CRC 106

Cotton Catchment Communities CRC

FINAL REPORT

(due within 3 months on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: 2.03.03

Project Title: Advancing environmental values in cotton catchments using risk assessment.

Project Commencement Date: 1 July 2005 **Project Completion Date:** 30 June 2008

Cotton CRC Program: The Catchment

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

Background

1. Outline the background to the project.

This project built on 12 years of environmentally focused research on cotton production by our group. Researchers at the University of Sydney have been closely associated with changes to cotton production and risk management issues, especially with respect of the use of pesticides. See for example, most recent CRDC projects (CRDC156C: *Classification of hazard of cotton gin trash;* US68C: *Management of risk for chemicals used in cotton production,* as well as the Cotton CRC project, "*Environmental benefits of on-farm wetlands*").

Changes in pest control for cotton production have been major, with a large reduction in pesticide use. These changes, including the introduction of BMP and of insect and herbicide resistant GM cotton, aimed at improving economic viability while reducing environmental risks and impacts. The primary aim of such initiatives was to ensure sustainable and adequate pest protection whilst facilitating environmental benefits, yet this had not been tested directly. It was therefore essential to test and document evidence for the success of these changes, to fully realise their benefits by providing factual data for the public forum.

Objectives

2. List the project objectives and the extent to which these have been achieved.

Objective A. Document and test the evidence for reduction of environmental risk within the Australian cotton industry associated with reductions in pesticide use.

A number of supplementary reports have been prepared that document environmental risk and pesticide risk. Benefits of Bt cotton varieties can be clearly shown when comparing pesticide use per ha. A strong trend between total pesticide used and rainfall was observed. We believe that rainfall is a precursor of insect pressure and can be used to predict periods of high pesticide use.
The environmental impact of herbicide use did not show a reduction as a result of the introduction of Roundup Ready cotton.

Objective B. To undertake strategic research designed to minimise environmental risk in the cotton industry as required by CRDC's steering committee.

A comprehensive study of the behaviour of residues in composting gin trash was conducted. It was found that pesticide degrade significantly faster in actively composted gin trash. This study also involved collaboration with CSIRO TFT, regarding contaminant in cotton seed and lint. This objective was also met through the development of simple on-farm test kits for the quick analysis of basic water quality parameters, the details of which are reported in project 2.03.04.

Objective C. To further develop practical risk assessment techniques, including assessing the use of GIS to reinforce risk assessment and the management of environmental data.
Detailed results of the risk analysis and the use of GIS in this project are reported separately within Centric. It was pleasing to have included students in the development of these techniques, gaining dual benefit for the industry. The GIS risk assessment framework has now developed into a PhD program (Mr Mitchell Burns).

New risk assessment techniques were developed for the gin trash project and are in the publication process.

Methods

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

This project adopted the most widely accepted approach to ecological risk assessment, which involves three phases, problem formulation, exposure and effect characterisation and risk characterisation and management (USEPA 1998; ECROFRAM 1999). An "extreme values" modelling approach was adopted to better characterise the probabilistic risks for exposure of pesticides from gin trash. This was a unique approach with respect to the methodology for ecological risk assessment and involved the analysis of rainfall events using Generalised Extreme Value theory. These methods are to be detailed in a peer reviewed publication, which will be available via Centric.

The diversity of pesticide use and fate within cotton production required different methods depending upon the assessment focus. Risk assessment regarding pesticide used in the cotton industry has ranged from planning new developments and risks with application methods (US49C; US51C), retrospective review of pesticide contamination (US50C), the impact of pesticides to local ecosystems (Sanchez-Bayo *et al.*, 2002), as well as the review of pesticides in cotton seed and gin wastes (US66C/68C and US156C). As shown by the collection of approaches above, a vast resource exists that contains methodologies to characterise exposure and effects data as well as risk. There are two approaches currently being developed within the Cotton CRC. The first is a collaboration using the EIQ scoring approach (Kovach *et al.*, 1992) and the second incorporates spatial analysis and GIS into the risk assessment approach (Burns pers. comm.). The EIQ approach (Kovach *et al.*, 1992) was used to inform the CRC board (January 2008) of the status of environmental impact with respect to herbicide use in the industry.

With respect to the assessment of gin trash (GT) and pesticide residues the following methodology was adopted. Three windrows of cotton gin trash were segregated at the study site (Myall Vale, NSW, Australia). Two windrows were formed using trash from conventional cotton and one windrow of trash from Bollgard® cotton. The mass of each trash pile was calculated using the average mass of each GT load (4347 ± 186 kg), determined by weighting three loads on the onsite weigh bridge, and counting the number of loads to form each pile. One windrow (A0), which comprised 17.4 t of trash, was used as a control. The remaining two windrows, Ac (Conventional composted) and Bc (Bollgard composted), weighing 30.4 and 26.1 tonnes respectively, were composted by addition of water and nitrogen. The piles were periodically watered and mixed using a tractor drawn implement. Because this experiment was the first of its kind, local composting practices were used for the experiment with the view to study composting efficiency in following studies.

The temperature of the actively composted trash piles were recorded using temperature probes and data loggers at 15 and 50 cm in each pile. The probes were removed at each treatment of the trash pile and replaced immediately after treatment had finished. Because of the uneven decay of the control pile it was not possible to record a uniform temperature profile during the experiment.

Samples of cotton GT were collected at days 1, 20, 44, 65, 146 and 209 after the gin trash piles were created. Eight replicate samples of 5 L were collected from each trash pile. Each replicate consisted of 10 separate grab samples from random locations and depths (all greater than 10 cm) within each trash pile. Because of concerns of pathogens in cotton GT, which prevent redistribution back to cotton fields, GT samples at the beginning and the end of the experiment were analyzed for *Fusarium* Sp., T basicola and *Verticillium* Sp. (involving collaboration with Dr Dave Nehl and group). Samples for chemical residue analysis were transferred directly for extraction and analysis. The sample transfer time varied between 10 to 24 hours for the 600 km journey depending upon the connection between sample collection and the courier aircraft or vehicle. Samples were sealed, covered and kept at ambient temperature during overnight transport and then extracted immediately on arrival. It was not possible to freeze samples because of the large volume of samples and the remote study location.

