Australian Government
Cotton Research and Development Corporation

FINAL REPORT 2013

Part 1 - Summary Details

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

CRDC Project Number: **1108**

Project Title: Social, economic, environmental sustainability performance information for the cotton industry

Project Commencement Date: 1 Oct 2010 **Project Completion Date:** 30 June 2013

CRDC Program: 3

Part 2 – Contact Details

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Signature of Research Provider Representative: **30/9/13**

Part 3 – Final Report

Background

Worldwide demand for food and fibre is increasing to service the needs of a growing population and higher standards of living. At the same time, communities are striving for more sustainable management of natural resources. Farmers manage the majority of Australia's land and diverted water resources. As a result they have a direct influence on the sustainability of our economy, environment and communities. Cotton farms are intensive large scale cropping systems and the industry is continually under pressure to demonstrate sustainable management practices.

The cotton industry needs to achieve both the demands for increased output of agricultural products and those for sustainability. For this to be possible, it is important for farming industries to measure and understand their current sustainability trends and adapt practices as required. For the purpose of this project, sustainability includes three distinct, but related economic, environmental and social parameters.

Monitoring and benchmarking is essential to measure achievements, identify areas for improvement and communicate trends to interested parties. Measurement of industry sustainability requires consistent approaches across multiple farms, regions and sites, repeated over long periods of time. The cotton industry needs to establish a core set of indicators applicable across the range of farming situations, both large and small.

Every farm is unique due to its location, history, natural resources and human components. Cotton farms around the world face many common challenges. These challenges include falling profitability, increasing crop yields, and improving fibre quality. They also include energy use, greenhouse gas emissions, the management of biodiversity, salinity, water use and quality, soil health, interactions with river and groundwater systems, pesticide use and transgenic trait crop management. There are also many external pressures such as climate change and variability, market forces, community views and changes to government policy.

Sustainability indicators will also assist with business planning, resource allocation of industry funds, and provide documented evidence of natural resource stewardship and community impacts of the cotton industry.

At the international scale the Global Reporting Initiative of the United Nations is the most common framework for reporting sustainability. It is now common for companies and organisations to publish sustainability information in Australia. The International Cotton Advisory Committee also has commenced some research on sustainability.

Roth (2009) completed his doctorate thesis (211 pages) that set out to compile data from a wide suite of published and unpublished research and monitoring data sets to provide and overall picture of the sustainability trends of the Australian cotton industry. It included coverage of economic, environmental and social metrics, and a 10 year analysis of the Best Management Practices Program audit results. The thesis summarised important economic, environmental and social sustainability indicators for cotton industry and their relative ease of collection and current information quality.

The cotton industry does have some excellent sources of information. There are hundreds of research reports and scientific papers. The industry has held 14 national conferences, which include conference papers. The stories in The Australian Cotton Grower Magazine contain about a 30 year repository of information and events. There is a vast amount of information that is available for a 'point in time'. However, there are very few data sets that can be easily used to monitor changes over time, especially longer term trends, across the industry. However, by pulling together data from various reports it should be possible to build a longer term trend.

Objectives & Methods

The project's objectives were to:

1. Develop and implement a robust, credible, flexible and efficient system for reporting on the social, economic and environmental information for the cotton industry.

2. To foster a creative and empowering forum that builds industry human capacity and knowledge across the breadth of economic, environmental and social disciplines that make up the cotton industry.

Following novation of the project from the Cotton CRC to CRDC in June 2012, the following milestones were contracted by CRDC for 2012-13.

- Milestone 3.1.1 Agreed work plan with project steering committee (30th Sept). (Completed)
- Milestone 3.1.2 progress report completed by 30th November 2012. (Completed).
- Milestone 3.1.3 Final report.

A new CRDC steering committee (Allan Williams, Bruce Pyke, Greg Kauter,; Apologies Jane Trindall) met in September 2012 at CRDC. The following was agreed for the remaining project period:

- Completion of the Australian Cotton Water Story. (Completed)
- Provide a summary of possible sustainability indicators in a Table for November milestone report. (Completed).
- Produce a scientific paper reviewing water use efficiency in the Australian Cotton Industry. (The paper has been submitted to *Journal of Crop and Pasture Science).*
- Communication some data to regional grower groups in February 2013.

  (Additional data was compiled specifically on soil nutrition and presented in "Cotton Farming Practices Snapshot of trends" which was mailed to growers as part of another CRDC Grower Survey project. Some data was also presented at 4 regional grower workshops in March/April 2013).
- Include in the final report updated data sets where possible and commentary on priority indicators. (Included in this report)

Results & Discussion

1. Thesis Publication

The first activity in 2010 of this project was to desktop publish Roth's 2009 thesis "Economic, Environmental and Social Sustainability Indicators of the Australian Cotton Industry" (120 pages). Some additional funds were provided for the desktop publishing. This report was placed on the Cotton CRC web site. It has been commonly cited by others researching Australian Cotton Industry, the Murray Darling Basin Plan, and the Cotton Industry Environmental Review and Rural Communities research. During this project the principal researcher has received a number of ad-hoc requests (about one per week) for information from a range of stakeholders. An extract from the document is shown below showing rising cotton yields (economic), less pesticides in the river system (environmental) and less complaints be received by the NSW EPA (social).

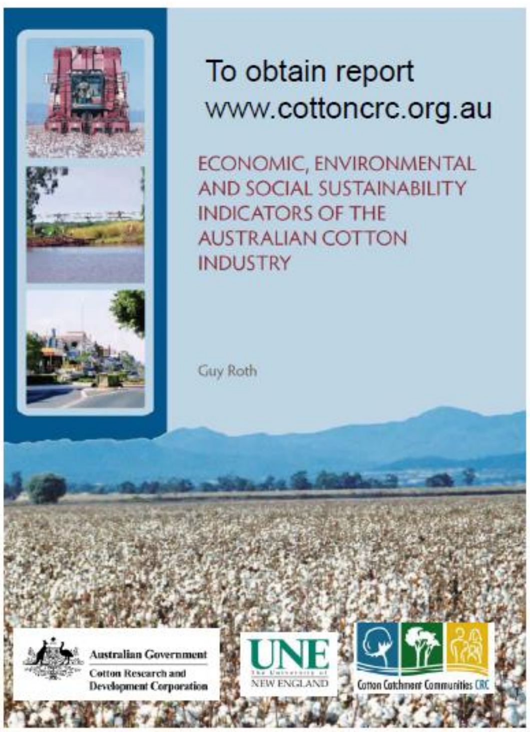


Figure 5 The rise of cotton lint yields 1962–63 to 2008–09 and some related impact factors

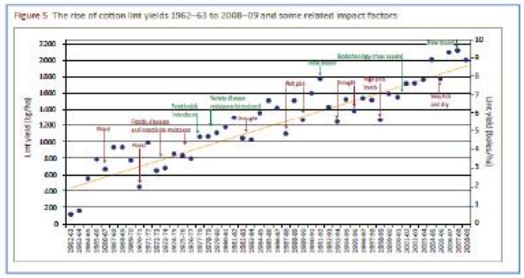


Figure 45 Total endosulfan concentrations in the Namoi Catchment from 1991–1992 to 2006–2007

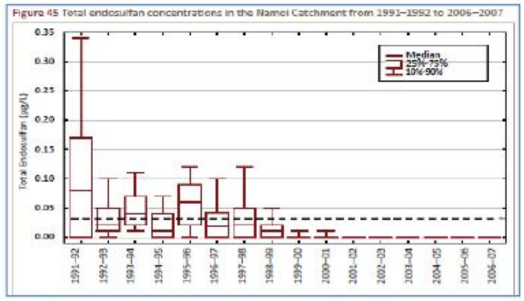
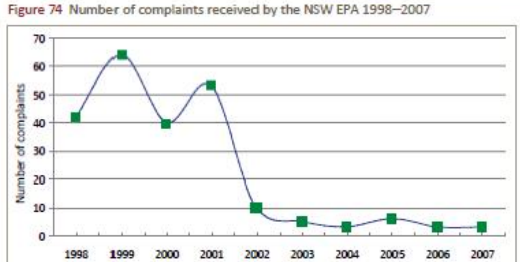


Figure 74 Number of complaints received by the NSW EPA 1998–2007



Source: NSW EPA, pers. comm. 2007

2. Cotton Sustainability Project Collaboration

In March 2012, in order to progress the broader discussion and collaboration of research projects in the cotton sustainability space this project arranged a "sustainability" meeting at UTS in Sydney as part of a steering committee meeting. The meeting included the UTS Value Chain project team, Francois Visser UQ on carbon accounting, Victoria Whitaker, Australian Manager of the Global Reporting Initiative, Cotton Australia, CRDC and a guest speaker on fashion. This was attended by about 20 people. The meeting feedback sheets indicated this was a worthwhile meeting. Subsequently, this project spent more time with the UTS team including hosting a farm tour and follow up meetings in Narrabri.

3. *Book Chapter in Defending the Social Licence of Agriculture*

A book chapter on the Cotton Industry as a case study on self-managing its social licence to operate was published by CSIRO Publishing "Defending the social licence of farming. Issues, challenges and new directions for agriculture" and was launched by Hon Tony Windsor MP, in November 2011. A copy of the entire book was distributed to CRDC, Cotton Australia and the Cotton CRC staff members. There was a related media story in
The Land newspaper 17th November 2011, which discussed cotton as an example of best practice. A full page article was also compiled by Angela Bradburn, Cotton Australia and included in the Autumn 2012 Spotlight on Cotton R&D magazine on the social licence to farm.

The specific focus of the cotton chapter was the BMP Program and data of practice change using the BMP audit rankings was presented. Below is the related media story The Land newspaper 17th November 2011, which discusses cotton as an example of best practice.

NEWS THE LAND | Thursday, November 17, 2011

Forget right to farm

Farmers need to fight for social licence

By MATTHEW CAWOOD

DEFENDING "the right to farm" is unproductive, a new book argues; farmers instead need to lead the community in establishing the terms of agriculture's social licence.

That social licence is going to become more difficult to attain, and more important, says Paul Martin, co-editor of the new book, *Defending the Social Licence of Farming*.

Professor Martin, director of the Australian Centre for Agriculture and Law at the University of New England, defines social licence as "the freedom that society allows owners of resources to do what they want with that resource".

Australians still have a strong basic desire to support farmers, Prof Martin thinks.

"But there have been enough examples that have violated community expectations to ensure farming doesn't have a universally positive image, and can't really rely on society supporting farmers rather than somebody else.

"At the moment there is a political grouping of farmers that are characterised by responding on a defensive basis to new issues, which means they are always on the back foot, always defending or always attacking.

"But there's a different kind of dialogue that farmers can have with the community."

Three examples of that "different dialogue" outlined in the book are the Australian cotton industry, Biological Farmers of Australia (BFA) and Iceland's farming sector.

The cotton industry successfully shifted from a costly defense of much-criticised practices to management innovations that made defence largely unnecessary, and also greatly improved the industry's bottom line.

BFA had built its organic brands and labels around community concerns about chemical use in farming.

"Farmers in Iceland needed to defend their legitimacy because of the effects of farming on a very vulnerable landscape," Prof Martin said.

"They embraced a program called 'Farmers Heal The Land', modelled on Landcare.

"While Landcare in Australia has had some challenges, the Icelandic program has persuaded the community that farmers really do care for their landscape.

"That in turn has helped them with the politics of maintaining subsidies and legitimacy as an industry."

Setting out on a path of proactive self-regulation involves considerable challenges, not least internal politics.

"If the community can't detect a difference between those who are genuine stewards of the land, and the others, they probably aren't going to treat them any differently," Prof Martin said.

"Unless the good farmers are prepared to take some level of action against poor farmers, then self-regulation doesn't work.

"And very few farmers are prepared to dob on their neighbours."

Because of these tensions, any farming sector that wants to proactively develop its social licence has to have the determination to do the job right, and the leadership to carry it off.

"It's quite a different model than the political-legal model that many people think is the way to go.

"It's not enough to be prepared to defend: they have to be prepared to embrace what the community is saying and respond."

Prof Martin instead argues for a model "in which the industry searches its soul to find out what harm might it cause and how might it minimise it, and work with community to find out what good might it do and how to maximise that good".

"Then it has to take some real responsibility for those things – and shout that fact from the rooftops."

■ *Defending the Social Licence of Farming* is available from CSIRO Publishing.

