32 mm, Figure 2) dramatically reduced

honeydew concentration on bolls. Data over three years showed that as little as 10 mm of rainfall removed up to 80 % of honeydew (Figure 3). Further rainfall removed more honeydew but at a slower rate.

Short term exposure of contaminated bolls to sunlight and dry conditions did not show any significant reductions in honeydew (Figure 4). Sooty mould fungi growing on honeydew may degrade honeydew, reducing contamination and we are currently investigating this.

Impact

We have established that sunlight alone is unlikely to reduce honeydew in the field while rainfall or overhead irrigation can remove significant amounts of honeydew from contaminated lint. Our data provides a basic guideline to the amount required to ensure non-sticky bolls at harvest. Rainfall intensity and distribution

also plays a part in the speed and efficiency of honeydew removal and we intend to investigate this and further rainfall effects in relation to sooty mould development and fibre deterioration due to excessive moisture.



1. OVERHEAD sprinkler system used to simulate rainfall

2. MICROSPRINKLER system used to simulate rainfall

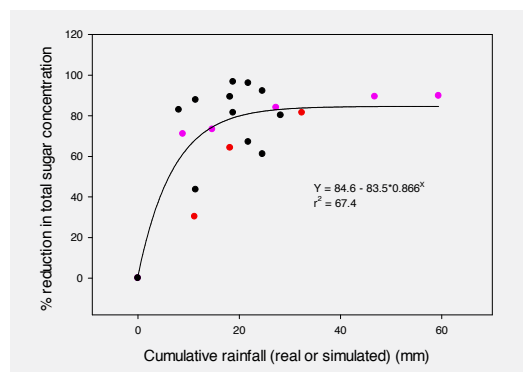


FIGURE 3. Percentage reduction in honeydew sugars due to natural rainfall (black dots), micro-sprinkler irrigation (red dots) or overhead irrigation (pink dots).

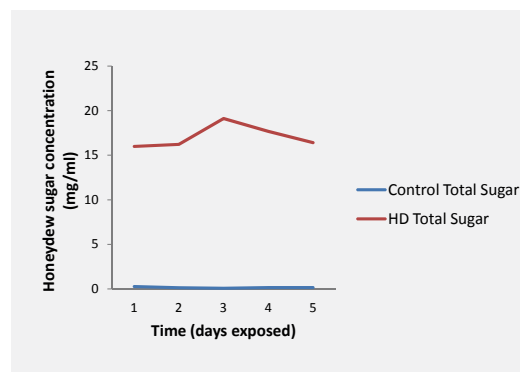


FIGURE 4. Behaviour of honeydew under short term exposure to sunlight

SAFEGUARDING AGAINST SILVERLEAF WHITEFLY INSECTICIDE RESISTANCE

AUTHORS Jamie Hopkinson | Stephanie Kramer | Richard Lloyd | Paul Grundy
ORGANISATION Queensland Department of Agriculture, Fisheries and Forestry

Outline

Silverleaf Whitefly (*Bemisia tabaci*) is a major pest of cotton. This is because it produces sticky honeydew that contaminates lint, reducing the quality of cotton. Silverleaf Whitefly can be controlled with insecticides, but if mismanaged – whitefly will develop resistance. Each year Silverleaf whitefly are collected from cotton production regions and screened for resistance to insecticides, e.g. Admiral®, Pegasus® and Talstar®. The results of this research support Insecticide Resistance Management Strategies (IRMS) to prolong the life of the currently used insecticides.

Results

In 2013 and 2014 Silverleaf whitefly (Figure 1) were collected from cotton farms at Emerald, Theodore, St George, Namoi valley, Moree and Macintyre Valley. Dose response bioassays were completed for each of the insecticides registered for whitefly control. Our bioassay results demonstrate that whitefly in the above regions are fully susceptible to Admiral®, Pegasus®, Movento® and Talstar®. Limited testing of Silverleaf whitefly from horticultural crops at Ayr revealed populations there have resistance to Admiral (Figure 2). Results from cotton regions indicate the IRMS for Silverleaf whitefly is



FIGURE 1. Silverleaf Whitefly adults and eggs.

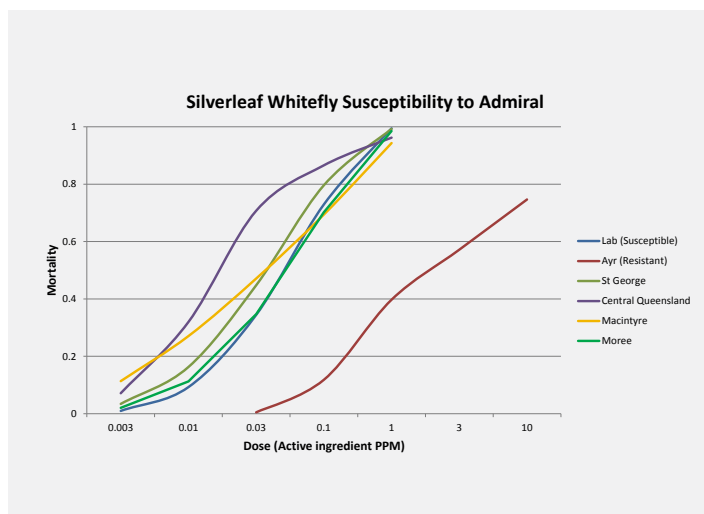


FIGURE 2. Summary of results from Admiral® dose response bioassays 2013-14.

working. The results from Ayr demonstrate the potential for resistance with less prescriptive insecticide use control measures.

Benefits of Research

Results from this research provide reassurance to growers and consultants that Silverleaf Whiteflies are susceptible to insecticides registered for their management. Adhering to the Insecticide Resistance

Management Strategy is important for maximising the lifespan of insecticides which remain critical for sound whitefly integrated pest management.

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COTTON: PART OF THE SOCIAL FABRIC?

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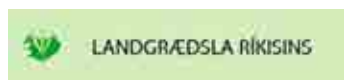
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Department of Sustainability, Environment, Water, Population and Communities

Imagine a future where cotton farms are run by sophisticated machines. Computerised systems monitor crop conditions; aerial drones collect real time information about your crop; pickers, gins and classers are operated by only a few people, in a 24 hour cycle dedicated to economic efficiency. Sounds like a productivity paradise! There's only one thing missing. ... viable and thriving cotton communities in rural and regional Australia.

The Australian cotton industry has faced concern about environmental impacts by embracing regulation, best practice and innovation. The industry has shown it can increase profitability and productivity while capturing a social license to operate. Future trends suggest a more competitive global marketplace ahead, as man-made fibres combine with nano-technology to challenge Australia's "pure fibre" focus. If the industry continues to focus on economic gain, rural communities and economies will start to suffer. This research asks how can we maintain the social fabric of cotton communities?

Recently I attended a cotton industry tour hosted by the CRDC. As a social researcher I am always interested in how people talk about their experiences, what their views are, and what they think about the future. Many of the individuals that talked to our tour groups were proud of the cotton industry, and of their contribution to the rural economy. They told stories of innovation and risk-taking as part of their success, and

how important good scientific research was to improving their business. They also talked about economic productivity, and the need to reduce costs through labour-saving technologies. We heard about the new technology in the USA that will eventually replace cotton classers; we saw new pickers that could also bail, eliminating another step in the production process.

As we talked to corporate operations and family businesses, I began to question the impact these efficiencies might have on the local community over time. If machines can replace low skilled workers, where will these people go for seasonal work? If cotton classers are replaced by visual technology, what happens to the expertise and knowledge of these workers? If large-scale operations can afford to invest in new machinery, how will family owned farms compete?

All of these questions are relevant to those who care about the future of rural and regional Australia. What happens to rural towns when jobs disappear? If low skilled workers and young people can't find jobs, they either move away or become another welfare statistic. Family farms can't compete against the economies of scale of large corporations, and come under increasing financial pressure.

The cotton industry is a proud contributor to rural communities, but it is possible that a one-eyed focus on economic productivity may start to unravel the social fabric, as families and young people move away, to other industries, or to

bigger cities.