Each replicate sample was analyzed for 49 pesticides used in cotton production. Sub-samples were extracted for GC/MS analysis by shaking (1 min) and then soaking overnight in pesticide grade acetone/hexane (Mallinckrodt® 1:1) with 400 µL DEF *(4H-cyclopenta[def]phenanthren-4-one)* (10 µg mL-1 in toluene) as an internal standard. Moisture content of each sample was determined by difference after drying (105° for 24 h). The mixture was then filtered through 90 mm Whatman GF/C glass fibre filters (Whatman #1822 090) using a Büchner apparatus. The filtrate was evaporated to dryness and the residue redissolved in a hexane/acetone (2:1) solution using ultrasonication. The residue solution was then eluted under vacuum through a SPE column (Bond Elut Jr SAX/PSA, 500 mg, Varian Aust. #12166052B) preconditioned with 40 mL of pesticide grade acetone and 10 mL of column eluent (2:1 pesticide grade hexane/acetone). The columns were washed with 4 volumes of sample eluent and all aliquots were collected and then evaporated to dryness. The residue was redissolved in Toluene (2 mL Mallinckrodt pesticide grade) using an ultrasonic bath to dissolve wall adhering solids. At least 1 mL of the residue solution was transferred to a GC vial, capped and analysed by GC/MS (Hewlett-Packard 6890 GLC equipped with a 5972 MSD and a 30 m x 0.25 mm fused silica column coated with HP-5MS).

Sub-samples for LC/MS analysis were extracted after soaking overnight in a mixture of pesticide grade acetonitrile (Mallinckrodt® ACN) and water. After centrifugation, the extract was filtered and the organic and aqueous layers are separated by the addition of NaCl and $MgSO_4$. An aliquot of the ACN (organic) layer was taken and diluted. The sample was then filtered into a LC/MS vial and analysed by LC/MS/MS (Varian®). To correct for loss of dry matter from the CGT matrix during the study, highly persistent DDE residues were used as an internal standard.

These methods were justified because they include sufficient replication and quality control of the data. Interpretation of the results was aided by the DDE residues detected within GT.

Results

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

Objective A

Environmental Impact Quotient (EIQ) and Insecticides

The analysis of EIQ/ha within each catchment (Figure 1) shows the variation between catchments and the use of GIS mapping to aid interpretation of risk and to inform management. These data show that the differences in pesticide application (as recorded by CCA) provide different EIQ scores within each catchment. Surprisingly EIQ values were observed to increase, see 2003/04, even considering the large proportion of Bollgard cotton used within the industry. We expected to observe EIQ values decreasing in proportion to the percentage of Bollgard cotton planted.

EIQ and Herbicides

The EIQ and herbicide analysis focused on eight herbicides that are routinely detected in the river water quality monitoring (DECC). Although glyphosate has not been included in the water quality monitoring program, it was featured in our analysis because of the introduction of RR cotton. The 14 season EIQ trend with and without the value for glyphosate is shown in the figure below (Figure 2).

Unlike records for conventional and Bollgard cotton varieties, it is not possible to identify which products are applied to each herbicide tolerant variety. It can be assumed that most glyphosate would have been applied to RR varieties, except for channel and pre-plant applications (which accounted for 41.8 % of all glyphosate applications during the 2006/07 cotton season). Based upon the regression analysis between the percentage of RR planted and EIQ scores, no significant correlation was observed (Figure 3a and b). Clearly, the environmental impact of herbicide use has not reduced with the introduction of RR cotton.

Other analyses have included a comparison with average precipitation from four cotton catchments (Figures 4 a and b). Herbicides were not expected to show climatic trends within an irrigated crop, because based upon the per hectare analysis, water is equally available each season. However, a slight negative correlation can be observed (r^2=0.3). This suggests that during dryer years there is either greater focus on crop protection because of the increase relative value of water, or weed pressure is greater thereby requiring more control. These climatic influences were not strong with respect to herbicide use trends, which is different for insecticide use where stronger climatic trends can be observed.