4. *Global Reporting Initiative – www.gri.org*

A guide to reporting environmental indicators for triple bottom line reports was produced by the Australian Government in 2003 (Environment Australia 2003), which outlines environmental management indicators, including links with the Global Reporting Initiative. It is almost universally acknowledged that the Global Reporting Initiative is the emerging international standard for sustainability reporting (Parliamentary Joint Committee on Corporations and Financial Services 2006). This was the most prominent and widely accepted framework from submissions to the Australian Parliament Committee examining corporate reporting (Parliamentary Joint Committee on Corporations and Financial Services 2006).

The Global Reporting Initiative (GRI) was convened in 1997 by the Coalition for Environmentally Responsible Economies (CERES) in partnership with the United Nations Environment Program (UNEP).

The guidelines are for voluntary use by organisations reporting on economic, environmental and social dimensions of their operations performance. The GRI framework presents reporting principles and specific content indicators to guide the preparation of organizational-level sustainability reports. It is possible for organisations to produce an "in accordance" report for organisations ready for a high level of reporting, or they may report using the incremental process.

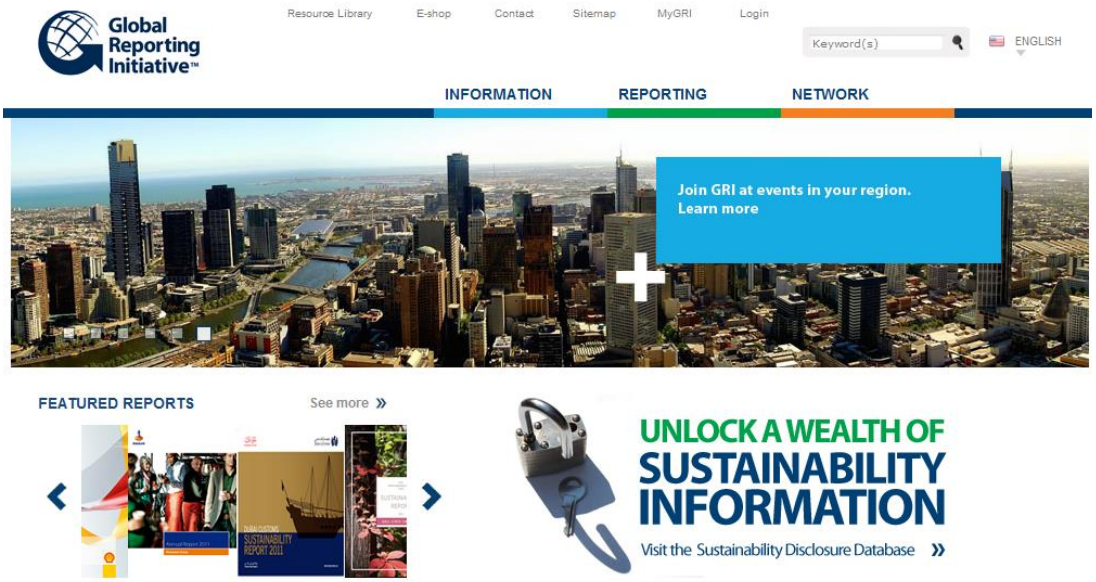
Many companies use the GRI, but a notable gap is the lack of agricultural companies and organisations in Australia. Further evidence of the lack of agricultural participation is that GRI has produced sector specific supplements to enhance the generic principles, but agriculture is a notable omission from these sector supplements which include energy, mining, telecommunications, automotive, finance, real estate and other sectors of the economy.

This project investigated the relevance of the GRI. This included:

- Reviewing the literature
- Meeting with staff of St James Ethics Centre who host GRI in Australia.
    - In March 2012, Guy Roth attended the inaugural Australian GRI Conference on Sustainability and integrated reporting. He presented a poster which is now on the conference website. https://www.globalreporting.org/information/events/australian-gri-conference-2012/abstracts-and-posters/Pages/default.aspx More than 250 participants discussed sustainability reporting trends and its role in a sustainable economy. These included major companies like BHP, Woolworths, Westpac, etc. as well as Superfunds and Government. For the cotton industry:Wal-Mart, Addis, PUMA & South African Cotton rated mentions as GRI leaders.
- The Australian Manager of GRI made a presentation at the previously mentioned cotton sustainability meeting in March 2012.
- A written submission was made to the International review of sector supplements on the GRI. In essence saying the GRI indicators are not well suited to individual farm business/organisations, evidenced by a notable gap in farms (or farming organisations) in GRI. The current GRI indicators are better suited to organisations higher up the supply chain such as food manufacturers. A publically listed agricultural company would be able to use the GRI guidelines and this project did approach one such company.

- The GRI is growing in statue and it remains important for agricultural groups to monitor. It is suggested through engagement any technical matters can be addressed and influenced.

This would possibly be done best at the National Farmers Federation level through their sustainability blueprint indicators or Council of RDCs via DAFF, which is working with the NFF.

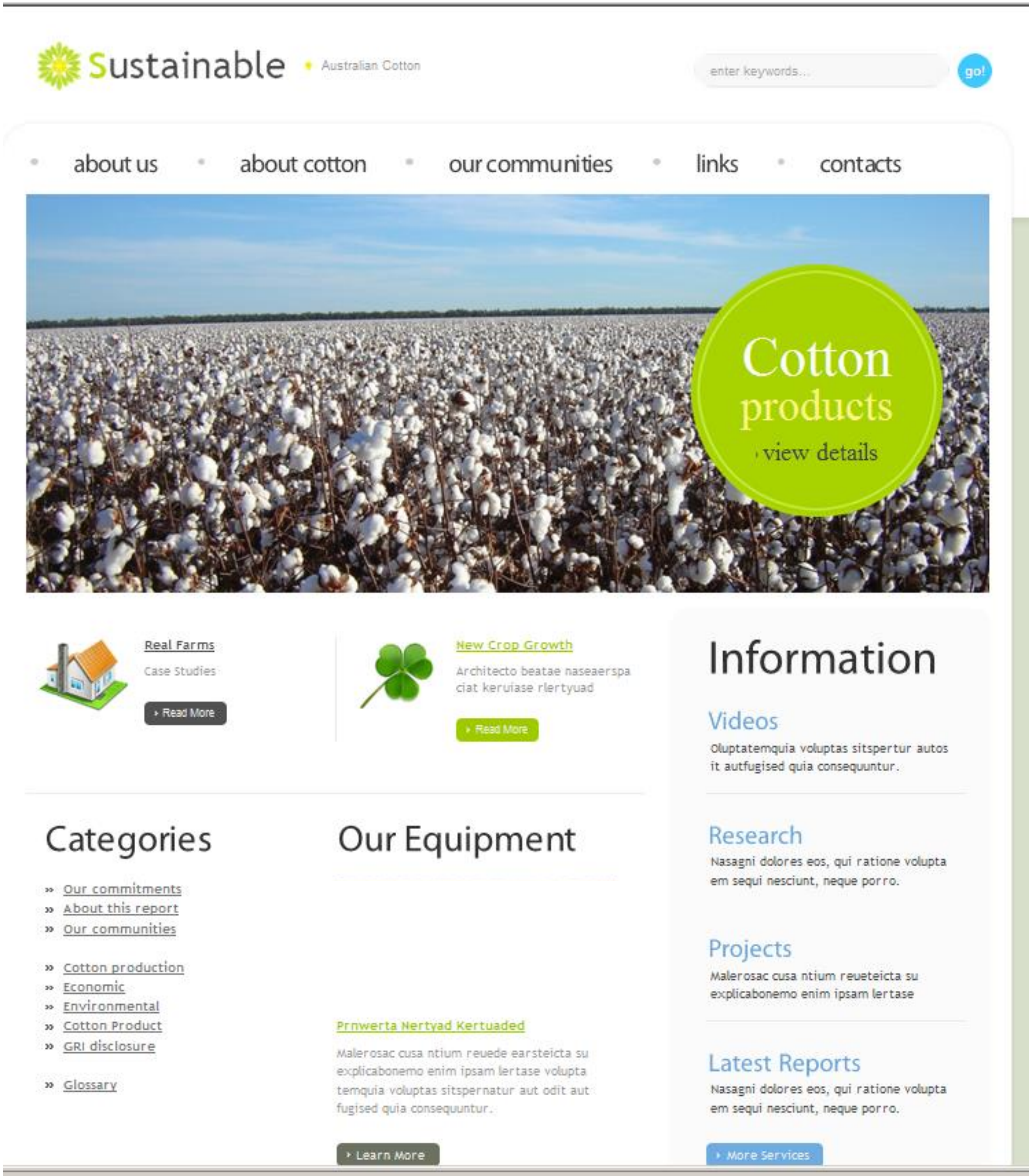


5. *Cotton CRC's Impact Report 2005-2012*

Technical support was provided to the Cotton CRC team producing the Cotton CRC's 2005-2012 impact report. This included attending meetings scoping out metrics and data sources. A draft document was produced for Janine Powell on water metrics and data, as well as a draft document on soils in July 2011. Input was also provided to the GHD 2010-11 grower survey project by reviewing the questions and providing some comments on the draft report, which is now completed. This project also reviewed the social data from the CCA 2010-11 survey raw data and a paper was later produced for the Cotton Conference.

6. *Electronic portal for cotton sustainability data*

The steering committee had suggested an "e portal" or "capture and edit system" be scoped as the future access and delivery mechanism to industry and the general public. At the time, CRDC, myBMP and Cotton Australia websites were all being upgraded in 2012 and contact was made with each of the web site managers. It was suggested in the upgrades a Sustainability reporting page (or tab) might be the best option. In order to progress the intent of the steering committee, a dummy web page was compiled. This is below and includes example tabs (eg economic, our communities, environment, GRI disclosure tab, research links, video links etc.) that would make up the page on whichever site the industry chose to place the information. An "e portal system" remains an unresolved issue and any future project will need to consider it further.



A sustainability web page or tab would be an option on one of the industry web sites. The above is an example that could be easily modified.

7. Australian Cotton Water Story

Earlier reviews of sustainability data sets had identified water information as a significant gap that this project could enhance. Therefore, a major effort of this project's time was devoted to The Cotton Water Story. This included four main outputs;

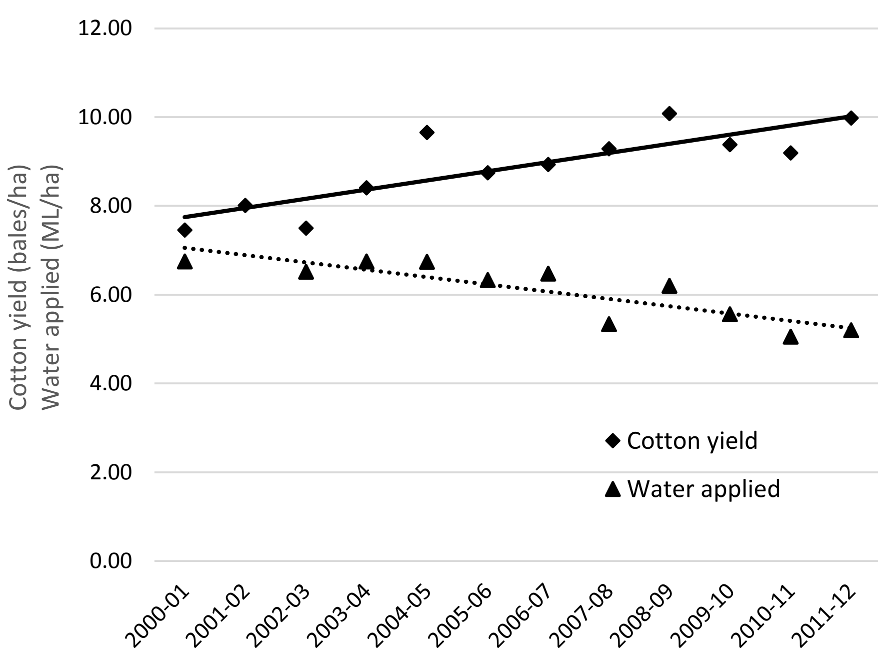
i. Contributing to the organisation of the "water research review forum" held at the Cotton Collective in August 2011. In relation to the forum organisation, Guy Roth attended planning meetings/teleconferences, recruited and managed the independent external review panel (Dr G Schrale SARDI retired, Prof I Falconer Water catchments and quality expert, Dr D Whitfield Vic DPI, and Mr R Moxham MDBA).

ii. The publication of The Cotton Water Story Special edition, by the Australian Cotton Grower Magazine August 2012. This is a 132 page publication, with 76 papers The Publication was launched at the Australian cotton conference, August 2012. This projected played a major role in editing the papers, writing content and providing photographs.

iii. A paper and presentation on The Australian Cotton Water Story at the Irrigation Australia and International Conference on Drainage, June 2012, in Adelaide.

iv. Lead author of a peer reviewed scientific paper on cotton farm water management. Two examples of data in the paper are below.