Australia is at a cross-roads. The 'Lucky Country' has always relied on the high value of natural resources and raw materials to generate wealth. Australia's cotton industry exports fibre, it doesn't process, and this makes sense in a marketplace with high labour costs. However, there is an opportunity to change this model and start thinking about how to add value to the product. This will allow the cotton industry to play to its strengths, using innovation and technology to create new fibres that can compete against man-made products in a global marketplace. By moving away from an export efficiency model, the cotton industry can position itself for the challenges of the future, and also deliver employment possibilities for cotton communities.

Summary

These challenges suggest the need for research with cotton growers, distributors and participants in the production cycle, to understand what people think the future holds for the industry, and it's cotton communities. Combining social perspectives with economic and community development, this research can work with the industry to plan for both the challenges of the marketplace, and the challenge of maintaining community viability. While scientific research helps the cotton industry to achieve better production, social research can help the industry develop a plan for the future that strengthens the social fabric with cotton fibre.

CAREERS BY KIDS FOR KIDS - A SUSTAINING RURAL COMMUNITIES PROJECT

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An innovative collaborative project run by NSW DPI Cotton Pathologist Dr Karen Kirkby and CSIRO Cotton Industry Education Officer Trudy Staines introduced students from year 10 Narrabri High School to possible career pathways within both science and agricultural fields. Students role-played different career options working as cameramen, script writers, interviewers and editors producing a short film covering the three careers. The career videos produced by kids for kids have been placed on the Narrabri and District Chamber of Commerce website.

Key results and findings?

- Promoted exciting and rewarding careers in science and agriculture
- Promoted Narrabri High School as a school of choice
- Provided students access to the great facilities at Australian Cotton Research Institute
- Functionality of the ACRI brought to the communities attention

What impact will this have on the Australian cotton industry?

This innovative project addressed workforce capacity within the cotton industry. We feel it is an effective strategy for attracting, developing and retaining people in the cotton industry. This project highlighted some of the exciting career options to students in year 10 and may help to attract the future leaders of the cotton industry.



IMAGE 1. Students At the ACRI, Back, Jack Hardy, Liam Parker, Dylan Verrier, Tyler Allen, Eden Walker, Corer Robinson, Thomas Hedley, Will Jones, Rachael Lilliebridge, Dr. Karen Kirkby, front, Zoe Tomlinson, Courtney Boyd, Sara Little, Riley Dafter, Amy Larsen, Damon Marshall, Luke Hennessy-McLeod, Trudy Staines, Absent: Chloe Atkinson, Zac Frawley and Isabelle Madden.



IMAGE 2. Back: Amy Johnson, Dr. Karen Kirkby, Corey Robinson, Tom Hedley and Zac Tomlinson. Front: Trudy Staines, Sarah Little, Courtney Boyd, Isabelle Madden and Damon Marshall.

DISEASES OF COTTON XI

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Questions, issues being addressed?

Research undertaken by NSW DPI Pathology in the project Diseases of Cotton XI continues to ask questions with regard to pathogens causing diseases of cotton.

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Key Questions	How these are being addressed
What are the primary diseases of cotton, including what is the incidence and severity?	NSW biannual cotton disease surveys 2013/2014 season represents 31st consecutive year of surveys
Are there any exotic cotton diseases in Australian cotton crops?	Surveillance of commercial cotton crops
Is Fusarium wilt within infected fields spreading and if so, how far?	Fusarium transects in commercial fields
Is there a link between high incidence of black root rot and high incidence of Verticillium wilt?	Data mining
What level of <i>Verticillium dahliae</i> (the pathogen that causes Verticillium wilt) inoculum is needed in soil to cause both external and internal symptoms?	Growth room pot experiment
What is the level of genetic diversity with <i>Verticillium dahliae</i> ?	Molecular studies Pathogenicity testing
What is the effect of different fertilisers (cow/chook manure/anhydrous ammonia/urea) on verticillium inoculum in the soil?	Field trial
Efficacy of existing and novel seed treatments?	Annual seed treatment trials in several locations throughout NSW
Is there high genetic diversity amongst <i>Thielaviopsis basicola</i> (the pathogen causing black root rot) isolated from different geographic locations?	Molecular studies Morphological growth rates (laboratory experiment) Pathogenicity assays (pot trials)
Does the planting of biofumigation crops offer an alternative management strategy for reducing incidence and severity of black root rot?	Long term Biofumigation field trial at ACRI
How does NSW DPI respond to industry issues as they arise?	Free and confidential diagnostic service PathWAY – communication tool linking pathologists, virologists and other industry experts
What if there was an exotic incursion of hypervirulent bacterial blight?	Contingency plan for bacterial blight being written Differential lines being tested

What impact will this have on the Australian cotton industry?

Data provided by the surveys continues to indicate the relative importance of each of the diseases present and the impact of cultural practices and the adoption of new varieties on disease distribution, incidence and severity. Surveillance also documents the absence of exotic diseases in NSW commercial cotton farms. Survey results have therefore been used to support and justify requests for research funding and have contributed to the development of Integrated Disease Management strategies. Answers to questions regarding pathogens will ultimately assist the effort being made to reduce the impacts of disease on the sustainability of cotton farms through adoption of new strategies.

COTTON INDUSTRY PROFESSIONALS: THE NEXT GENERATION

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Question/Issue Being Addressed

How can we enhance the supply of young professionals and researchers into the cotton industry? Through expansion of collaboration between the Cotton Research and Development Corporation (CRDC), agribusinesses and the Primary Industry Centre for Science Education (PICSE), 2013/2014 has seen the extended engagement and mentoring of students in their early stages of university studies. A Cotton Undergraduate Internship program has been developed to provide participants with a practical experience within a diverse range of Cotton industries, designed to align with individual areas of interest.

Key Results/Findings

The success of the 'Cotton Industry Young Professionals Program', a partnership between PICSE and CRDC, highlighted the need to maintain contact with students once they embarked on their tertiary career. To maintain constructive and meaningful connection, a 5-day internship scholarship was designed and established to connect tertiary undergraduate students with industry scientists, university researchers and agribusiness organisations affiliated with the Australian cotton industry.

In the application process, students were asked to identify their enrolled tertiary course, year of study and indicate their

top three preferred areas of interest. Identified areas of interest included: Soil Science; Legumes; Plant Agronomy; Plant Physiology & Pathology; Entomology; Semiochemicals; DNA & Elisa testing; Plant breeding; Nutrition; Agribusiness & Agricultural Engineering

Three students were selected to participate in trials, with their internships occurring between December 2013 and May 2014. On completion, students submitted written reports outlining the practical activities of their placement, as well as their opinions of the experience. All students identified that their knowledge of the industry increased, as well as identifying a specific influence on their tertiary study and career pathways and a desire to undertake more engagement with the cotton industry. Student comments included:

UG1: "The industry placement was really an eye opener and a huge motivation boost for me to achieve well at university and do more work placements."

UG3: "As a result I am now rearranging my enrolment pattern so I can study USQ's Microbiology courses as part of my biology major."

UG 2: "The week gave me a solid direction to pursue throughout the rest of my studies. I'll now make better choices for myself when it comes to picking electives in my final year."

UG 1: "... was a great experience and Not only did I gain an insight into how the cotton

industry works and operates, but I also made some strong contacts with industry professionals."

UG 1: "Before I started... my interests were with irrigation development as this was really all I imagined an agricultural engineer could do. However, after seeing the Greenstar in action, and the technology involved my interests have really shifted towards precision agriculture."

UG 2: "After the internship, I realised how much career potential there is within the industry. I am looking forward to becoming more involved within the industry and, through further experience and my 4th year engineering thesis."

Impact Benefits on Australian Cotton Industry

Allowing university undergraduates to experience first-hand the diversity of roles within the cotton industry, not only increase their awareness, it enables students to see real world applications of the often theoretical-focus of their tertiary studies. Through active participation with the industry, students have the opportunity to foster industry contacts, investigate future workforce opportunities and make informed career decisions. This engagement assists cementing connections with tertiary students, potentially influencing areas of university study that could enhance research for the cotton industry, as well as facilitating personal connections with agribusinesses seeking personnel.