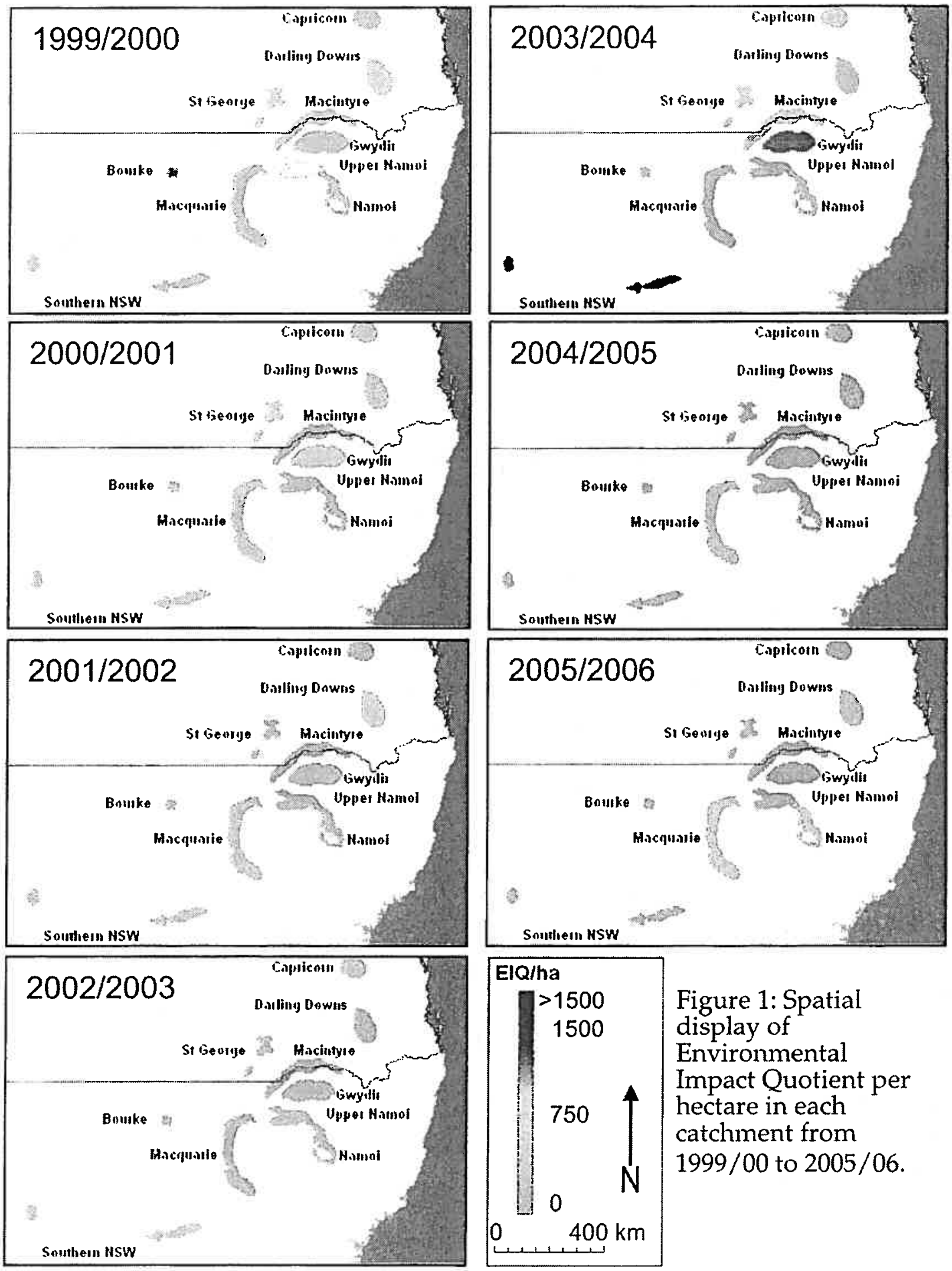

Figure 1: Spatial display of Environmental Impact Quotient per hectare in each catchment from 1999/00 to 2005/06.

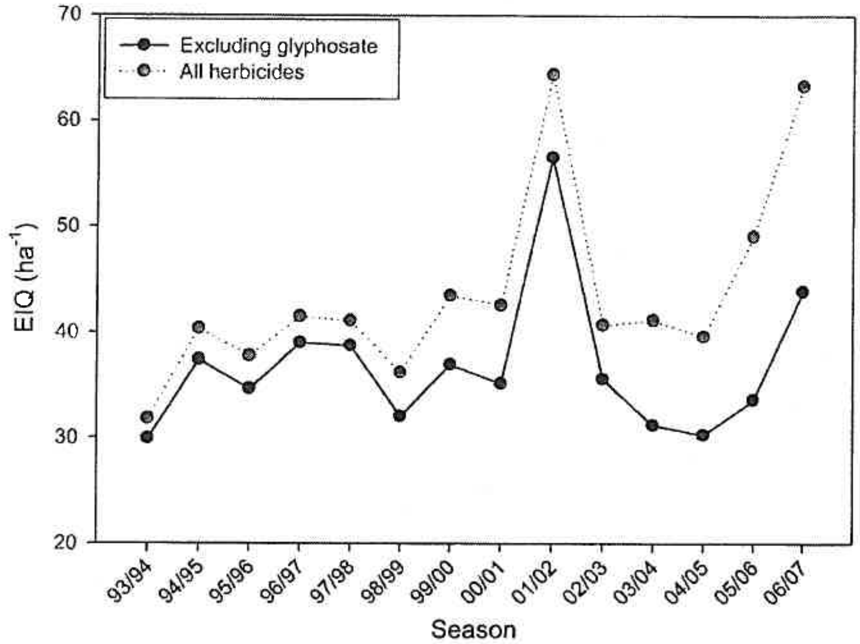

Figure 2: Fourteen season analysis of total EIQs for the herbicides included in this analysis.