Roth G, Harris G, Gillies M, Montgomery J, and Wigginton DW (2013) A review of water use efficiency and productivity trends in Australian irrigated cotton. *Journal of Crop and pasture Science (in press).*



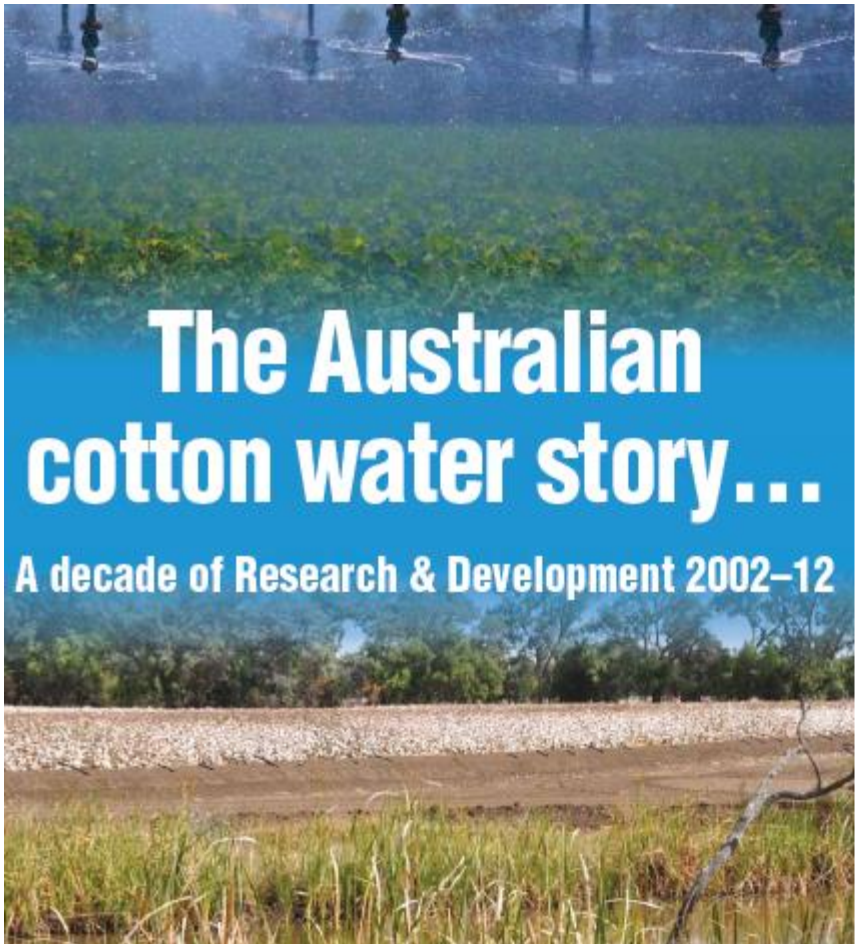
This figure shows irrigated cotton yields and water applied in Australia, 2001-2012 (227kg per bale). It shows the lint yield per hectare of cotton has been increasing, whilst at the same time the average total amount of irrigation water applied has decreased.

Surface irrigation systems are used on 80% of the irrigated Australian cotton crop and utilise 6-7 ML/ha depending on the amount of seasonal rain received. Over the past decade water use efficiency by Australian cotton growers has improved by 3-4% per annum, or by 40% increase in the water use productivity. This has been achieved by both yield production increases and more efficient use of applied irrigation water. The whole farm irrigation efficiency has improved from 57% - 70%, while crop water use index is above 3 kg/mm/ha and is high by international standards. The seasonal evapotranspiration of surface irrigated crops averages 729 mm over the last 20 years

A summary of key studies of the cotton industry between 1988 and 2011**.**

Year	*Number of Farms*	*Average amount of irrigation water applied ML/ha*	*Range of irrigation water applied ML/ha*	*ET mm*	*Lint yield bales/ha (227kg bale)*
1988-95[1]	11	5.37	0.52 - 10.9		6.73
1996 - 99[2]	25	6.96		735	7.96
1998- 00[3]	7	7.5			
2000- 03[4]	29	7.51	6.85 - 9.40	721	8.73
2006-07[5]	36	8.90	4.87 – 13.50	733	11.12
2008-09[6]	45	6.27	1.87 - 10.53	759	10.63
2009-10[7]	14	6.53	3.33 - 11.57	679	9.23
2010-11[7]	12	6.69	1.69 - 10.78	747	10.3

(Data is from; 1 Cameron Agriculture and Hearn (1997), 2 Tennakoon and Milroy (2003), 3 Dalton *et al* (2001), 4 QRWUE (2003), 5 Williams and Montgomery (2008), 6 Montgomery and Bray (2010),7 Wigginton (2011)).



The cover of the Australian Cotton Water Story Book.

8. Ongoing updating of data sets

During the project there has been the ongoing updating of key data sets. In particular, all the economic data sets, water information, soil nutrition data, and social metrics from the 2011 ABS census and NSW EPA complaints information.

On the following pages is a summary of many of the priority indictors.

Sustainability indicators for Australian Cotton.

Sustainability reporting is the practice of measuring and disclosing economic, environmental and social performance. Sustainability reporting is now entering the main stream of business operations with the Global Reporting Initiative being the most widely used framework. The cotton industry is striving for the sustainable development and its key organisations include reference to it in their strategic plans. A number of economic, environmental and social indicators can be used to measure progress towards the sustainability goal. Sustainability should be considered a journey. Many data sets exist as well as some gaps and opportunities for improvement.

The project has updated economic indicators with data from ABARES, Cotton Australia, and the International Cotton Advisory Committee, etc. There is excellent economic data allowing long term trends to be monitored over time. Information at the local government scale has been updated from the 2011 census. There is a gap in the profitability figures of farm business such as return on equity and interest coverage, which are sometimes requested by stakeholders. This information is difficult to collect due to private business (wealth) sensitivities, and government surveys do not segment the cotton industry figures as opposed to larger industries such as grain and beef cattle.

A few years ago an important gap was employment data, which was not well quantified on farm, in the service industries and value chain. A few projects have helped addressed this in recent years (University of Melbourne, CRDC project, 2011& 2012 grower survey).

Key environmental indicators include soil, water, pesticide and transgenic crop trait stewardship, biodiversity, carbon and greenhouse emissions. Environmental indicator data is patchy. There are some excellent data sets available from case studies, research reports and the two industry environmental audits and the 2012 environmental review. However, these generally provide a 'point in time' story rather than a long term trend and are rarely provide an industry wide coverage.

There is data over a reasonable timeframe for fertiliser rates, disease levels, river water quality, pest (weeds and insects) density and distribution and their resistance levels to various chemistries to manage them. Water use data has improved significantly in recent years. Notable environmental data gaps include soils (physical, chemical and biological status), biodiversity, and greenhouse emissions/carbon balances/energy use.

A key issue for the cotton industry is understanding river health and environmental flows. This knowledge is linked to water sharing plans and monitoring outcomes related to these plans. Improved monitoring of river health is needed and will need to be resourced by Government.

Insecticide resistance is a major sustainability risk for the cotton industry. The management of insect resistance to transgenic cotton traits is perhaps the greatest potential immediate sustainability risk perceived by cotton industry stakeholders. Non cotton stakeholders are possibly focused on water and chemicals, while on the international stage labour working conditions is a key issue.

Key social sustainability indicators include education levels, demographics, employment, health, community attitudes, social capital, research and development and compliance with the law.

Gaps in the social data include; vocational training and other non-degree capacity building measures such as apprenticeships, number of deaths, and measures of social capital related with other local industries such as grain production, bee keeping, cattle or fruit production. Another notable gap for social responsibility and environmental management is data related to compliance with legislation related to natural resource management. Government agencies do not provide this information and it is unlikely they will into the foreseeable future.

The 2011 ABS Census data has been obtained and compiled into the older data sets to provide trends over time. It includes data such as age, education levels, salaries, and some other demographics of cotton growers and ginners that can be added to current data sets between 1995 – 2006. Contact was also made with NSW EPA to update the complaints received data.

As discussed there are many indicators for different audiences. Tables 1-3 contain further details and suggestions.

A "snapshot" of Economic, Environmental and Social Performance Indicators for Australian COTTON

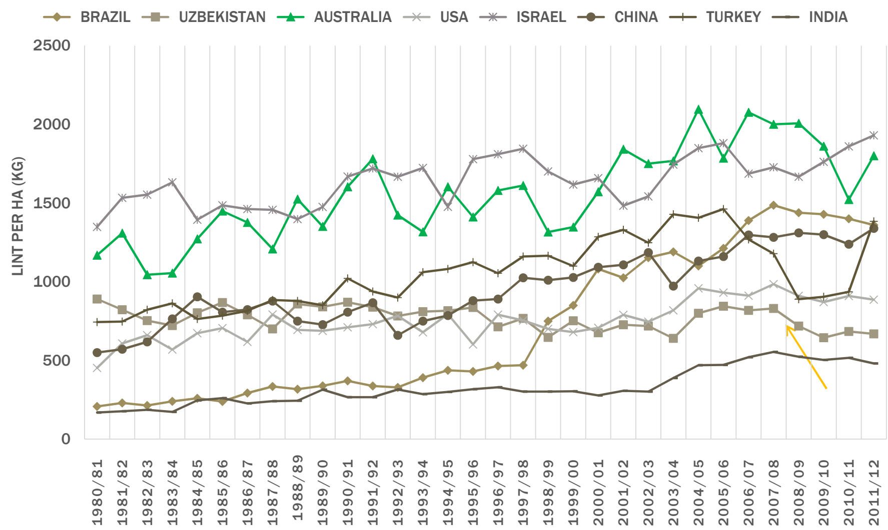


ROTH RURAL & REGIONAL

Australian Government Cotton Research and Development Corporation

Economic

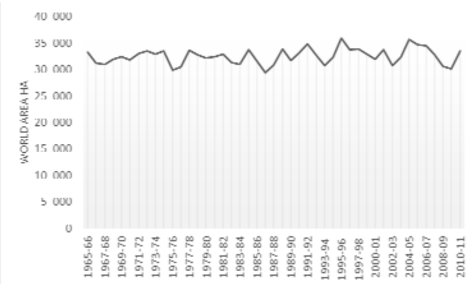

WORLD LEADER – YIELD

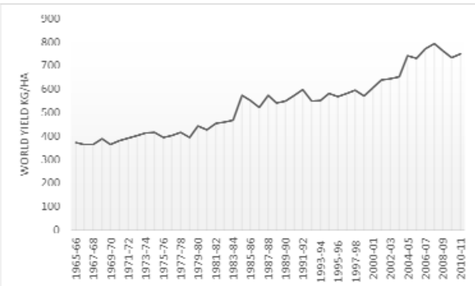


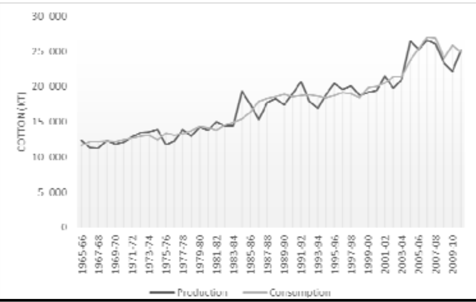
Australian cotton is highest yielding in the world. 2.5 times the world average. Dramatic rise in Brazil. Israel very small producer.

Data adapted from ICAC reports 1980-2012.