VERTICILLIUM WILT IMPORTANT QUESTIONS WE NEED TO ANSWER

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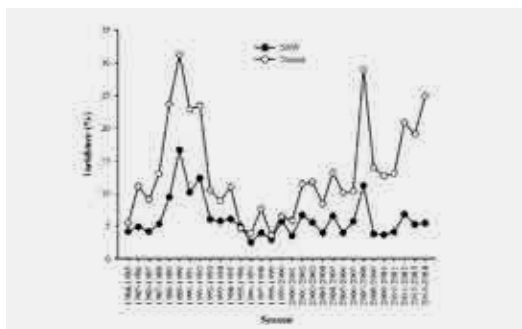
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Questions, issues being addressed?

- Verticillium wilt issues that NSW DPI Pathology in the project Diseases of Cotton XI have been and are continuing to look at.
- Quantify the propagules of Verticillium in different field's soil.
- Quantify the relationship between Verticillium inoculum and symptoms.
- To find what the relationship between Verticillium and (soil/water) pH is.
- To see the effect of different water sources (bore water compared to river water) on Verticillium wilt.
- To see the effect of different irrigation systems (furrow compared to lateral irrigation) on Verticillium wilt.
- Potential interaction between field levels of black root rot and Verticillium wilt.
- Collection of reference cultures to determine VCG's present.

Research outcomes

Verticillium was observed
in 38% of fields surveyed



GRAPH Verticillium Incidence (%) for NSW & Namoi from NSW DPI cotton disease surveys.

in NSW during the 2013-14 season. However, the average incidence was only 5.5% of plants infected. This can be compared with average incidences of 5.3%, 6.8%, 3.7%, 3.8% and 4.1% in the 2012-13, 2011-12, 2010-11, 2009-10, and 2008-09 seasons (respectively).

During the 2013-14 season the disease was observed in 91% of fields surveyed in the Namoi valley, 75% of fields in the Macintyre Valley, 54% of fields in the Gwydir Valley and 32% of fields in the Macquarie Valley where the average incidence of the disease was 24.9%, 2.0% 1.7% and 0.3% (respectively).

What impact will this have on the Australian cotton industry?

Verticillium wilt has been recorded in the NSW cotton disease surveys since 1984-1985. With the highest levels recorded in the Namoi valley. Areas with severe symptoms of Verticillium wilt were observed in several fields over the last three seasons. These areas have caused big yield reductions in these fields.

We will be continuing our collection of Verticillium reference cultures from the surveys. These cultures will be used to determine VCG's present in NSW cotton crops. Particularly important given a new strain VCG2A has been recorded in a NSW cotton crop. We will be working in collaboration with QDAFF by providing our reference cultures for VCG's determination.



1.



2.



3.



4.

1. AERIAL view of NSW cotton fields with severe Verticillium wilt.

2. GROUND view of NSW cotton field with severe Verticillium wilt.

3. VIEW of plants in NSW cotton field with severe Verticillium wilt.

4. A COTTON leaf displaying characteristic yellow mottle.

RPA CONFIGURATION FOR AUTONOMOUS CLOSE-UP FIELD SURVEILLANCE

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Outline

Current RPA (Remotely Piloted Aircraft, also known as drone) technology is capable of a wide range of applications. Detailed crop inspection has become possible as RPAs become cheaper and can easily carry light-weight cameras. This research will design a RPA system to autonomously monitor cotton fields, and explore the improved camera capabilities for new navigation techniques. This method of surveillance will give more frequent in-crop information than currently-available crop surveillance methods. The autonomous capability of the RPA will enhance on-farm useability.

Anticipated Results

Current RPA technology has been reviewed (Figure 1). The following research requirements for an autonomous RPA for cotton inspection have been identified.

- Mission planning and logistics - currently, RPA flight missions are defined manually pre-flight. There is potential for flight missions to update autonomously, based on field conditions detected during the flight.
- High precision localization - camera-based navigation for RPA (e.g. row detection, Figure 2) has potential to improve positioning accuracy compared to standard GPS.



- Image data management - required to enable real-time processing of imagery for autonomous navigation and storage for later high spatial resolution analysis.

Impact

The anticipated impacts of the RPA for crop inspection include improved water management in irrigation (from monitoring of real-time irrigation progress, Figure 3) and general crop growth monitoring.

In autonomous operation RPA systems are adaptable for other monitoring functions with a broader impact of the cotton industry, e.g. for specific early pest and disease detection and weed coverage detection to inform management decisions (e.g. pesticide and fertiliser application).

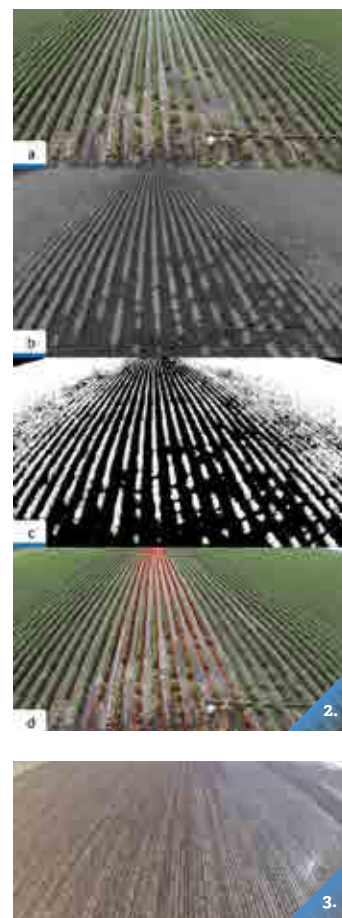


FIGURE 1 Typical RPA systems currently in research use for precision agriculture.

FIGURE 2 Captured image (a); represented in 'excess green' (b); binary thresholded (c); with row-detection (d).

FIGURE 3 Irrigation water use can be optimised with real-time aerial monitoring.

COTTON FARM HEALTH AND SAFETY PROFILE - 2014 UPDATE

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Aim

To provide the cotton industry with an update of the rates of work related serious injury and fatality to ensure that the most current and complete data possible is made available so that any priorities for and/or actions to improve cotton farm health and safety, can be based on up to date, comprehensive evidence.

Method

Information was derived from several sources, including:

1. National Coroners Information System 2001 - 2013
2. National Workers' Compensation Data 2008 - 2012
3. Injury and near-miss incident self-reports

Results and Discussion

National Coroners Information System

Data from 2001-2013 were accessed and analysed using several different strategies as the industry coding on the data is unreliable. From this process cases were classified as definitely occurring within cotton production or possibly occurring in cotton production. Where it was clear the fatality involved another commodity (e.g. cattle or grains), these cases were deleted from the analysis.

Cotton Related - seven cases were identified with mechanisms involving the

following:-aeroplane, cotton picker, dam drowning (child), farm ute, module builder (x2), water pump). Further data on the costs associated with the cotton related fatal incidents is being compiled.

Potentially Cotton Related - a further 28 possible cases involved properties where cotton is also grown were identified, with mechanisms being:- dams, earth moving equipment, firearms, forklifts, fuel store, motorcycles, quads, tractors, utes and being hit by objects (trees / equipment / structures).

Workers Compensation Data
Workers Compensation data were accessed for the four year period 2008/09 to 2011/12. Data for 2011/12 is provisional and it is expected that further cases will be added in time.

Number of Claims

- There is around 2,000 claims (0-4 days) and 3,000 (5+ days) per year across all Australian agriculture. Cotton represents less than 0.02% of all claims in agriculture for injuries less than 4 days and 5+ days.

Claims by Nature of injury

- Sprains and strains accounted for around one-third of both short term (0-4 days) and serious (5+ days) injury claims.
- Open wounds (without amputation), followed by contusions, foreign bodies and fractures were common in claims of 0-4 days duration.

- For the more serious injuries (5+ days), apart from sprains and strains, fractures, open wounds and contusions were most common.

Claims by Mechanism of injury

Being hit by moving objects, hitting stationary objects, falls and muscular stress (not carrying) were the major causes of short term (0-4 days) injury claims.

- A broader number of causal factors were involved in the more serious claims (5+ days) - falls from height (n=19), muscular stress (lifting), muscular stress (not carrying), hitting stationary objects, being hit by moving objects, vehicles and falls on same level.