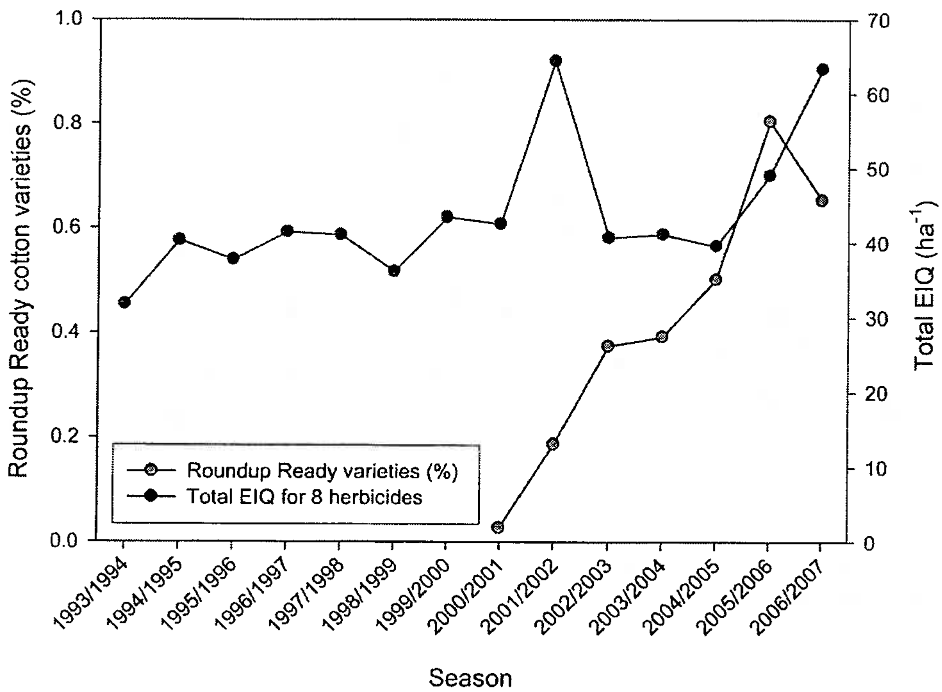

Figure 3a: Total EIQ per hectare of eight herbicides and the percentage of Roundup Ready cotton grown each season.

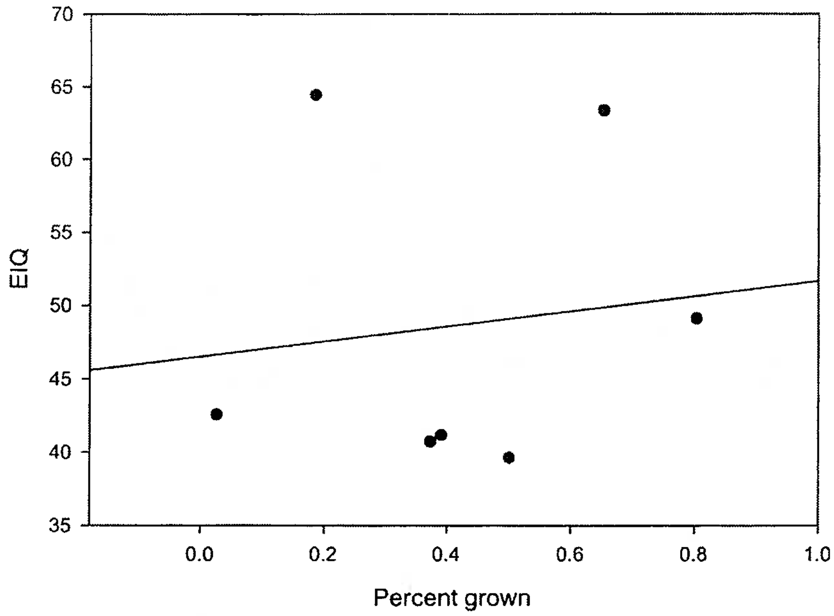

Figure 3b: Regression of data from 3a (poor regression r^2=0.02, n=7, indicating no trend between environmental impact and RR cotton).

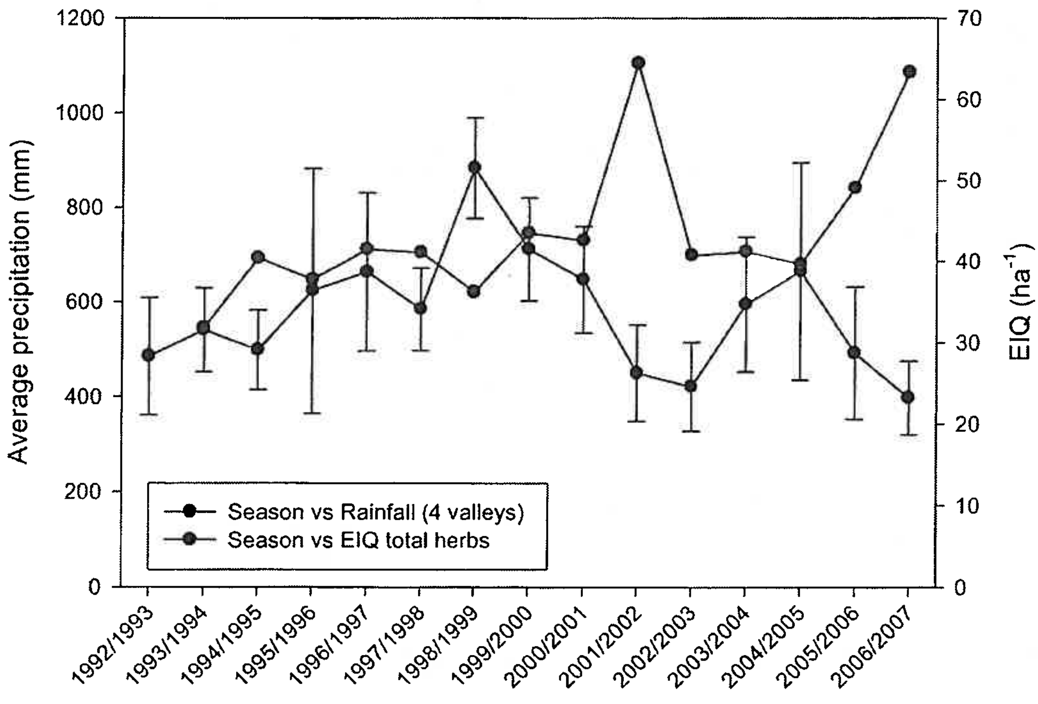

Figure 4a: Fourteen season record of EIQ scores and average precipitation from four cotton growing valleys (error bars indicate standard deviations).