WORLD TRENDS (AREA, YIELD, PRODUCTION, CONSUMPTION)



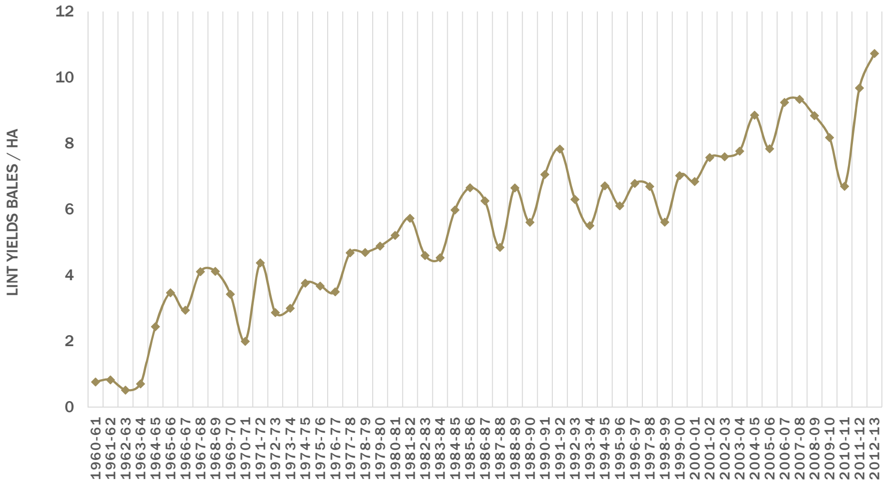




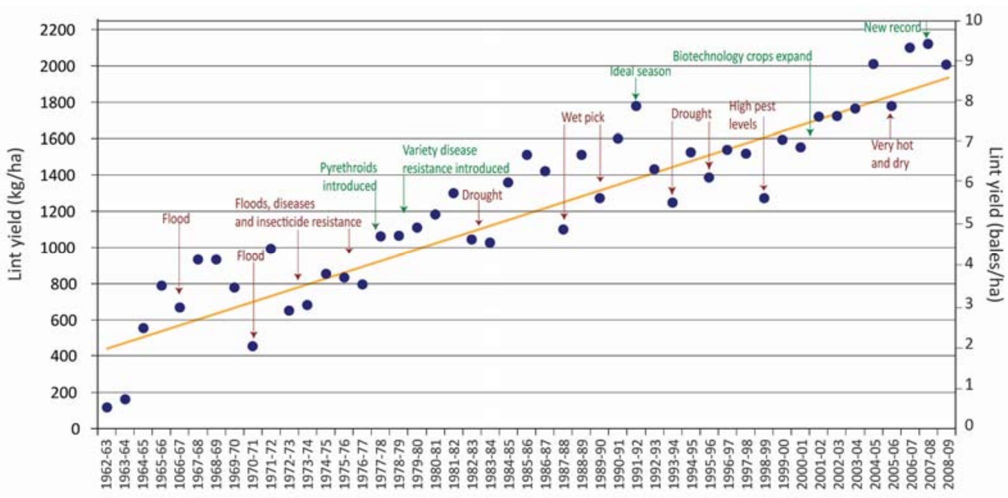
ICAC publishes global data, world yields are rising, total area used to grow cotton is static. Ie more production from less land.

ICAC reports

AUSTRALIAN LINT YIELDS 1960-2013

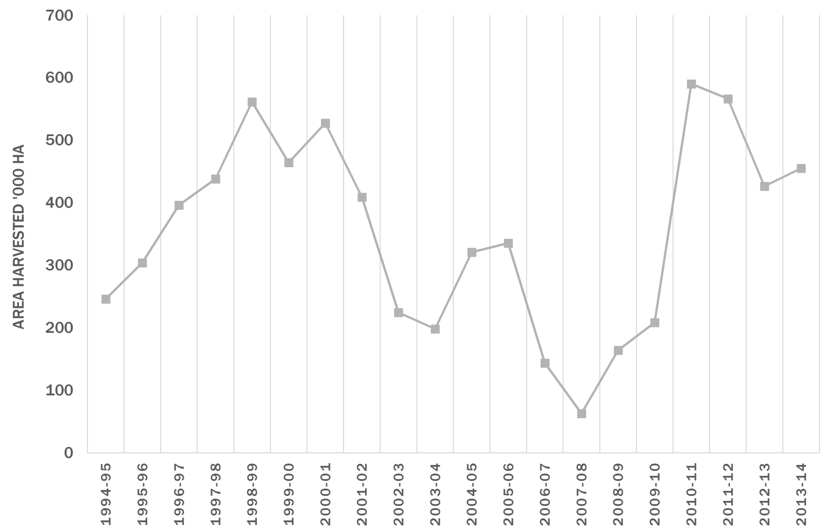


Australian cotton lint yields. Technology and weather impacts

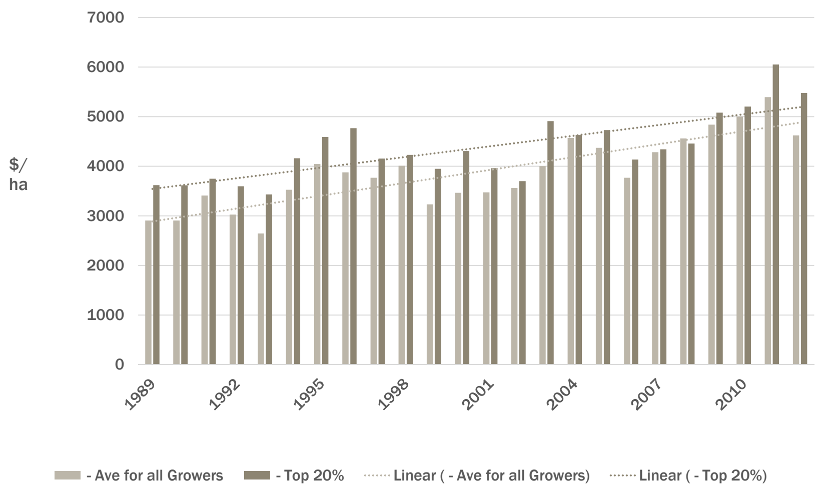


The impact of droughts and floods can be seen in the yield trends as well as advancements in technology. Source Roth 2010.

AUSTRALIAN COTTON AREA 20 YEARS (1994 - 2014E)

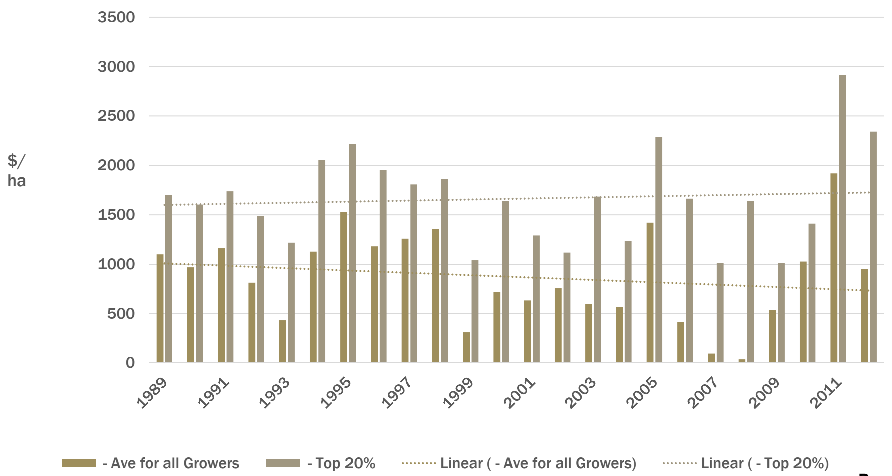


TOTAL COTTON INCOME (PER HA)



Boyce Accountants

OPERATING PROFIT BEFORE INTEREST



Boyce Accountants

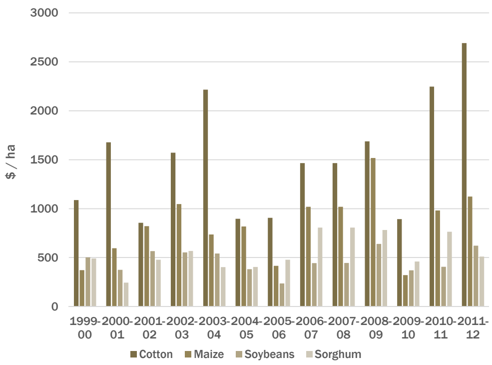
PROFITABLE PRACTICES

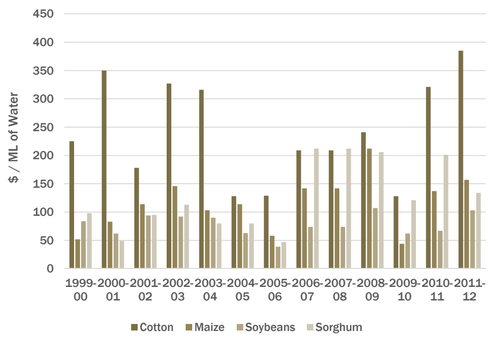
Long term average figures of top producers prove that it is possible to achieve a benchmark cost of production in the $290-$350/bale range in a 'normal' year'
Source: 2012 Boyce and CRDC Cotton Comparative analysis

- Average price per bale $486
- 2012 Average Yield 9.71 bales/ha
  Top 20% 11.45 bales/ha
- Operating costs
  Average $3236 /ha
  Top 20% $3524 /ha
- Farm operating profit
  Average $1213 /ha
  Top 20% $2090 /ha
  Low cost $1390 /ha

Source:2012 Boyce Cotton Comparative analysis

GROSS MARGIN PER HA AND PER ML OTHER CROPS

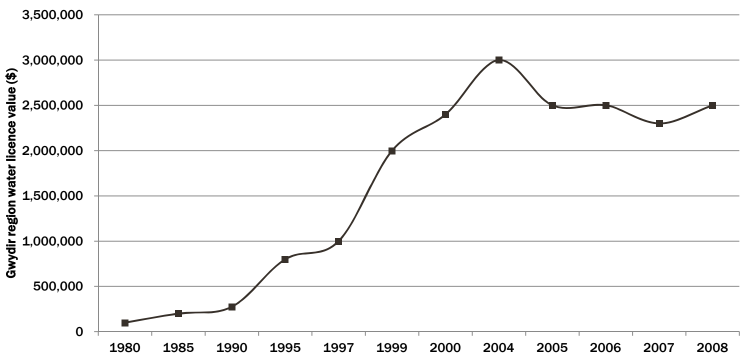




Cotton usually has the highest gross margin per hectare and per megalitre of irrigation water compared to other crops.

Modified from various NSW DPI

CAPITAL VALUE OF WATER



The value of a Gwydir valley irrigation river licence (based on 972 ML).

(Source Roth, unpublished data).

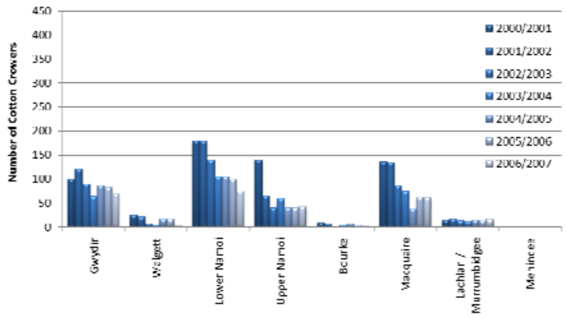
AUSTRALIAN GROWER NUMBERS

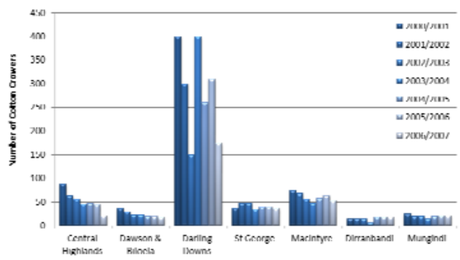
- Season Number of Farm Units
- 2003-04 813*
- 2004-05 1036
- 2005-06 1069
- 2006-07 711*
- 2007-08 427*
- 2008-09 611*
- 2009-10 795*
- 2010-11 1501
- 2011-12 1753
- 2012-13
- Averages 968

Number of cotton growers varies each year depending on availabilty of irrigation water and the cotton price. * Drought years.

Source: Monsanto / Cotton Australia unpublished

REGIONAL VARIATION GROWERS NUMBERS





There are a lot of growers on the Darling Downs growing small areas of cotton. The Namoi Valley (Walgett, Upper and Lower Namoi also has a large number of growers). The impact of the drought is evident in this data.

Roth 2010

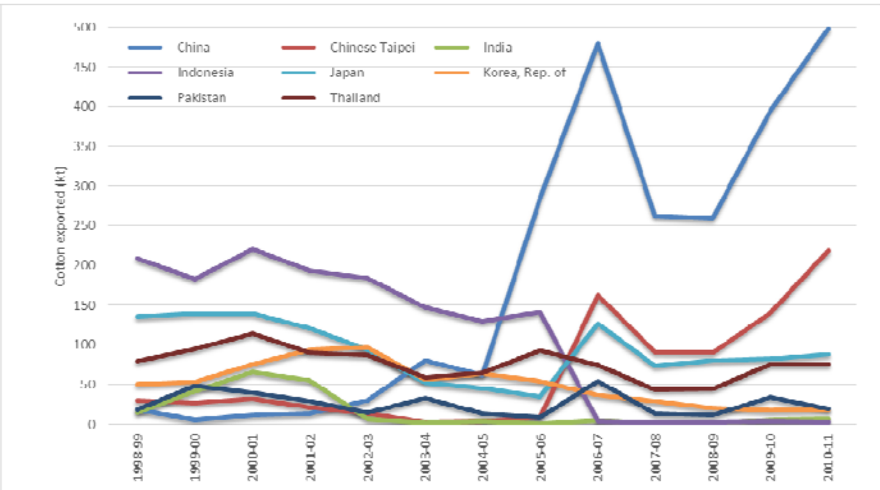
REGIONAL GROSS VALUE COTTON PRODUCTION

Cotton is a major proportion driver of the gross value of the total agricultural production where it is grown in Qld and NSW.