Claims by Time Lost and Cost

- Almost 2,100 weeks of work time were compensated in the cotton sector costing over \$5 million. This compared to 182,000 weeks across all Australian Agriculture, costing \$296 million.
- The relevant proportion of time lost and related compensation costs within the cotton sector represented approximately 0.1% of all time lost and costs in Australian agriculture.
- The median time (weeks) off for injuries in the cotton sector (1.35 weeks) was around one-third of that for the grains sector and less than half that of all agriculture.
- The median cost of all injuries was around \$2,150 in the

cotton sector, which was significantly lower than the median for the grains sector (\$4,275) and all Australian agriculture (\$7,100).

- The serious injury claims comprised between 97.8-99.4% of all time lost and 94.6-99.03% of all compensation costs in these years. This indicates that the major burden associated with injuries is those that are more severe in nature. Consequently, these should be prioritised for attention as key risks or hazards.

Injury Self-Report

A series of cotton farm safety workshops were conducted with growers throughout the last six months of 2013. Workshop venues included - Boggabri, Bourke, Brookstead, Carroll, Dalby, Gunnedah, Moree, Mungindi, Narromine, St George (x2) and Theodore. In total approximately 80 growers attended these farm safety workshops.

At these workshops, growers were asked what have been the major types of injury on their properties in recent years. Growers reported that recent serious injury and near miss incidents involved motor vehicles, pickers, module builders, tractors, spray rigs and quads.

Summary

Workers' Compensation Injury Data alone does not identify and provide detailed information on the mechanism and cause of injury compared to data from the National Coronial Database.

To more accurately provide the cotton growing industry with better health and safety

information and strategies to further reduce the cost of serious injury; better apportioning of Workers' Compensation injury claims to industry sectors (i.e. mixed farming operations) is required.

Better information is also required from cotton growers, to provide more detail about how serious injury and near-miss incidents occur. This would increase the rate of health and safety improvement, especially to obtain a significant reduction in serious injury, Workers' Compensation costs and claims.

IMAGE ANALYSIS-BASED WEED DETECTION FOR SPOT SPRAYING

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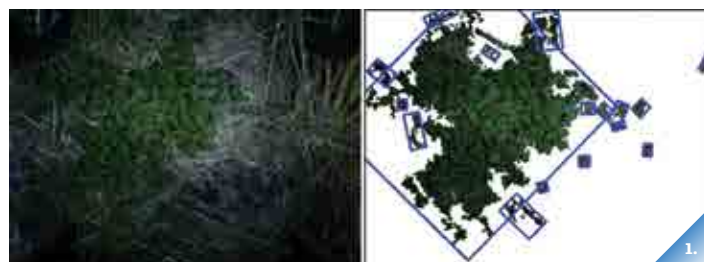
Issue being addressed?

Volunteer Roundup Ready cotton is becoming an emerging weed issue for the Australian cotton and grains industry. Innovative weed management strategies that specifically address volunteer cotton are required to eliminate a potential and significant problem for the industry into the future. A key component of volunteer cotton management is the ability to detect volunteer cotton in fallow fields and amongst other crop. An image analysis-based detection system is being developed to achieve such discrimination.

Results and findings

Proof-of-concept image analysis algorithms have been developed (Figures 1 to 3) and will be implemented on a three-metre weed spot sprayer for commercial-scale evaluations.

- Green from brown segmentation based on the greenness of pixels in controlled lighting successfully detected 100% of manually discernible plants, on soil and trash background.
- Grass from broadleaf discrimination based on the long leaves of grasses was successful at identifying 100% of sorghum plants amongst low-lying broadleaf weeds.
- Volunteer cotton up to 10-node stage was discriminated successfully from other plants



(vines, thistle and grasses) using criteria based on the cotton plant's morphology.

Weed Management and formulation of weed control strategies

Impact on industry

Weed detection using image analysis has potential application to weed spot spraying, targeted tilling and weed scouting. The technology will support:

- minimum- and no-till farming practices and the associated environmental benefits
- reduced chemical application rates through targeted treatments of individual weed species
- labour-saving infield weed identification for Integrated

The technology can be used to generate weed maps over different seasons with potential for emerging weed problems to be identified.

CRDC FUNDED CENTRE FOR THE DEVELOPMENT OF NEW BIOPESTICIDES AND SEMIOCHEMICALS (CBS) FOR IPM

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Issue being addressed

Australian cotton farmers have achieved substantial reductions in insecticide use from their adoption of GM technology to control *Helicoverpa* spp. However they now face problems associated with a wider range of insect pests that were once incidentally controlled, such as green mirid, cotton aphid and white fly. These pests have few insecticide options available for their control, forcing ongoing use of older, broad-spectrum insecticides that are likely to face increased regulatory scrutiny. Reliance on limited insecticide options can also create other problems by destroying beneficial insects and causing pests to become resistant over time. Thus, there is an urgent need to investigate and develop new alternatives such as pesticides derived from natural materials (biopesticides) and chemicals that mediate interactions between organisms (semiochemicals).

Work to date

A newly established Centre for Biopesticides and Semiochemicals aims to develop novel IPM products for the Australian cotton industry. The Centre will work with commercial partners to deliver rapid commercialization of its discoveries. It will also conduct training in biopesticides and semiochemicals R&D. Inaugural core Centre partners are the CRDC, NSW DPI, University of

Western Sydney and University of New England.

Initial projects under way are:

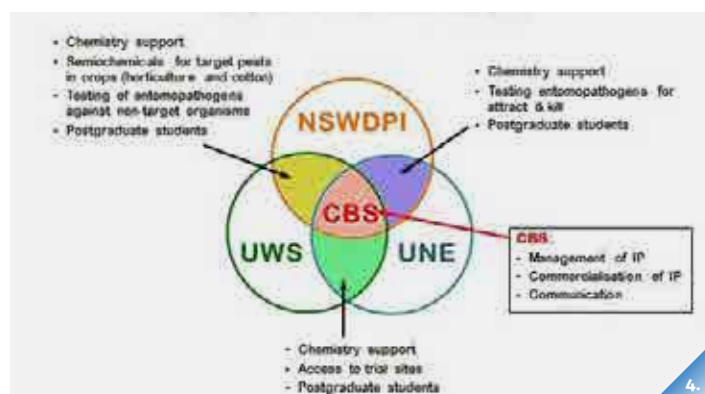
- Fungal biopesticides and semiochemicals for control of pests on cotton and other crops
- Novel insecticides and synergists from endemic and exotic flora
- The evaluation of pheromone-based monitoring for green mirids

The benefits of this research

The CBS and its projects will contribute to improving the sustainability and economic viability of the Australian cotton industry. As well as direct economic benefits, development of new strategies and products based on biopesticides and semiochemicals is likely to prolong the life of existing insecticides and other management strategies by reducing the risk of pests developing resistance to them. It will also train new researchers in this interesting area of plant protection.



1. **HEALTHY** adult green mirid.
2. **GREEN** mirid attacked by entomopathogen.
3. **ASSESSING** efficacy of biopesticides with a Potter Spray Tower.
4. **STRUCTURE** of CBS



IMPROVING PRODUCTIVITY WITH A TRANSIENT, UNSKILLED WORKFORCE?

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CRDC funded research - project *UM1201 Innovative work: Cotton workforce development for sustained competitive advantage.*



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The issue being addressed?

With yields now approaching cotton's known physiological limit, the focus is on how to sustain productivity growth through crop management. A key component of this is staffing, yet there are long-standing and unresolved workforce issues in the Australian cotton industry. These include the difficulty of attracting new entrants because of the poor perception of agriculture as a career, low levels of formal education and training in agriculture, and restructuring resulting in fewer, larger farms combined with reduced familial succession.

Key results

CRDC funded research into the on-farm workforce found a heavy reliance on predominantly unskilled casual international workers, in an industry which requires competence in operating GPS guided machinery. Due to the departure of the permanent workforce during the drought, combined with the demands of production post-drought the prevailing focus is on production, in lieu of investing in skill development and career pathways that could produce tomorrow's workforce. In addition while the demand for long working hours remains many staff now expect a work-life balance. Although initiatives to attract staff exist,

a collective, strategic approach to resolving the workforce issues is yet to emerge.

What impact could this research have on the cotton industry?

A skilled and experienced on-farm workforce has a key role in driving the sector's competitiveness and innovation. Through this research short and longer term strategies to develop a more sustainable approach to workforce development have been identified, and shared regionally and nationally. Will the industry choose to target continued productivity growth through addressing workforce shortages and skills issues, or will it continue to rely on a transient, unskilled workforce?