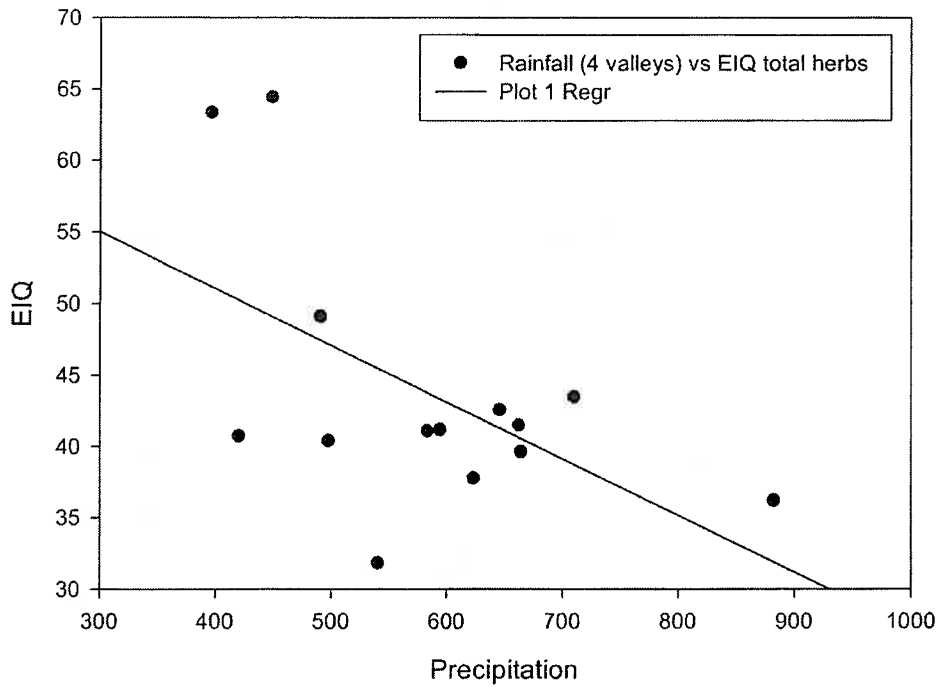

Figure 4b: Regression of data from figure 3a. Slight negative correlation observable (r^2=0.3; n=15).

Objective B

The comparison of the dissipation rates of pesticide residues in GT is presented below in Figure 5 and Table 1. Clearly the rates of dissipation are greater in actively composted GT (Ac) than for the passive control (A0). These results show that composting cotton gin trash reduces the pesticide residues significantly faster than when piles of cotton GT are left to decay passively.

We also showed that the use of Bollgard cotton can reduce the detection of pesticide residues in GT, however, this ultimately depends upon the pesticide application scenario. In this small study, minimal insecticides were applied to the crop. Consequently, the GT from the crop did not contain pesticide residues that were observed in the trash from conventional cotton.

Analysis of the use trends of pesticide in Bollgard cotton shows a different story. On average across the industry, it was found that a number of insecticides are used more in GM systems than in conventional production (Table 2). This includes a number of pesticides detected in GT, such as chlorpyrifos, dimethoate, and indoxacarb. It follows that residues of these compounds could still be detected in cotton GT from Bollgard and conventional varieties.

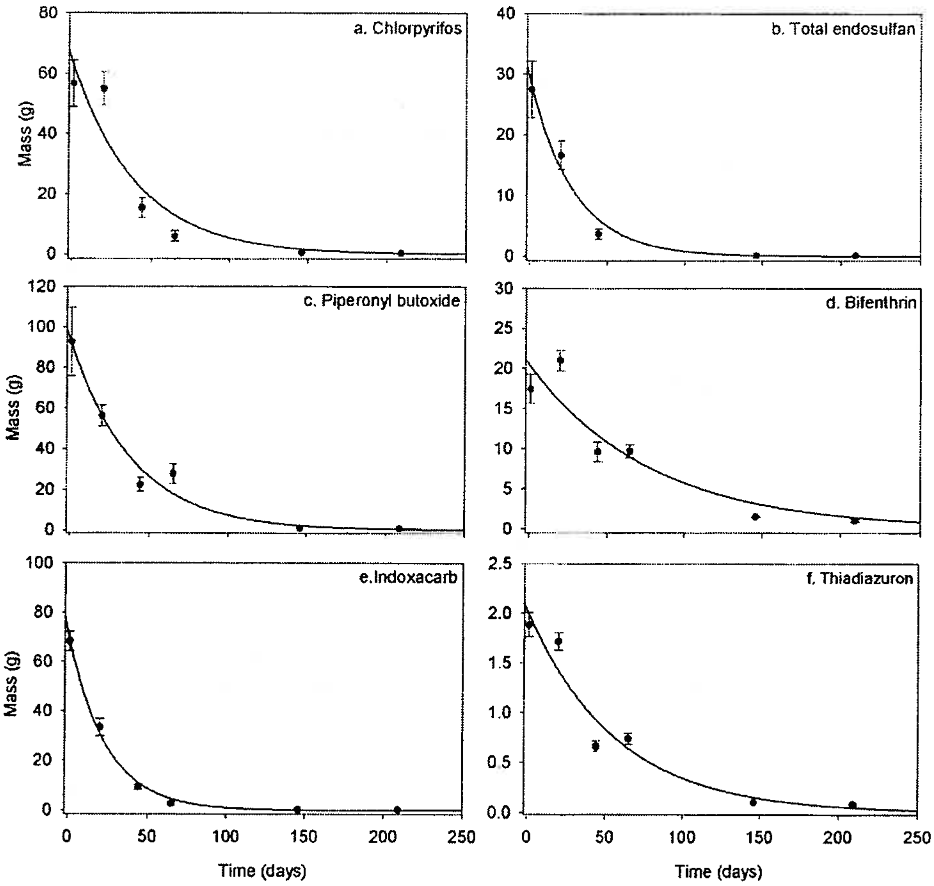

Figure 5: Dissipation of chlorpyrifos (a), endosulfan (b) piperonyl butoxide (c), bifenthrin (d), indoxacarb (e), and thidiazuron (f) in composted gin trash (Ac). Error bars show 95% confidence intervals of eight replicates.