LOCAL GOVERNMENT AREA	1997[1] % of agricultural production ($)	2001[2] % of agricultural production ($)	2006[3] % of agricultural gross value production ($)	2011[4] % of agricultural gross value production ($)
Emerald	37.5	23.6	22.5	29.2
Bananna	22.2	13.7	10.4	6.2
Balonne	53.1	59.4	32.6	58.1
Wambo	29	25.9	19.4	38
Dalby	49.4			38.1
Jondaryran	27.3	18.7	12.5	35
Pittsworth	44.2	44	20.1	17.8
Chinchilla	8	4.8	2.7	16.9
Milmerran	35.8	20.5	15	18.1
Waggamba	30	35.2	34.5	45.6
The Darling Downs			10.9	20.4
Moree	55	62.6	44.9	52.9
Narrabri	60.2	63.8	52.7	56.6
Walgett	28.6	41.8	23	25.9
Gunnedah	33	26.8	24.8	30
Narromine	26.1	37.5	18.4	16.6
Warren	49.7	57.3	27.4	20.9
Bourke	66.4	61.7	34.4	59.5
Carathool	0.6	n/a	2.7	11.6
Lachlan	n/a	n/a	2.1	1.6

(Source: Figures compiled from data supplied by ABS from 1997 ABS Agricultural Census and 2001 Census[1-2]; ABS agricultural census 2006[3], ABS 2011-12 Agricultural Resource Management Survey 2011[4]). (Note Qld LGA changes by 2011.) (Qld LGAs in maroon, NSW LGAs in blue !)

AUSTRALIAN EXPORTS DESTINATION

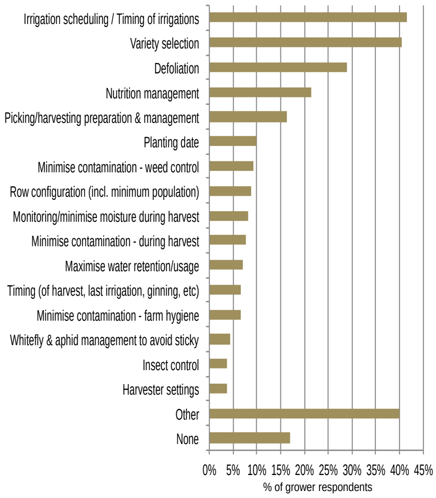


Large increase in the proportion of Australian cotton going to China. Japan, Thailand also significant. Decline in Korea and Indonesia.

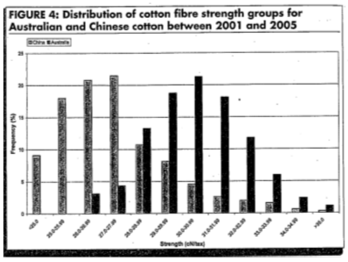
From ABARES data

FIBRE QUALITY

Strategies used to manage for fibre quality 2011 Grower Survey



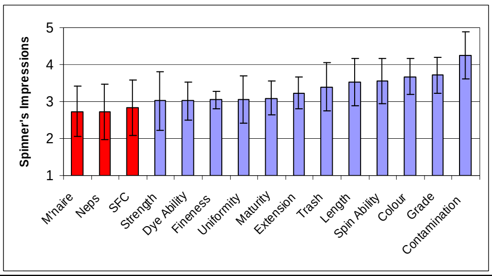
"Other" included: Avoid stress (5 respondents), Best practice agronomy (6), Maximise Yield (3), Fertiliser/nutrition choices (4), Minimise/eliminate tillage (2), Rotations (3), Nature (weather, etc) (3)



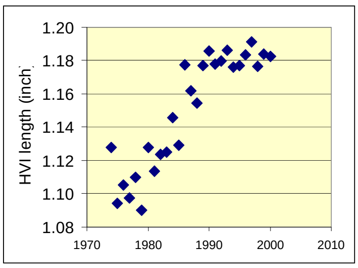
Source: Liu et al 2010, Australian Cotton grower magazine

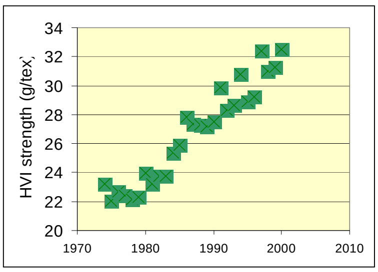
Spinners impressions of Australian cotton fibre quality (1 bad 5 good)

The Australian Cotton CRC Mill Survey 2007

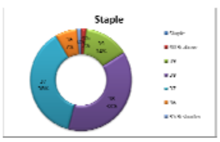


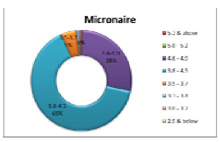
FIBRE QUALITY

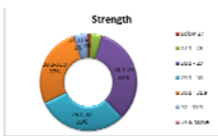


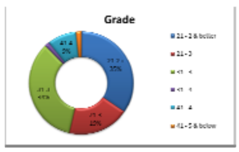


Improvements in fibre length and strength of Australian cotton 1972 – 2007.
(Source CSIRO, Dr W Stiller,). (HVI – high volume instrument). There is more up to date data.





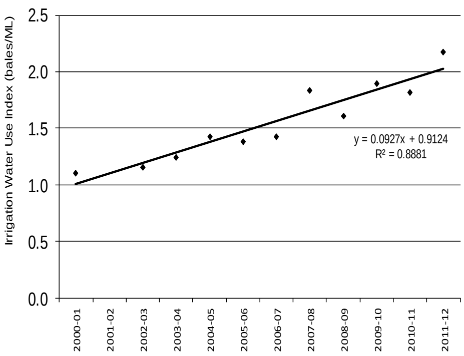


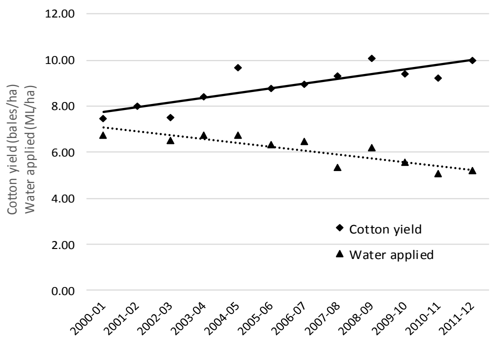


Australian Cotton Shippers Association Publish Fibre quality data for each season. These graphs show 2012 season data. Australian cotton is of high quality on the world stage.

ENVIRONMENTAL

Water





Water use productivity and water application efficiency have both improved.

Source: Roth *et al* 2013 Crop and Pasture Science Journal

Indicator: Water use efficiency / productivity (bales /ML or kg/ML)

Water

Year	Average IWUI bales/ml	Average GPWUI bales/ml	Average CWUI kg/mm/ha	Range IWUI bales/ml	Range GPWUI bales/ml	Range CWUI kg/mm/ha
1988-95[1]	1.48	0.82	2.9			
1996 - 99[2]	1.32	0.79	2.52			2.0-3.2
1998- 00[3]						
2000- 03[4]	1.16	0.93	2.79			
2006-07[5]	1.30	1.13	3.47	0.9-1.92	0.82-1.71	2.66-4.31
2008-09[6]	1.99	1.14	3.20	0.8-5.75	0.64-1.58	2.29-4.36
2009-10[7]	1.47	0.93	3.11	0.96-1.89	0.78-1.14	2.20-4.04
2010-11[7]	1.84	0.94	3.14	0.97-3.17	0.64-1.33	1.73-3.56

40% improvement in water productivity in the last decade. Opportunities for further gains as there is a large range in the data sets

Source: Roth *et al* 2013 Crop and Pasture Science Journal

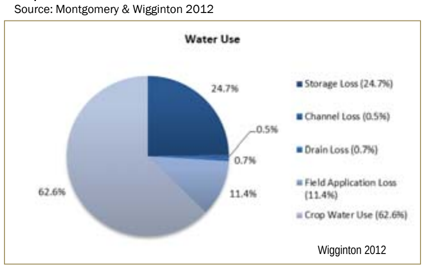
WATER MANAGEMENT

Industry has improved its water productivity by 40% over the last decade. The industry has a goal of further doubling water use efficiency/productivity again over next 10 years.

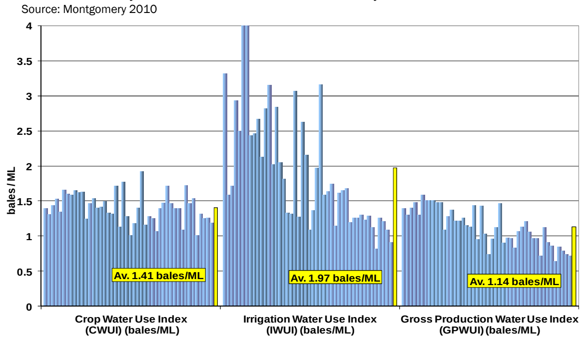
Measured farm benchmarking data shows there is a large range in the data. 63% of water is used by the crop.
The largest loss of water was on farm storages (evaporation). There is a large variation around these averages.

This data was published in the Australian Cotton Water Story (2012)

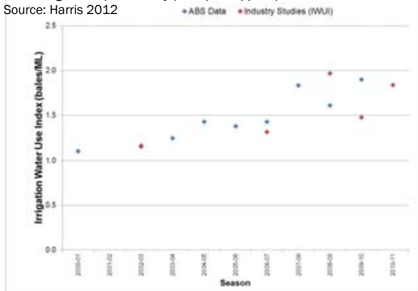
Proportion of water used or lost across all farms
Source: Montgomery & Wigginton 2012



Water use efficiency benchmarked on farms across the industry
Source: Montgomery 2010



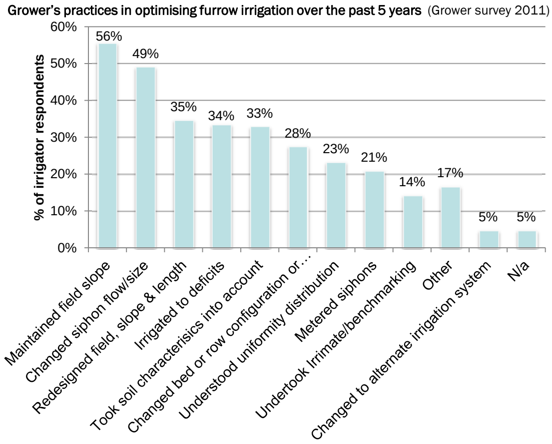
Increasing cotton productivity (bales/ML applied)
Source: Harris 2012



WATER MANAGEMENT

Grower survey findings	2006	2011
Irrigators using soil moisture probes for scheduling	40%	70%
Irrigators monitoring groundwater quality	20%	62%

Grower's practices in optimising furrow irrigation over the past 5 years (Grower survey 2011)

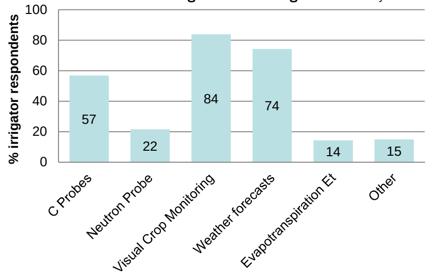


Between 2006 and 2011:

- Half of all irrigators made changes to their siphon flow and/or size
- 42% more growers monitored groundwater quality
- The use of soil moisture probes for irrigation scheduling increased by 30%

Some irrigators are using both neutron probes and capacitance probes such as Environscans (eg neutron probes for timing of first irrigation/s and CProbes later season)

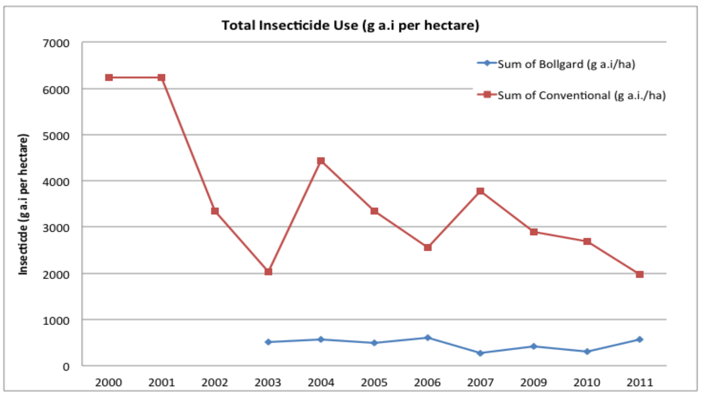
Methods used for irrigation scheduling Grower Survey 2011