FIGURE 1. Precision agriculture from the use of GPS guided machinery.

FIGURE 2. Skilled workers required for round bale pickers.

FIGURE 3. Example of an employment advertisement.

CLOSING THE SOIL CARBON BALANCE IN COTTON FARMING SYSTEM

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The project will investigate the impact of land management practices (tillage, stubble management, crop rotation) on carbon losses through terrestrial pathways such as runoff, erosion, and leaching.

Knowledge on carbon loss by soil erosion will assist in determining accurate carbon budget for cotton farming system. The findings will feed

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into decision making process for cotton growers whether or not to participate in carbon farming initiative or direct action plan to mitigate climate change.

Soil has the potential to store large quantities of carbon which can offset against emissions that occur largely as a result of fossil fuel usage and land clearing. However, theoretical estimates of soil carbon sequestration in Australian farming systems often do not coincide with measured values of soil carbon, possibly due to post sequestration carbon losses. Previous research on carbon transport from the soil to the river system focused mainly on native forest and wetland areas, with only limited information available for cropping soils. In Australia, there is a lack of scientific data on carbon losses through soil erosion and runoff in cotton farming systems. The information on these carbon losses gains significance, especially, with the federal government's recent carbon farming initiative (CFI) or direct action plan to mitigate climate change. The main objective of this project is to

1. To determine the annual amounts of carbon lost through erosion in cotton farming systems.
2. To study the impact of land management practices and crop rotation on carbon loss and soil health.

Method

Investigation will be carried out initially at ACRI, Narrabri. The management practices include tillage, stubble management and crop rotation. Flumes will be used to measure and sample the runoff from each block of a particular management practice. Irrigation water sampling and analysis will be carried out to measure the carbon inputs through irrigation. Soil sampling will be done annually to monitor the carbon balance in each treatment. Deep drainage measurements will be carried out using ceramic cup solution samplers and a lysimeter. Runoff and drainage samples will be measured for total and dissolved carbon.

Results and Discussion

Annual loss of carbon from each management practice will be calculated from the results. The impact of long term land management practices such as tillage and stubble management, crop rotation and their interaction on soil carbon loss in furrow irrigated system will be assessed. The information on interaction of land management and crop rotation on soil carbon loss will help to feed information into cotton best management practices and carbon models.

Conclusion

This study will provide information on annual

terrestrial loss of carbon from irrigated cotton farming systems. Besides enhancing the existing knowledge on carbon benefits to cotton farming systems, this research will also provide managers and policymakers with sufficient information to determine whether cotton growers could successfully become involved in the Federal Government's carbon farming initiative (CFI) or direct action plan to mitigate climate change. Knowledge of carbon loss through the terrestrial pathways and quantifying its rates will enable improvement of current models of soil carbon sequestration for irrigated cotton-farming systems.



1. LONG TERM crop rotation trial in cotton farming systems at ACRI, Narrabri

2. DIRECT drilled cotton germinating among wheat stubbles

TOLERANCE TO BT TOXINS IN *HELICOVERPA* SPECIES

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Field surveys of *Helicoverpa* reveal low but significant levels of tolerance to Bt toxins, which appear distinct from high dose resistance. Additionally, laboratory strains of *H.armigera*, show incrementally increased levels of tolerance to either Cry1Ac, Cry2Ab or both Cry1Ac and Cry2Ab combined if they are fed low doses of the appropriate toxin over many generations.

Can these laboratory strains also survive on toxin to which they have not been exposed, and can they survive on Bollgard II flowers?

The Cry1Ac and Cry2Ab exposed strains showed 46- and 12-fold increased tolerance (at LC50) to their respective toxins (after 20 and 12 generations respectively). The combined strain that was exposed to both toxins responded with 18- and 38-fold increased tolerance to Cry1Ac and Cry2Ab, respectively (after 13 generations; Table 1). While tests with the Cry1Ac and combined strains are incomplete, 30-50% of Cry2Ab exposed neonates fed Cry1Ac toxin survived at doses lethal to susceptible controls (Fig 1). In addition, these neonates survived equally well on both non-Bt and Bollgard II flowers and bolls (Fig 2).

Our results suggest that tolerance to Bt toxins in *Helicoverpa* can increase under continuous low-dosage exposure under laboratory and field conditions. The increase

in tolerance could be due to physiologically induced maternally-transmitted tolerance and/or minor genes providing some resistance to the toxins, and these factors could reduce Bt crop efficacy in

the field. If either mechanism is significant, the refuge strategy must be refined to "dilute" both major gene resistance (the current focus) and minor gene or induced effects among larvae in the Bt crops.

Insect Strain (Generation)	Toxin	LC ₅₀	Ratio at LC ₅₀	n
Cry1Ac tolerant (C1)				
Susceptible C1G20	Cry1Ac	16.2	1	398
		743	46	359
Cry2Ab tolerant (C2)				
Susceptible C2G12	Cry2Ab	150	1	450
		1742	11.6	494
Cry1AC & Cry2Ab tolerant (C1C2)				
Susceptible C1C2G13	Cry1Ac	16.2	1	398
		290	17.9	400
Susceptible C1C2G13	Cry2Ab	150	1	450
		5679	38	359

TABLE 1. Tolerance to Cry1Ac and Cry2Ab in laboratory *H.armigera* strains. LC50: estimated micrograms of bacterial suspension per millilitres of solution required to kill 50% of the larvae; Ratio at LC50: the relative amount (in comparison to the susceptible control) of Cry1Ac or Cry2Ab bacterial suspension necessary to kill 50% of the larvae; n: number of total larvae in each full dose response bioassay.

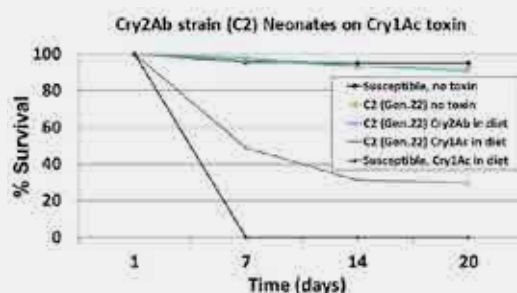


FIGURE 1. Survival of Cry2Ab strain neonates (C2 Gen.22) on Cry1Ac impregnated artificial diet. The C2 neonates survived best on Cry2Ab, and better on Cry1Ac than the susceptible neonates.

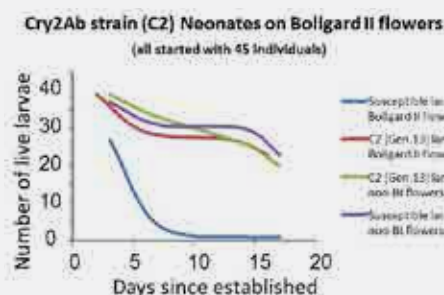


FIGURE 2. The survival of Cry2Ab tolerant neonates (C2 Gen.13) on Bollgard II flowers. The C2 neonates survived just as well on the Bollgard II flowers as they did on the non-Bt flowers.

ASSESSING ON-FARM ENERGY USE AND GHG EMISSIONS.

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Question/issue being addressed?

Continued pressure on oil price affects cotton production because it is a highly mechanised and high-input crop that relies heavily on diesel, fertilisers, chemicals and water. Increased greenhouse emissions and global warming places further limits on water, land, energy and other resources and meeting the demands of an expanding world population is becoming increasingly difficult. There is scientific certainty that climate change is real; the exact impacts of this are not fully understood.

Key results and findings?

To address these concerns, a CRDC-funded project entitled 'A protocol for assessing on farm energy use and associated greenhouse gas emissions' investigated how the cotton industry can identify and reduce their energy use. The project has a range of outcomes, including:

- A protocol for measuring energy use in cotton production,
- a library of energy use benchmarks for various operations
- an upgraded version of EnergyCalc, an on-line software that enables a novice person to quickly estimate energy use on their farm.

The project found that pumping, which consumes 50 to 70% of all energy used directly on-farm, has a potential for up to 30% energy savings. A pump check is a worthwhile investment. The project also identified that fertiliser and chemical account for much larger amounts of energy, which are used in-directly on-farm. Other potential areas for energy, cost and GHG gas savings include water application efficiency and tillage efficiency.