Table 1: Results of regression analysis and model fitting ($y = ae^{-bx}$) for pesticide dissipation in composting gin trash. Coefficient standard errors (SE) also displayed.

Active Compost (A_C)	r^2	a	a_{SE}	b	b_{SE}	P value	n	$t_{½}$ (d)
Chlorpyrifos	0.89	64.4	9.6	0.025	0.008	0.004	6	28
Total Endosulfan	0.98	29.1	2.1	0.036	0.006	0.001	6	19
Piperonyl Butoxide	0.97	94.1	6.4	0.026	0.004	0.0003	6	27
Bifenthrin	0.87	20.5	2.8	0.013	0.004	0.006	6	55
lambda Cyhalothrin	0.93	5.4	0.8	0.030	0.010	0.2	3	(23)
Indoxacarb	0.99	71.9	1.9	0.042	0.002	<0.0001	6	16
Thidiazuron	0.94	2.0	0.2	0.018	0.004	0.001	6	39
Passive Compost (A0)[a]								
Chlorpyrifos	0.81	33.2	2.6	0.0039	0.001	0.015	6	178
Total Endosulfan	0.52	12.8	2.4	0.005	0.003	0.1	6	128

[a]Piperonyl Butoxide (r^2=0.31); Bifenthrin (r^2=0.32); lambda Cyhalothrin (r^2=0.45); Indoxacarb (r^2=0.21); Thidiazuron (r^2=0)

Table 2: Comparison of insecticide use on genetically modified and conventional cotton systems (GM:Conventional). Chemicals in bold typeface indicate high use ratios. (Data from 2007 CCA data). N/C =no reported use on conventional cotton; zeros or dashes indicate no significant uses.

CHEMICAL AND FORMULATION	***Historical Use Ratio (GM/Conventional)***					
	02/03	**03/04**	**04/05**	**05/06**	**06/07**	**5 yr Ave**
ABAMECTIN 18SC	0.96	0.43	0.37	0.63	0.82	0.64
ACETAMIPRID	-	2.40	0.43	1.12	7.25	2.80
ALDICARB 150G	1.35	0.88	1.20	1.11	1.47	1.20
ALPHA-CYPERMETHRIN 100EC	0.26	0.05	0.11	0.65	-	-
ALPHA-CYPERMETHRIN 16UL	0.00	2.83	0.16	0.00	-	-
BETACYFLUTHRIN 25EC/UL	1.90	0.02	0.10	0.34	0.07	0.49
BIFENTHRIN 100EC	0.00	0.03	0.05	0.22	0.02	0.06
CARBOSULFAN 250EC	-	0.00	2.48	0.00	-	-
CHLORFENAPYR 360SC	0.10	0.08	0.49	2.93	-	-
CHLORPYRIFOS 300EC/UL	0.14	0.07	0.04	0.01	0.00	0.05
CHLORPYRIFOS 500EC	0.55	0.55	0.53	1.24	1.50	0.87
CHLORPYRIFOS 750	0.06	-	-	-	-	-
CHLORPYRIFOS-METHYL EC/UL	0.21	0.31	0.23	0.00	0.00	0.15
CYPERMETHRIN 40UL	0.00	-	-	0.76	-	-
DELTAMETHRIN 27.5EC	0.00	0.09	0.04	0.26	0.03	0.08
DELTAMETHRIN 5.5UL	0.43	0.00	0.13	0.04	-	-
DIAFENTHIURON 500SC	1.36	2.04	0.26	0.96	3.12	1.55
DIMETHOATE 400EC	2.25	1.11	1.40	2.51	233.00	48.05
ENDOSULFAN 350EC	*0.11*	*0.12*	*0.06*	*0.17*	*0.002*	*0.09*
FIPRONIL 200SC	0.00	2.13	5.20	2.34	10.67	4.07
IMIDACLOPRID 200SC	-	0.28	-	-	-	-
LAMBDA-CYHALOTHRIN 6UL	-	0.12	0.20	-	-	-
LAMBDA-CYHALOTHRIN EC/UL	0.00	-	0.23	0.00	-	-
LAMBDA-CYHALOTHRIN ZEON	0.00	0.12	0.34	0.80	0.38	0.33
METHOMYL 225LC	0.00	0.00	0.03	2.46	0.00	0.50
NPV-Gemstar	0.00	0.09	0.00	0.02	-	0.03
NPV-Vivus	0.04	0.06	0.02	0.00	-	0.03
OMETHOATE 800SL	4.67	1.33	8.33	3.05	-	4.35
PARATHION-METHYL 500EC	0.00	0.00	0.00	0.26	-	-
PHORATE 200G	2.04	0.68	2.35	4.32	N/C	2.35
PIRIMICARB 500WG	0.00	0.00	0.95	0.00	-	-
PROFENOFOS 250UL	0.00	0.14	1.26	0.03	0.42	0.37
PROFENOFOS 500EC	0.00	0.00	0.11	0.01	0.00	0.02
PROPARGITE 600	0.00	0.24	0.21	0.46	0.54	0.29
PYMETROZINE	-	1.55	-	-	-	-
THIODICARB 375SC + 350LV	1.00	0.06	0.01	0.05	-	-

Objective C

New approaches to risk assessment have been initiated by this project. Catchment scale assessment using GIS is the focus of a new PhD program, which was developed from early findings of this project. More detailed description and results will be made available in due course.