CHEMICAL USE

Change in insecticide use over time Source: CCA survey historical data / CRDC

- Indicator: Active ingredient used (kg/Ha)



CHEMICAL USE – ENVIRONMENTAL IMPACT

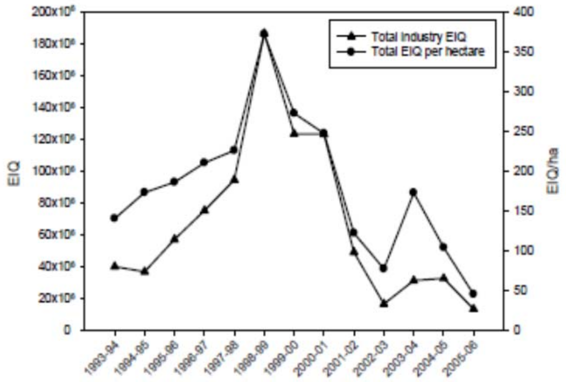
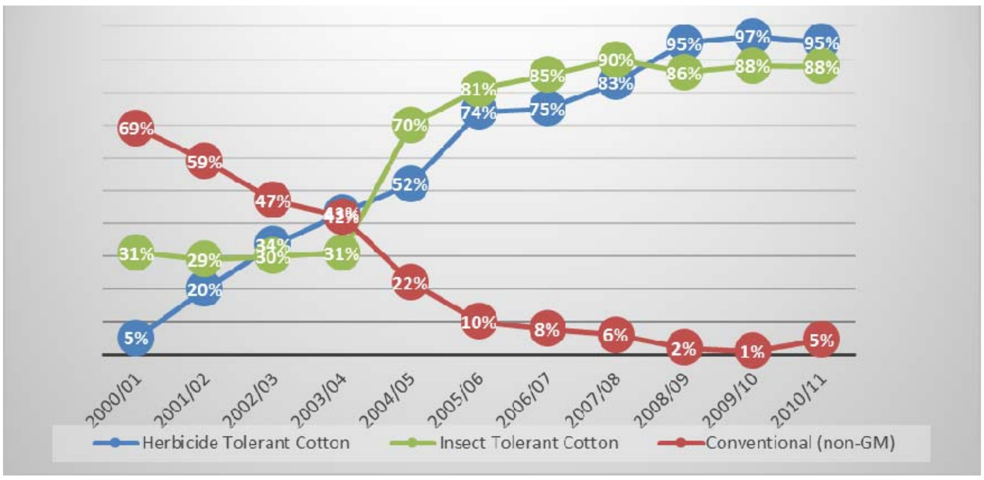


Figure 7: The total environmental impact and the environmental impact per hectare of the Australian cotton industry over the growing seasons since the introduction of Bt cotton varieties, Ingard and Bollard II.

Kennedy et al , Sydney University

GM COTTON TRAIT DEPLOYMENT % (AREA)



26

Cotton Australia 2012

SOILS – ATTRIBUTES EG: C, N, P, K, Na, EC

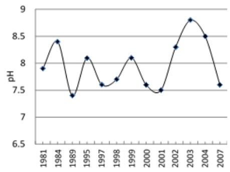


Figure 32: Soil surface (0-30 cm) pH (water) levels between 1981 and 2007.

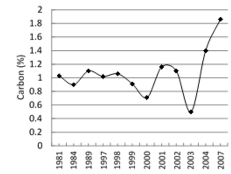


Figure 33: Soil carbon levels between 1981 and 2007.

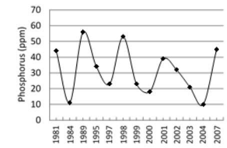


Figure 34: Soil availabe phosphorus levels (Colwell test) between 1981 and 2007.

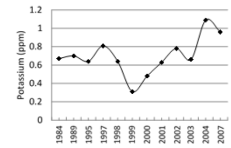


Figure 35: Soil potassium levels between 1981 and 2007.

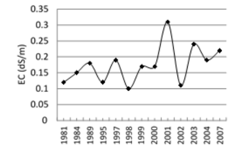


Figure 36: Soil electrical conductivity levels between 1981 and 2007.

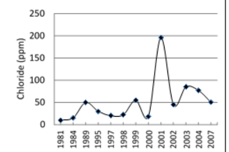
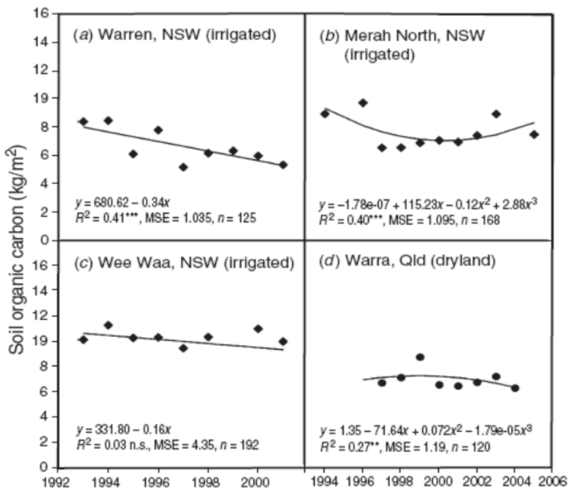


Figure 37: Chloride levels between 1981 and 2007.

More challenging to obtain long term data sets. There are some research reports

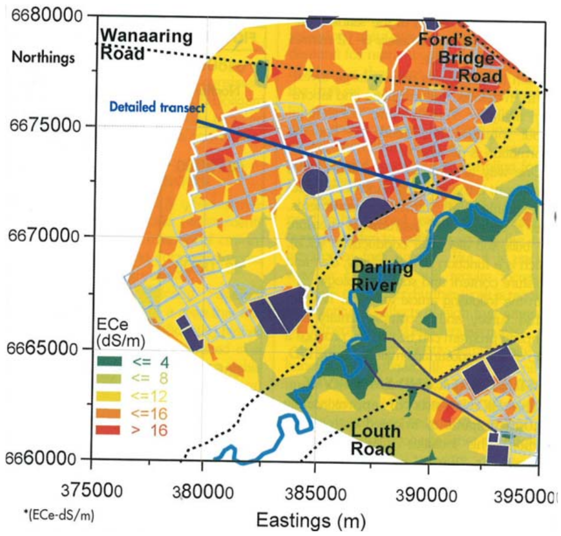
SOIL CARBON



Variation of soil organic carbon in the 0-0.6 m depth with time in irrigated and dryland cotton farms in NSW and Queensland.

(Source: Hulugalle and Scott 2008).

SALINITY

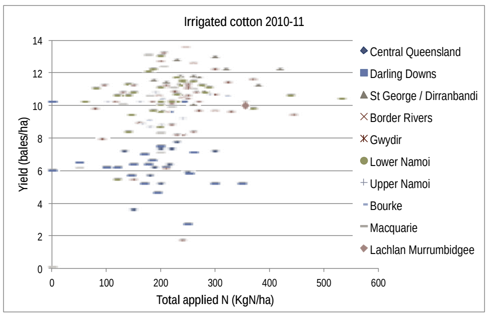


Distribution of saline subsurface material between 6-12 metres at Bourke. Other data sets for other regions exist.
(Source: Triantafilis *et al* 2004).

FERTILISER USE

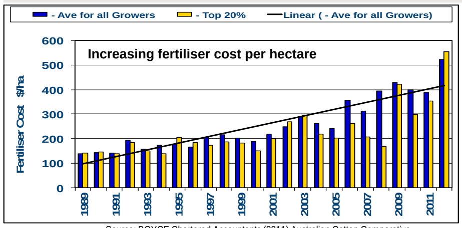
Grower Surveys

FERTILISER	1997	2001	2006	2007	2011 Irrigated	2011 Dryland	Trend
Pre season nitrogen - solid fertiliser (kg N/ha)		80	87	101	142	89	↑
Pre season nitrogen - gas fertiliser (kg N/ha)		78	71	60	155	84	↑
In season nitrogen – solid fertiliser (kg N/ha)		17	29	60	99	45	↑
In season nitrogen – gas fertiliser (kg N/ha)		8	14	18	83	40	↑
In season N water applied (kgN/ha)					57	5	
TOTAL applied N kg/ha	125	176			217	96	
Pre season phosphorus fertiliser (kg P/ha)		23	30	35	42	14	↑
In season phosphorus fertiliser (kg P/ha)		2	3	2	20	13	↑
TOTAL applied P kg/ha					40	16	
Pre season potassium fertiliser (kg K/ha)		8	16	24	33	7	↑
In season potassium fertiliser (kg K/ha)		0	2	4	15	2	↑
TOTAL applied K kg/ha					28	7	
Zinc fertiliser (kg Zn/ha)		5	5	5	4.4	3.7	↔
Sulphur (kg S/ha)					6.3	2.4	
Trace elements					21	4	



SOIL HEALTH: NUTRITION

- On average, fertiliser costs have increased by $130/ha from previous year to the 2011/12 season (2012 Boyce Cotton Comparative analysis)
- 13% of farms surveyed in 2011 used manures or composts in their nutrition program. (2011 Grower survey)
- Nutrient rates are highly variable across farms
- Rates do not clearly correlate to yield or farm size.



Source: BOYCE Chartered Accountants (2011) Australian Cotton Comparative Analysis. Australian Cotton Conference presentation.

Kg N / bale	Avg	Min	Max
Central Qld	34	19	44
Darling Downs	35	8	100
St George / Dirranbandi	24	16	35
Border Rivers (incl Mungindi)	22	18	32
Gwydir	25	8	48
Lower Namoi (incl Walgett)	21	6	52
Upper Namoi	20	10	28
Bourke	23	19	30
Macquarie	20	8	29
Lachlan Murrumbidgee	23	9	36
All regions	**25**	**6**	**100**

Nitrogen rate per harvested bale from irrigated cotton in 2010-11 (2011 Grower Survey)

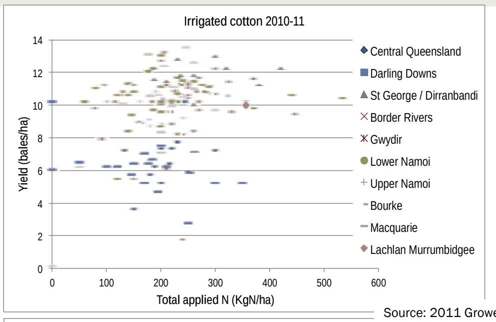
The 2011 grower survey and 2012 Environmental Audit identified that:

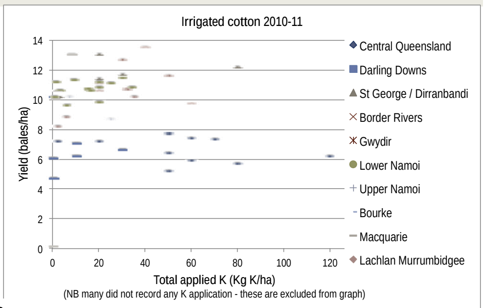
- 81% of growers in 2011 used soil testing in deciding fertilisers rates.
- 69% of growers in 2010 soil tested annually or seasonally
- 38% used leaf or petiole testing.
- 83% considered there had been improvement in use of soil & leaf testing.