What impact will this have on the Australian cotton industry?

Once adopted, these will result in a cotton industry that is more viable economically and better placed to meet the increasing demands of rising energy costs. Any reductions in energy use will also reduce the carbon footprint of the industry, which, as most cotton is exported, adds to the 'clean and green' image of Australian cotton production.



1. ENERGYCALC provides a simple interface to estimate your energy use.

2. THE PROJECT used sophisticated systems to measure pump performance.

3. TRACTION and engine management systems, and especially depth control reduce fuel use.

4. ENERGY assessments can be a simple process with very low data requirements.



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ALTERNATE ENERGY SOURCES FOR AUSTRALIAN COTTON

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Question/issue being addressed?

Identification of alternative energy and fuel options in the light of significant and likely increases to the cost of traditional energy sources will more favourably position the Australian cotton industry to respond to cost of production pressures. Investigating alternative energy and fuel options will assist the Australian cotton industry to identify alternative energy options that will save energy and money and reduce GHG and those that are unlikely to be feasible. From this, the cotton industry can be informed on opportunities, costs and greenhouse gas implications of applicable alternative energy and fuels.

Key results and findings?

This work is currently in its final stages and key findings are being developed right now. The first step was a broad review of commercially available alternative energy options / technologies and costs. 20% of growers told us about their attitudes to and experience with alternative energies. (Thank you respondents.) Controlled laboratory and field tests were conducted on a range of fuels and the economic feasibility of alternatives were examined.

Our survey told us that growers were generally receptive to alternative energies if they were economic, available and easy to use. However, there

was also some resistance to alternative energies from some respondents, particularly to the contentious issue of CSG.

The survey, along with other information, indicates that for some farmers there is plenty of room for savings in pumping costs. There is also plenty of information on the performance of different types of liquid fuels, which is important because diesel provides, on average, 88% of all energy directly used in cotton production.

What impact will this have on the Australian cotton industry?

Once the results of this work have been fully examined the cotton industry will have a roadmap of which energy sources are feasible, how much they will cost and how they can be obtained. This work will help to address the increasing costs and decreasing availability of traditional energy sources.



1. SOPHISTICATED precision equipment was used to test and optimise various blends of fuels.

2. LPG GAS injection is a cost saving for electronic diesels, but not for mechanically injected diesels.

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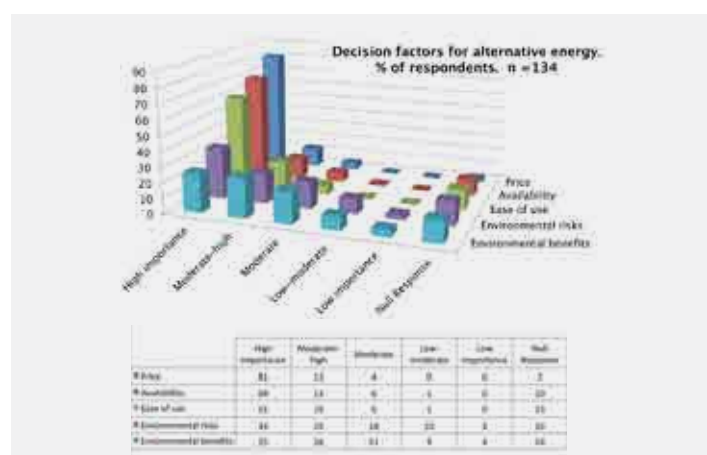


FIGURE 1. Importance of various factors in the adoption of alternative energies.

DETECTION OF NEW PATHOGENS IN AUSTRALIAN COTTON

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Why are disease surveys important?

Surveys are conducted by pathologists to monitor the distribution and importance of key endemic pests and record the presence or absence of new or exotic diseases. DAFF Qld has identified new strains of the pathogens that cause Fusarium and Verticillium wilt, two boll rots and reniform nematode. The impact of these findings on cotton production varies. Early detection is important so that management strategies can be implicated as soon as possible.

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What new pathogens have been detected?

- In 2005 a new strain of Fov in the Macintyre valley was detected. Using molecular techniques a new strain of the pathogen was determined (VCG 01113).
- Lasiodiplodia boll rot caused by *Lasiodiplodia theobromae* has been a common boll rot over the last three seasons in Queensland, however it has not been observed in NSW.
- In 2010 discolouration of cotton fibres within unopen bolls and seed rot were observed in the Burdekin. *Nematospora coryli* was isolated from discoloured tissue. This is the first record of this pathogen in cotton in Australia.
- In 2012 stunted plants were observed in Theodore. Roots were poorly developed and the tap root was covered with numerous swellings. Plant samples were collected and *Rotylenchulus reniformis* (reniform nematode) was diagnosed.
- Severe Verticillium wilt was reported in the Namoi Valley during the 2011/12 season. Analysis of the pathogen using molecular technique determined that the isolate was NOT an exotic strain. However the *Verticillium dahliae* isolate belonged to VCG 2A, a new strain of this pathogen in Australian cotton.

What impact will these new pests, diseases and strains of pathogens have on the Australian cotton industry?

- The new strain of Fov has not spread and is still limited to one field, hence no impact on Australian cotton production.
- Boll rots cause economic losses wherever cotton is grown. The extent of loss varies and is dependent upon local climate. The average incidence of boll rots in the 2013-14 season was 1.5% for Qld, of which *Lasiodiplodia* contributed.
- Seed rot was only observed in one crop in the Burdekin. If sucking insects are managed, *Nematospora coryli* should not be a problem for Australian cotton production.
- An intensive soil survey of post-harvest cotton of all farms in the Theodore region has determined that reniform nematode is widespread. Losses of 30 – 40% of yield were recorded in some fields. This nematode has the potential to cause significant losses to cotton production in this region.
- It is not known if the new strain of Verticillium is more virulent than the commonly known VCG in Australian cotton, however there was significant yield loss in the field where VCG 2A was detected. Research is underway to determine potential impact of this new strain on Australian cotton.



FIGURE 1. Lasiodiplodia boll rot (Photo Linda Smith)

FIGURE 2. Seed rot caused by *Nematospora coryli* (Photo L. Smith)

FIGURE 3. Defoliation caused by *Verticillium dahliae* (VCG 2A) (Photo Linda Smith)

FIGURE 4. Female reniform nematode excised from cotton root (Photo Jenny Cobon)

DEVELOPING EDUCATION CAPACITY IN THE AUSTRALIAN COTTON INDUSTRY

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The cotton industry is challenged with attracting and retaining core staff, on-farm labour, and access to professional advisers and service providers. This project is a strategy to link the cotton industry with schools, education organisations, government agencies and industry bodies to promote science and agriculture, particularly cotton. It links with other industry investments in education, development and delivery to attract, develop and retain skilled people in the cotton industry.

Key results and Findings

Since its inception in 2009 within the Cotton CRC, this project has delivered education programs linked to agriculture throughout 170 schools in 2 states and impacted 2865 primary school students and 1435 high school students. It has linked approximately 50 high school students with industry researchers and placed 18 undergraduate students as interns with cotton agribusinesses. There are emerging cases of students being engaged through this program at high school that have subsequently elected agriculture at university and are now engaged as professionals in the cotton industry.



What impact will this have on the Australian Cotton Industry?

This project aims to encourage students to elect science and agricultural as a career, either through academic training at universities or vocational education with agribusinesses. We are currently tracking successes through this project to gauge the impact on developing a capable and connected workforce that is resilient and highly skilled and contributes to a professional, profitable and sustainable community.

1. NARRABRI High School Year 10 students in the field at the Australian Cotton Research Institute participating in the Sustaining Rural Communities Bursary project "Careers by Kids for Kids".

2. WORK experience students at the Australian Cotton Research Institute, Katy Armson-Graham (Menai High School Illawong), Jess Kennedy and Gulio Heimoana (Narrabri High School), Kalinka Knudsen (Rotary exchange student from Denmark).

3. TENAYAH Woodward during her industry placement with Dr Karen Kirkby (NSW DPI).

4. DR SHARON Downes (CSIRO) helps a student create his own insect as part of the Narrabri Public School Science Extravaganza.

HIGH PERFORMANCE AUTOMATED FURROW IRRIGATION

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NCEA
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Issues being addressed?