The risk assessment of Cotton GT was advanced by combining the theories of probabilistic risk assessment and statistical modelling of extreme values. The model scenario involved the leaching of pesticides (based upon partition theory Eq. 1 and 2) from GT according to the volume of rainfall expected in the Myall Vale region. We found that there was potential risk of ecological harm, although the upper limit of rainfall provided a very narrow risk range. In short, assuming that full contact of rainfall and GT is made (a worst case assumption that should be corrected with experimental data) approximately 10% of species are at risk from chlorpyrifos, profenofos, bifenthrin and dimethoate. However, the maximum risk (<0.1%) is capped at between 15% and 40% of species (Figure 6).

Improvement of this approach would be aided by a detailed study of the leaching behaviour of these chemicals from GT. We suggest this would make a good student project and will seek a suitable candidate is due course.

Equation 1:

$$Kd = \frac{[CGT]}{[Aq]}$$

$$(Kd = K_{OM}.f_{OM})$$

$$(K_{OM} = K_{OC}.(1.7)^{-1})$$

Equation 2:

$$[CGT] = \frac{Pm - Pmaq}{Mcgt}$$

$$[Aq] = \frac{Pm - Pmcgt}{Vaq}$$

$$Pmaq = \frac{Vaq.Pm}{Mcgt.Kd + Vaq}$$

$$[Aq] = \frac{Pmaq}{Vaq}$$

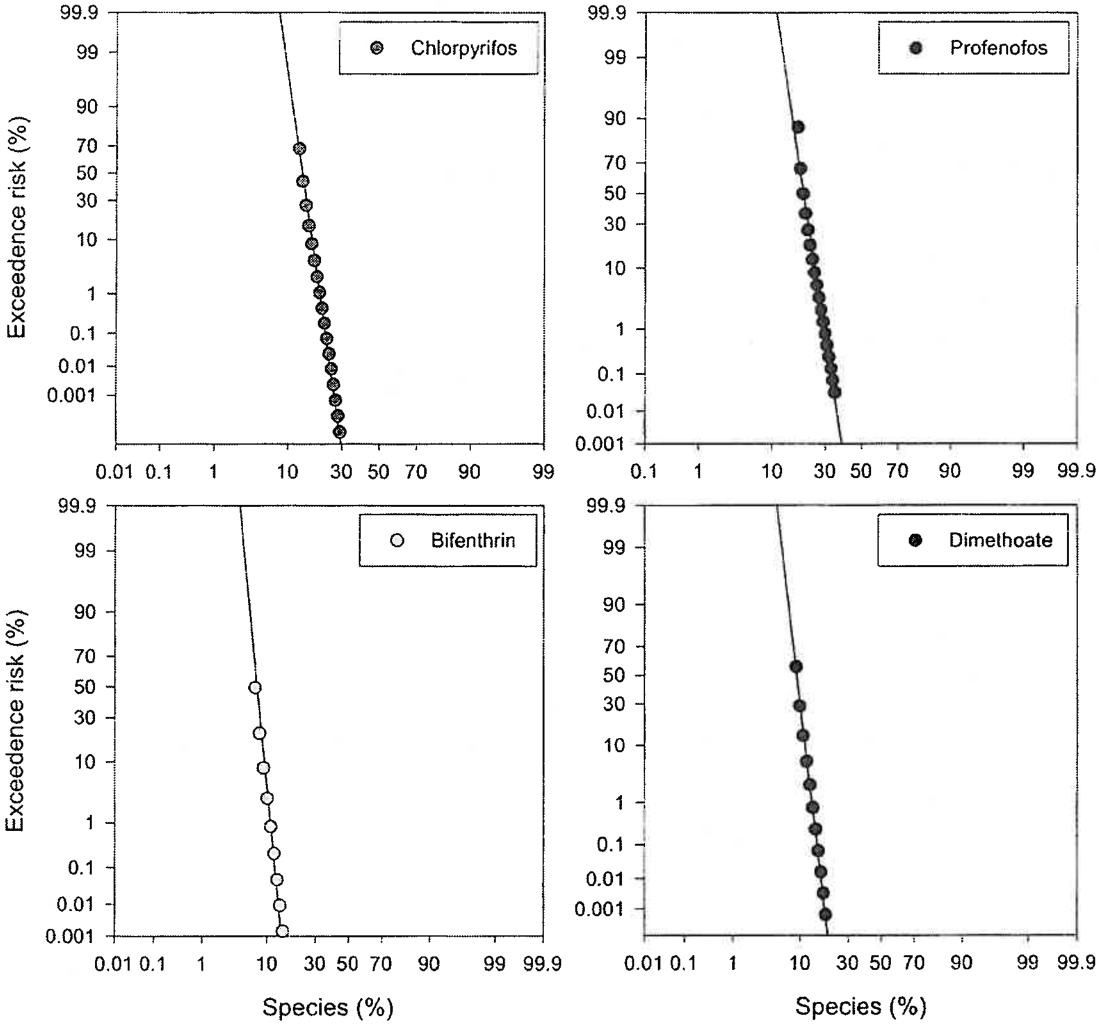

Figure 6. Joint probability curves illustrating the ecological risk of chlorpyrifos, profenofos, bifenthrin and dimethoate in leachate from cotton gin trash after rainfall.

Outcomes

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

The outputs of this project provide the basis of objective criteria for the measurement, validation and documentation of substantial beneficial changes to Australian cotton production regarding environmental management. Surprisingly, the impact of pesticide use was found to be strongly dependent upon climatic conditions, and use patterns within each cotton growing catchment. This information can be used by catchment/industry managers to manage the impact and risk of pesticide residues in cotton production. Currently, while growing conditions are poor, low risk is observed, however, it is likely that pesticide residue contamination issues will arise when growing conditions improve.
Even with the introduction of RR cotton, herbicide use within the industry continues to show sustaining ecological impact. This information has been used for industry strategy (Cotton CRC management) and is likely to form the basis of future, more realistic, environmental goals.