Average applied nutrient rates recorded in grower surveys 1997-2011

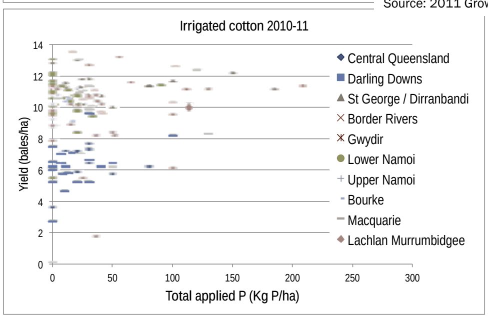
FERTILISER	1997	2001	2006	2007	2011 Irrigated	2011 Dryland	Trend
Pre season nitrogen - solid fertiliser (kg N/ha)		80	87	101	142	89	↑
Pre season nitrogen - gas fertiliser (kg N/ha)		78	71	60	155	84	↑
In season nitrogen – solid fertiliser (kg N/ha)		17	29	60	99	45	↑
In season nitrogen – gas fertiliser (kg N/ha)		8	14	18	83	40	↑
In season N water applied (kgN/ha)					57	5	
TOTAL applied N kg/ha	125	176			217	96	
Pre season phosphorus fertiliser (kg P/ha)		23	30	35	42	14	↑
In season phosphorus fertiliser (kg P/ha)		2	3	2	20	13	↑
TOTAL applied P kg/ha					40	16	
Pre season potassium fertiliser (kg K/ha)		8	16	24	33	7	↑
In season potassium fertiliser (kg K/ha)		0	2	4	15	2	↑
TOTAL applied K kg/ha					28	7	
Zinc fertiliser (kg Zn/ha)		5	5	5	4.4	3.7	↔
Sulphur (kg S/ha)					6.3	2.4	
Trace elements					21	4	

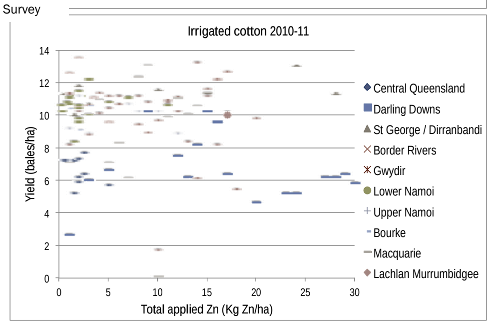
SOIL HEALTH: NUTRITION – N, P, K, ZN





Source: 2011 Grower Survey





SOIL HEALTH: NUTRITION

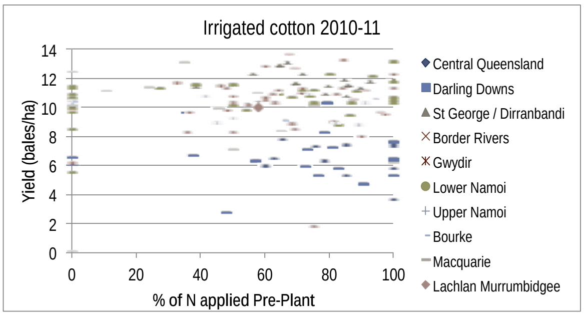
Timing of Nitrogen application

- Split applications of nitrogen are applied to most cotton crops.
- There was a wide variation in the proportion of Nitrogen applied pre-plant
- There was no clear link between the proportion of N applied pre-plant and the yield achieved.
- Water run nitrogen (generally Urea) was common for topping up N in-season.

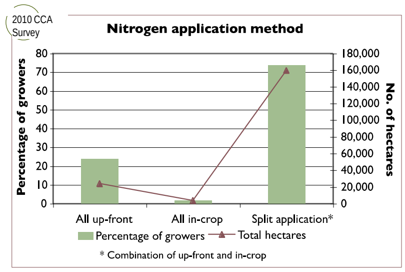
Sources: 2010 CCA survey & 2011 Grower Survey

Most growers had a wet winter in 2010 which may have affected some pre-plant fertiliser application. Flooding in 2011 likely resulted in some additional N applications.

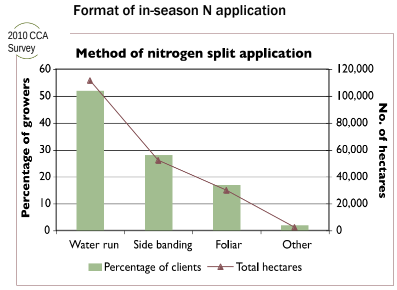
Proportion of N applied pre-plant vs yield
(2011 Grower survey)



Proportion of hectares using N timing strategies



Format of in-season N application



SOIL BMP RANKINGS

MANAGEMENT COMPONENT / BMP RANKING AND YEAR	2006	2007	2008	TREND
Soil management – structure and operations	1.7	1.3	1.4	Improving
Soil management - nutrition	1.5	1.1	1.2	Improving
Soil management – salinity and sodicity	2.1	1.6	1.7	Improving
Soil management – erosion	1.9	1.6	1.6	Improving

myBMP rankings have potential to track trends.

Roth 2010

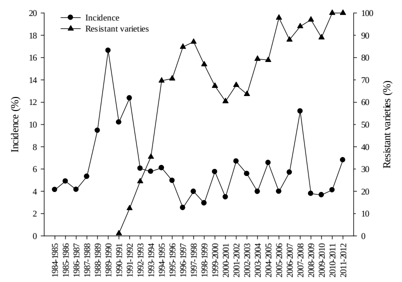
CROP ROTATIONS

COTTON PRODUCTION FREQUENCY	1997* (%)	2000** (%)	2006*** (%)	2007**** (%)
< 1 year	4	9	19	3
1 year cotton	42	22	36	28
2 years cotton	24	17	20	10
3 years cotton	9	15	6	6
4 years cotton	6	6	6	7
5 years cotton	2	6	2	8
6 years cotton	n/a	3	2	4
>6 years cotton	12	18	8	22

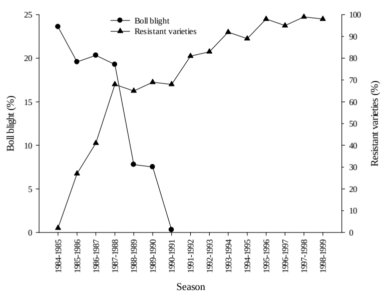
(Source: Modified from CRDC 2000a*, CRDC 2000a**, CCA 2007a***, WRI 2007a****).

DISEASE TRENDS

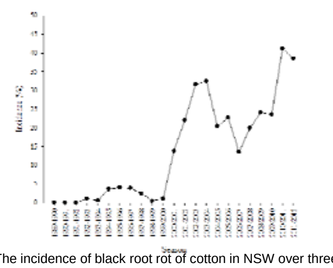
Kirby et al 2013



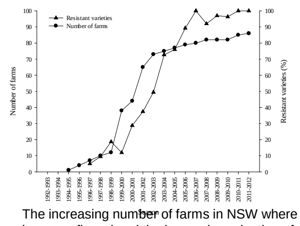
The average incidence of Verticillium wilt of cotton in NSW and the use of varieties with resistance to Verticillium wilt



Incidence of bacterial blight on cotton bolls and the increasing percentage of fields sown with blight resistant varieties.

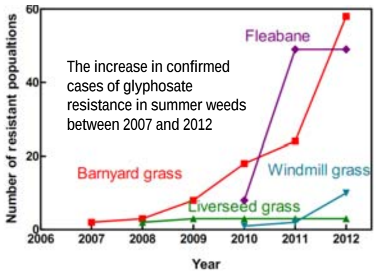


The incidence of black root rot of cotton in NSW over three decades

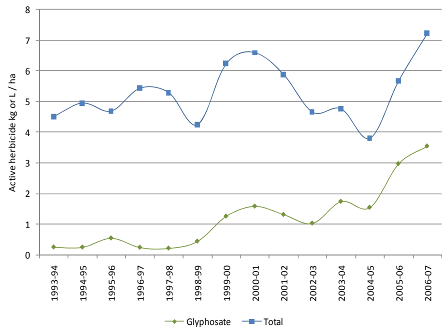


The increasing number of farms in NSW where Fusarium wilt of cotton has been confirmed and the increasing adoption of more Fusarium resistant varieties.

WEED RESISTANCE AND GLYPHOSATE USE



Source: Glyphosate Resistance Register Summary 2013
Australian Glyphosate Sustainability Working Group



Total herbicide use and glyphosate herbicide use in Australian cotton fields 1993- 2007.
(Source: Data sourced and modified from WRI 2007c). Need to update.

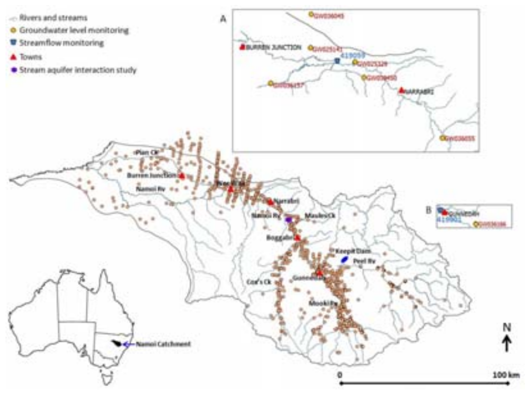
WEED SPECIES CHANGES

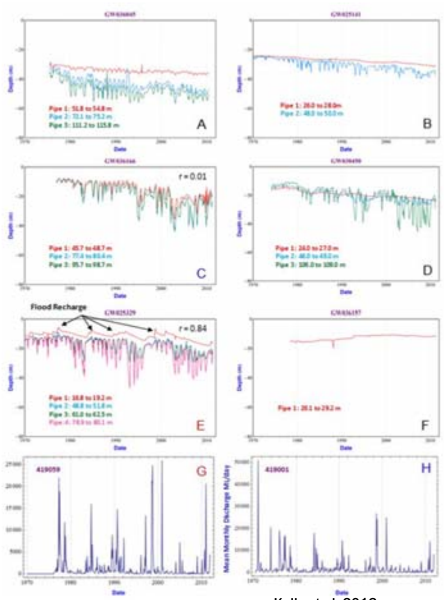
Rank	Weed Species		
	2001	2008	2010
1	Ipomea lonchophylla*+	Hibiscus sp.	Conyza bonariensis*+†
2	Hibiscus sp.	Conyza bonariensis*+†	Sonchus oleraceus+
3	Cyperus rotundus+	Sonchus oleraceus+	Ipomea lonchophylla*+
4	Echinochloa colona†	Convolvulus erubescens*+	Convolvulus sp.*+
5	Rhyncosia minima*+	Ipomea lonchophylla*+	Amaranthus macrocarpus*
6	Cullen cinereum*+	Cullen sp*+	Hibiscus sp
7	Gossypium hirsutum*	Tribulus sp.	Chamaesyce drummondii
8	Physalis sp	Cyperus sp.+	Cullen sp.*
9	Datura ferox	Echinochloa colona†	Echinochloa colona†
10	Neptunia gracilis*+	Fallopia convolvulus	Medicargo polymorpha
11	Convolvulus erubescens*+	Lactuca serriola	Neptunia gracilis*+
12	Polymeria pusilla*	Rhyncosia minima*+	Physalis minima*
13	Sonchus oleraceus+	Vigna lanceolata*+	Tribulus sp.
14	Sesbania cannibina*	Amaranthus macrocarpus*	Rhyncosia minima*+
15	Xanthium sp.	Avena spp	Vigna lanceolata*+
16	Amaranthus macrocarpus*	Phalaris paradoxa	Dactyloctenium radulans
17	Sida sp*	Physalis minima*	Datura sp.
18	Sida reflexa*	Polygonum aviculare*	Digitaria ciliaris*
19	Cyperus bifax+	Portulaca oleracea	Geranium solanderi*
20	Portulaca oleracea	Echinochloa crus-galli	Ipomea plebia*

Comparison top 20 weeds present in “irrigated” fields at the start of the season surveyed by Charles *et al.* 2004 (conducted in 2001) to the 2008 and 2010 surveys.

Source: 2013, Weed species changes since the introduction of glyphosate-resistant cotton. Jeff Werth[A], Luke Boucher[A], David Thornby[A], Steve Walker[B] and Graham Charles[C]

GROUNDWATER LEVELS



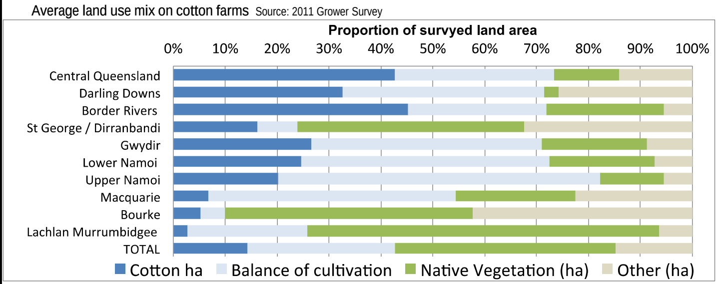


Representative groundwater and streamflow hydrographs from the Namoi Catchment

Kelly et al, 2013

NATURAL ASSETS

Average land use mix on cotton farms Source: 2011 Grower Survey



The 2011 Grower Survey identified:

- Around 40% of cotton farm area is dedicated to native vegetation.
- 63 % of farms have a riparian zone ranging between 2 and 15 km in length (on average 7 km).
- 70% of cotton growers have river frontage and 75% of growers are actively managing their riparian zones.