Furrow irrigation is the most popular irrigation method in cotton. However, two issues: low efficiency and huge labour involvement concern irrigators due to scarcity in recent years. To address these issues, NCEA and Rubicon Water, Australia are developing a commercial prototype smart furrow irrigation system. The system has shown that both issues disappear with adoption of real-time optimisation and automated furrow irrigation.

Key results and findings?

Automated furrow irrigation

Figure 1 represents the automated furrow irrigation system developed integrating real-time irrigation

optimisation with Rubicon's surface irrigation automation hardware and software. This system is able to adapt the control strategy in real time to the changing field conditions. This relies on measurement of key data such as inflow rate and the speed of water advance.

Findings

The automated furrow irrigation system (Figure 2) was evaluated over the 2013/14 cotton season and was found to work reliably without manual intervention. The preliminary results indicate that higher irrigation application efficiency (up to 90%) is achievable along with significant labour saving.



FIGURE 2. Automated system in operation.

Impact on the Australian cotton industry?

Fully tested commercial adaptive real-time furrow irrigation system would be available to compete with the pressurised alternative of centre pivot or lateral move machines on capital cost, water and labour savings but without the massive energy costs.

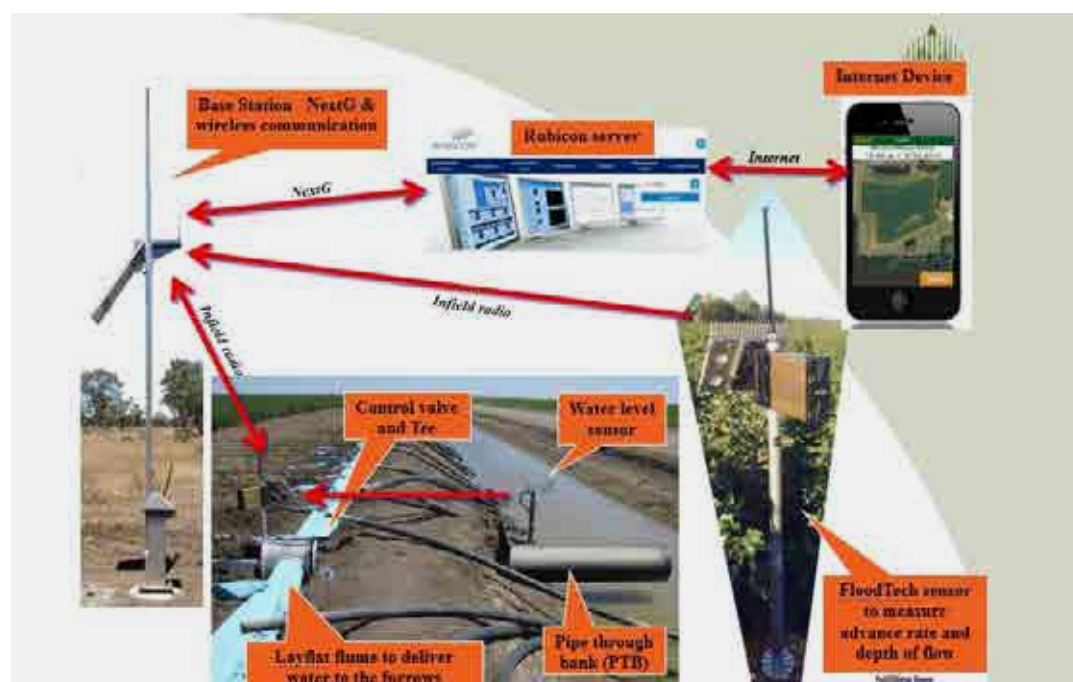


FIGURE 1. Automated furrow irrigation tested in field.

A SIMPLE STRATEGY TO MANAGE FURROW IRRIGATION EFFICIENTLY

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Issue being addressed?

Cut-off time is vital in furrow irrigation as it significantly affects the efficiency of irrigation. Traditionally, irrigators continue the irrigation until the water reaches the end of the field. Simulation software can also be used to optimise cut-off time. However, first method is proven inappropriate and the latter method is complex. Hence, a simple method to determine cut-off time for farmers to manage furrow irrigation efficiently was evaluated and found to give cut-off times similar to the optimum time.

Key results and findings?

Historical data analysis suggest two relationship between T_{co} and T_{adv} for cracking soils:

$$T_{co} = 2.55T_{adv50} - 0.11L$$

$$T_{co} = T_{adv90}$$

where T_{co} is the time to cut-off (min), and T_{adv50} and T_{adv90} are the advance rate (min) at 50% and 90%, respectively of the field, L is the length of the field (m). If it can be assumed that all of the cracking soil types have infiltration curves of similar shape then this relationship might be applicable for all cracking soils.

A comparison of different techniques to determine the cut-off time for some irrigation events in cracking soil is presented in Figure 2. The data revealed that cut-off time in farmers' managed irrigation was significantly higher than optimum. Figure 2 also shows that T_{co} obtained from the two relationships opposite were similar to the optimised cut-off time obtained from the simulations. The minor differences between methods suggest that the two methods react differently to differences in the shape of the infiltration characteristic.

Impact on the Australian cotton industry?

This technique will replace the farmer's guessing and complex optimisation techniques to manage the furrow irrigation efficiently with higher efficiency. It can save a significant amount of water and energy cost.

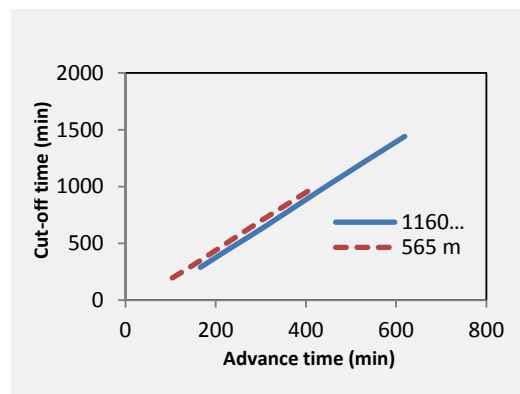


FIGURE 1. Relationship between advance time and cut-off time

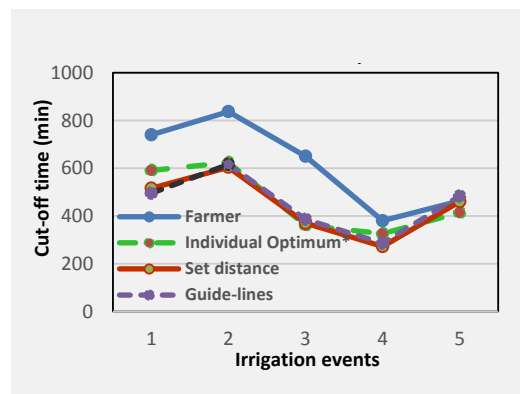


FIGURE 2. Comparison of cut-off time in different techniques.

OPTIMISING AMINOETHOXYVINYLGLYCINE APPLICATION RATE FOR WATERLOGGED COTTON

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Outline

Cotton (*Gossypium hirsutum* L.), an important economic crop of Australia, often experiences yield losses due to environmental fluctuations. Increased ethylene accumulation in waterlogged cotton plant induces young fruit abscission of waterlogged cotton. Earlier studies proposed the effectiveness of anti-ethylene agent aminoethoxyvinylglycine (AVG) for limiting ethylene biosynthesis in plants experiencing a variety of stresses e.g. salinity, drought and waterlogging. Through a series of glasshouse and field experiments, we optimised AVG application rate and time for waterlogged cotton.

Outcomes

- Reduced development of fruiting node, fruit retention and boll weight were the major causes of yield reduction in waterlogged cotton.
- Increasing application rate of AVG up to 125 g [ai] ha⁻¹ significantly improved cotton

yield, especially when applied during early reproductive growth phase of cotton.

- Pre-waterlogging AVG application caused 11-13% and 7-9% increase in seed cotton yield of waterlogged and non-waterlogged cotton, respectively, compared with non-AVG treated plants.
- AVG-induced yield improvement of waterlogged cotton was associated with increased boll number and weight, while in non-waterlogged cotton it increased final boll number only.