This project has advanced risk minimisation strategies, by providing information and data which can be used to plan responses and reduce pesticide residue contamination. For example, in addition to the use of EIQ information for industry planning, we identified that active composting of cotton GT reduces the concentration of pesticide residues. Whilst GM cotton varieties can be shown to lower environmental impact, careful planning of application scenarios should be considered to ensure benefits of the technology are realised.

6. Please describe any:-
   a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);
   b) other information developed from research (eg discoveries in methodology, equipment design, etc.); and
   c) required changes to the Intellectual Property register.

Conclusion

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

Whilst some assurance can be provided to cotton growers that the use of GM cotton varieties can reduce the environmental impact of cotton production, the benefits are strongly correlated with climatic conditions and specific application scenarios.

The active composting of cotton GT significantly reduces the concentration of pesticide residues compared to passively composted trash. The use of GM cotton does not reduce the potential contamination of GT because some chemical detected in GT are used more in GM crops than on conventional varieties.

Potential environmental impacts (EIQs) have not decreased with the introduction of RR cotton. This can be explained by the continued use of higher impact herbicides in weed management regimes. Environmental benefits of herbicide tolerant crops must consider the overall application program. It would be possible to develop herbicide programs that do reduce potential environmental impact.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:
   (a) to further develop or to exploit the project technology.
   (b) for the future presentation and dissemination of the project outcomes.

- The results from this study will be incorporated into two peer reviewed publications, both of which are currently in preparation.
- With assistance, we would be happy for the information to be presented in a format suitable for publication in the Australian Cotton Grower.
- There is the potential for better planning of application scenarios to reduce overall environmental impact. This would need to occur as a collaborative effort involving the identification of lower impact chemicals to be used in conjunction with GM (and convention cotton) to make full use of these technologies. This would likely involve environmental extension teams and catchment management personnel.

(c) for future research.

Re-use options for cotton GT need to be fully explored to ensure the costs of treatment are viable. Some further leaching studies need to be carried out to determine the extent of ecological exposure. We currently rely on worst case calculation which are likely to be an over estimation.

Publications

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

(NB: Where possible, please provide a copy of any publication/s)

Crossan AN and Kennedy IR (2008) Calculation of Pesticide Degradation in Decaying Cotton Gin Trash. Bulletin of Environmental Contamination and Toxicology (Online first).

Burns M, Crossan AN, Kennedy IR, and Rose MT. (2008) Sorption and desorption of endosulfan sulfate and diuron to composted cotton gin trash. Journal of Agricultural and Food Chemistry 56:5260-5265

Rational Environmental Management of Agrochemicals: Risk Assessment, Monitoring, and Remedial Action. ACS Symposium Series No. 966. Kennedy, Solomon, Gee, Crossan Wang and Sanchez Bayo (Eds). Oxford University Press, Washington, DC, 2007

Crossan AN and Kennedy IR (2007) Pesticide risk reduction by management practices - An environmental case study of the Australian cotton industry In, Rational Environmental Management of Agrochemicals: Risk Assessment, Monitoring, and Remedial Action. ACS Symposium Series No. 966. Kennedy et al. (Eds). Oxford University Press, Washington, DC.

Schofield, N., Williams, A., Holloway , R. and Pyke , B. (2007) Minimising riverine impacts of endosulfan used in cotton farming - A science into practice environmental success story. In, Rational Environmental Management of Agrochemicals: Risk Assessment, Monitoring, and Remedial Action. ACS Symposium Series No. 966. Kennedy et al. (Eds). Oxford University Press, Washington, DC.

Crossan AN and Kennedy IR (In prep.) The Effect of Composting on Pesticide Residues in Cotton Gin Trash. Journal to be determined.

Crossan AN and Kennedy IR (In prep.) Probabilistic Risk Assessment of Pesticide Residues in Cotton Gin Trash. Journal to be determined.

Crossan AN, Knox OG, Gupta, VS and Gregg PC (In prep.) Impact of Herbicide Use in Australia Cotton Production. Journal to be determined.

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

Part 4 – Final Report Executive Summary

This project provided valuable review of environmental impact and development of risk assessment strategies within the Australian Cotton Industry. It was found that GM technologies can reduce potential environmental impact by reducing or changing pesticide use practice. Although the benefits of Bt cotton varieties and reduced endosulfan use are well documented, a strong correlation between pesticide use (per ha) and average rainfall was observed. This indicates that climatic conditions offer a potential predictor of environmental impact. These results are based on the assumption that insect pressure is greater during wetter periods, thus requiring more insecticide use. We would therefore expect to observe an increase in pesticide use and environmental impact when growing conditions improve, commensurate to the use of Bollgard cotton within the industry.

Analysis of environmental impact of herbicide use did not show a significant reduction associated with the introduction of Roundup Ready (RR) cotton. These results indicate that improvements in herbicide use scenarios could potentially have been made by reduced use of "high impact" residual herbicides with introduction of RR cotton but this did not occur. However, the use of RR Flex® and Liberty Link® cotton may improve the potential environmental impact of herbicide use if such reductions in use of residuals is achieved. We also identified a slight negative trend (r^2=0.3) between herbicide application and precipitation. This indicates that if the climates become drier then an increase in herbicide use (g/ha) will be observed. We expect this was either a response of growers, aiming for a higher level of crop protection for improved yields or reducing the risk of crop failure, or a more virulent response by weeds during dry periods. The results of the analyses conducted within this project were used to direct industry goals with respect to environmental custodianship.

An experiment conducted within this project showed that pesticide residues dissipate faster in actively composted cotton gin trash (GT) than in passively composted GT. This experiment evolved from a previous study concerning potential environmental exposure and the regulation of GT wastes. Whilst composting of GT is recommended to reduce the concentration of pesticide residues, the resources required may be too large for an effective BMP. Further studies, with respect to re-use of GT, are more likely to identify a more suitable industry-wide management practices.