Summary

Higher fruit abscission is a common response of cotton to many stresses, which is accelerated by higher ethylene synthesis. Appropriate application rate and timing of AVG was found equally effective in increasing yield of waterlogged and non-waterlogged cotton. Positive effect of AVG on growth and yield of waterlogged suggested the importance of understanding the role of ethylene in cotton under abiotic stresses.



1a.



1b.



2.

FIGURE 1 Field operations; AVG spray (A) and waterlogging (B)

FIGURE 2 Plant growth inhibition under waterlogging conditions

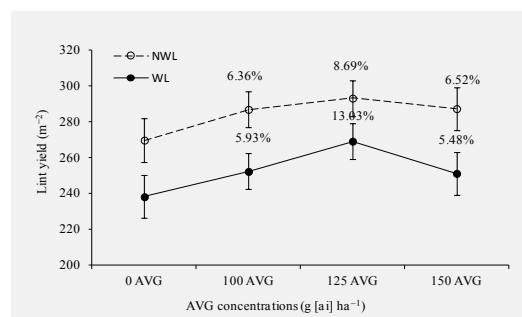


FIGURE 3 AVG-induced lint yield increase (%) in waterlogged and non-waterlogged cotton

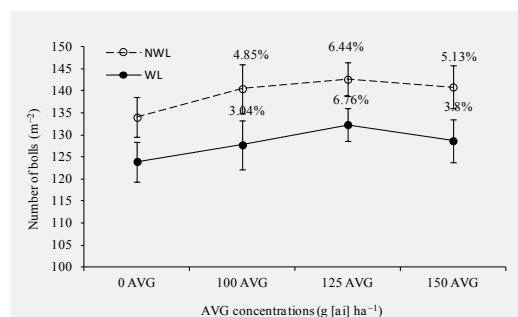


FIGURE 4 Increased fruit development (%) in AVG-treated waterlogged and non-waterlogged cotton

RELEVANCE OF *HELICOVERPA* EMERGING FROM BT CROPS

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A major threat to the longevity of Bt cotton is *Helicoverpa*'s ability to develop genetic resistance to high doses of Bt toxins. To counter this threat, refuges are planted to produce large numbers of moths to dilute any moths emerging from Bt crops which could be carrying Bt resistant genes. Using cages (Fig. 1), we compared the number of moths emerging from Bt cotton and productive refuges and their levels of resistance.

We found that relatively high numbers of moths emerged from Bt crops in comparison to their refuges. When these numbers were amplified to represent the amount of land planted in Bt cotton and refuge crops (90-95% and 10-5% respectively) they showed that about half the moths could have originated from Bt cotton (Fig. 2).

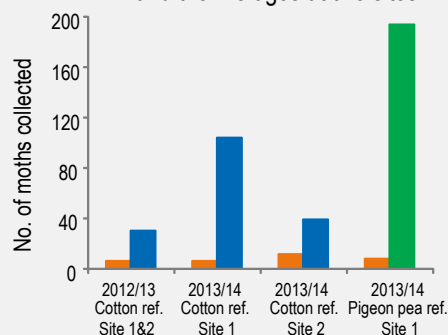
Field moths from Bt crops and refuges tested for genetic resistance to Bt toxins showed no difference in levels of resistance. However (in comparison to laboratory moths) the field moths were more tolerant to low levels of Cry1Ac, but not Cry2Ab Bt toxins.

Low level tolerance of *Helicoverpa* to Cry1Ac and low expression of Bt toxins by parts of the plant (particularly if under stress) may partially explain how susceptible *Helicoverpa* were able to survive on Bt cotton. These findings illustrate the pressure on Bt cotton and emphasise the importance of maintaining healthy refuges and a strong RMP.



FIGURE 1.

Number of *Helicoverpa* spp emerging from Bt cotton and their refuges at two sites



Percentage of *Helicoverpa* spp emerging from Bt cotton and their refuges proportional to their land area

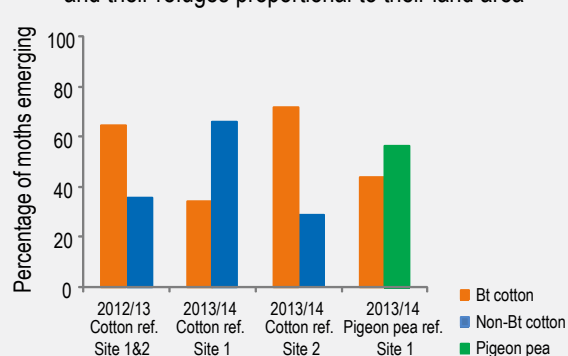


FIGURE 2.

LATE SEASON PEST DAMAGE – WORTH WORRYING ABOUT?

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The Problem

Periodically, late season outbreaks of pests such as thrips, jassids, cluster caterpillar and spur-throated locusts may cause damage to the cotton canopy and/or flowers. Research over 4 years investigated potential consequences for cotton by manually removing all leaves from the top 6 or 9 nodes at different dates from flowering to beyond cutout or removing 50 or 100% of leaf area. We also evaluated flower loss for a 1 week period to test if this interacted with leaf damage.

Results

In the first two experiments, removal of the top 6 nodes of leaves at late flowering or cut-out or of the top 9 nodes of leaves before cutout reduced yield by about 10-15% (Figure 1). Damage after cut-out did not reduce yield. In the second two experiments, removing 50% of the leaf area from the top 6 nodes of leaves did not reduce yield, while removing 100% at peak or early flowering did (Figure 2). The addition of flower removal for one week did not cause yield loss or delay maturity (e.g. Table 1).

Impact

Cotton can tolerate leaf damage after cut-out, requiring high levels of damage to reduce yield. At and before cut-out, leaf damage potentially reduces yield. Additional

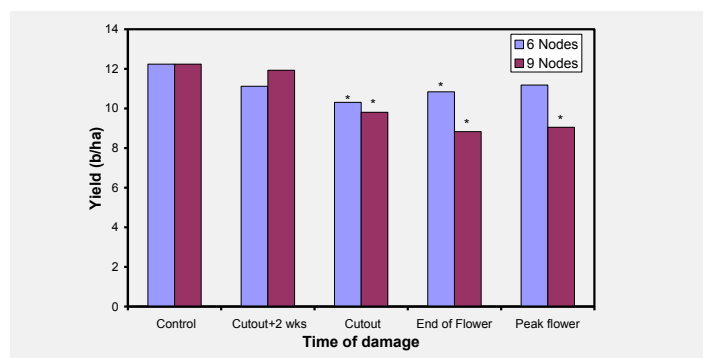


FIGURE 1. Effect of removing leaves from the top 6 or 9 nodes on yield

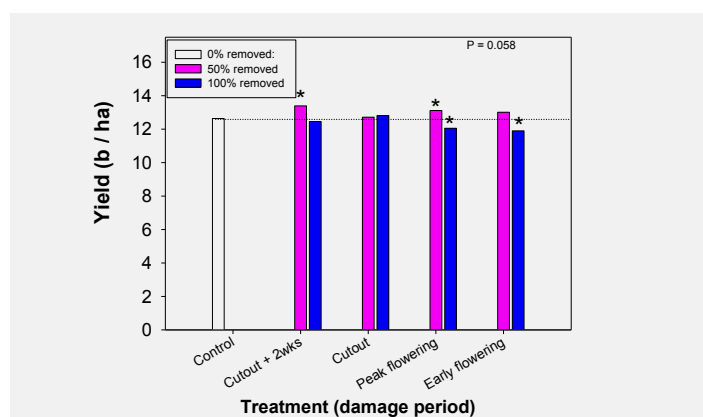


FIGURE 2. Effect of removing 50% or 100% of leaf area of leaves in the top 6 nodes.

Nodes damaged	Flowers removed					
	Yes		No		No	
	Mean number of flowers removed/m		Yield b/ha		Maturity (days after sowing to 60% bolls open)	
0	16.2	0	10.8	8.6	161.6	159.8
6	18.0	0	9.7	8.8	159.4	157.5
9	18.1	0	7.4	7.7	152.1	153.2

TABLE 1. Effect of flower removal on cotton yield, ACRI, 2007/08

flower damage did not reduce yield though further research should test if flower loss at different times or durations has an effect. Thresholds for leaf damage need refinement but a tentative threshold of 50% leaf damage in the upper 6 nodes post cut-out, and 20% leaf damage in the top 6 nodes pre-cut-out is suggested.