Natural assets management in the past 5 years Source: 2011 Grower Survey

	% Growers who revegetated	% Growers actively managing	Revegetated Area (Ha)	Area managed (Ha)	% Growers with riparian zone	Average (km)	Range (km)	Riparian zone actively managed (avg km)
Central Queensland	7%	36%	4	261	57%	4	2 to 11	4
St George/Dirranbandi	6%	50%	20	47,846	63%	16	0.2 to 60	20
Darling Downs	6%	28%	3	812	56%	4	0.7 to 10	4
Border Rivers	50%	38%	1,107	900	75%	8	2 to 20	6
Gwydir	23%	59%	561	6,003	77%	14	3 to 44	6
Lower Namoi	13%	38%	838	17,546	60%	8	0.5 to 30	9
Upper Namoi	27%	45%	224	1,233	73%	6	2 to 10	4
Macquarie	13%	31%	120	3,380	69%	10	3 to 20	6
Bourke	0%	67%	0	5,100	100%	23	10 to 40	
Lachlan Murrumbidgee	29%	41%	145	13,242	53%	7	2 to 15	7
Totals	15%	40%	3,021	96,323	63%	9	0.2 to 60	8

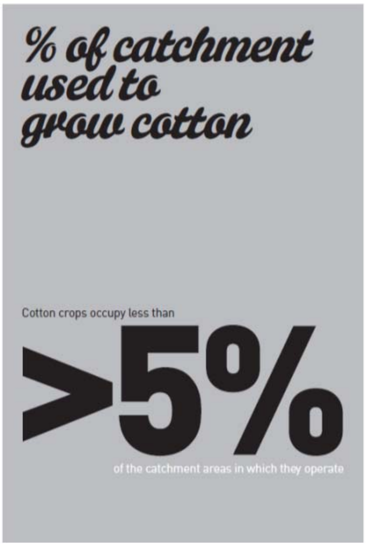
Tactics used by growers to manage riparian areas include:

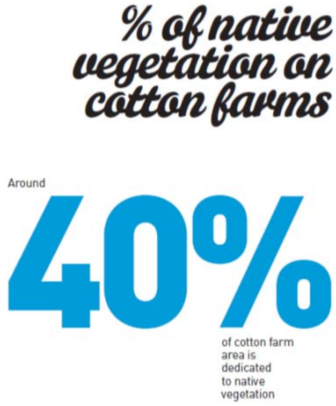
- Fencing & selectively grazing
- No grazing at all
- Control of weeds and pests
- Provision of alternative water points for stock
- Maintain filter, buffer strips
- Planted native trees and other vegetation.

Source: The Australian Cotton Water Story, 2012

BIODIVERSITY : HABITAT:

- Most focus is on land clearing and vegeation

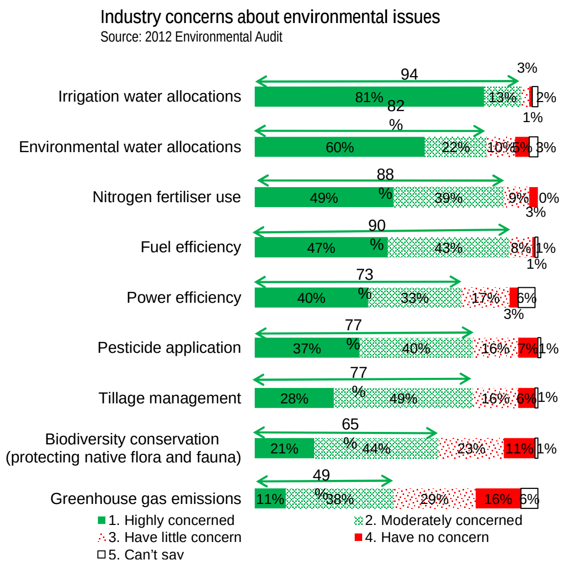




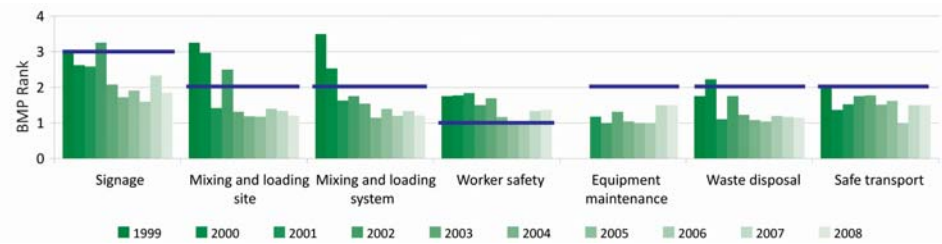
NATURAL ASSETS

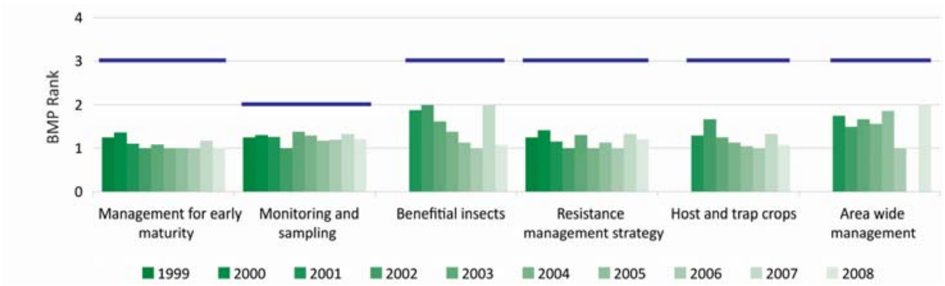
The third environmental assessment represents the continuation of a 21 year commitment of the cotton industry in undertaking comprehensive independent environmental assessments, a process unique in agricultural industries in Australia.

Cotton growers have improved soil, riparian and native vegetation management which is contributing to improved biodiversity and delivering important ecosystem services.
Source: Cotton Industry's Third Environmental Assessment, 2012



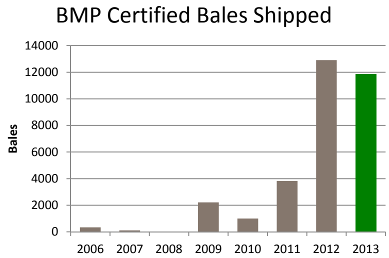
BMP PRACTICE CHANGE

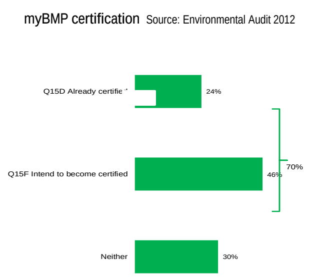




Roth 2011

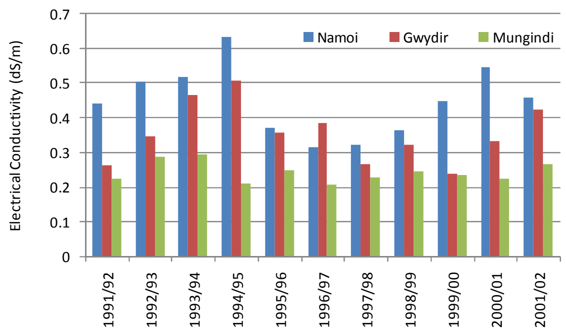
BMP





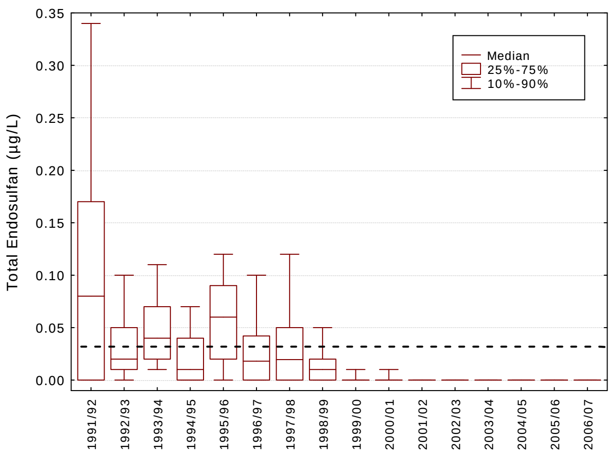
WATER QUALITY - SALINITY

- Median electrical conductivity (µS/cm) for three sites (Namoi River at Bugilbone, Mehi River at Bronte and Barwon River at Mungindi) located downstream of major cotton growing areas in each valley from 1991/92 through to 2001/02.



(Source: Mahwinney 2004).

WATER QUALITY - PESTICIDES



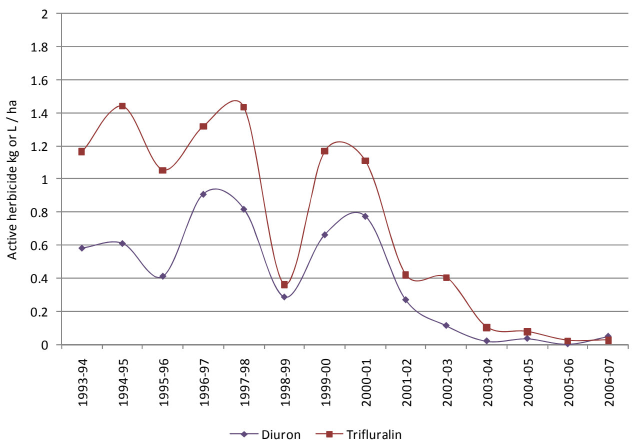
Total endosulfan concentrations in the Namoi Catchment from 1991-1992 to 2006-2007.
(Source: Mawhinney 2008).

WATER QUALITY - PESTICIDES

YEAR	ENDOSULFAN	ATRAZINE	DIURON	FLUOMETURON	METOLACHLOR	PROMETRYN	N
1991/92	43 (32%)	57 (43%)	11 (8.2%)	2 (1.5%)	0	10 (7.5%)	134
1992/93	47 (44%)	26 (24%)	4 (3.7%)	2 (1.9%)	0	3 (2.8%)	107
1993/94	34 (49%)	33 (48%)	3 (4.3%)	5 (7.2%)	10 (14%)	3 (4.3%)	69
1994/95	33 (37%)	19 (21%)	0	0	2 (2.2%)	3 (3.4%)	89
1995/96	41 (48%)	32 (37%)	1 (1.2%)	0	9 (10%)	4 (4.7%)	86
1996/97	75 (47%)	79 (49%)	4 (2.5%)	19 (12%)	15 (9.4%)	12 (7.5%)	160
1997/98	69 (43%)	48 (30%)	12 (7.4%)	39 (24%)	30 (19%)	33 (20%)	162
1998/99	57 (35%)	73 (44%)	14 (8.5%)	23 (14%)	40 (24%)	7 (4.2%)	165
1999/00	20 (11%)	90 (51%)	11 (6.2%	14 (7.9%)	38 (21%)	4 (2.2%)	178
2000/01	14 (7.8%)	98 (55%)	13 (7.3%)	40 (22%)	44 (25%)	9 (5%)	179
2001/02	0	16 (14%)	4 (3.4%)	4 (3.4%)	5 (4.2%)	5 (4.2%)	118
2002/03	0	21 (19%)	3 (3%)	7 (6%)	3 (3%)	1 (1%)	112
2003/04	0	63 (62%)	3 (3%)	6 (6%)	11 (11%)	2 (2%)	102
2004/05	8 (7.8%)	58 (57%)	1 (1%)	4 (3.9%)	27 (26%)	5 (4.9%)	102
2005/06	0	67 (64%)	1 (1%)	9 (8.6%)	14 (13%)	8 (7.6%)	105
2006/07	0	50 (71%)	3 (4%)	2 (3%)	7 (10%)	2 (3%)	70

Number and percentage of detections of common pesticides for all samples collected in the Namoi Catchment from 1991-1992 through to 2006-2007. (Source: Mahwinney 2008).

LESS DIURON HERBICIDE USE

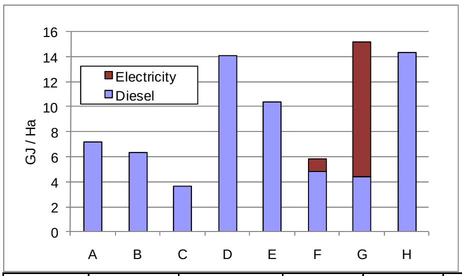


Diuron and trifluralin use in Australian cotton fields 1993- 2007.
(Source: Roth 2010, Data modified from WRI 2007c).

ENERGY

The National Centre for Engineering in Agriculture (NCEA) has conducted 8 case study energy assessments across the Australian Cotton Industry for a range of farming regions and farming practices (e.g., conventional tillage, minimum tillage, dryland farming, and irrigation) in both NSW and Queensland.

On farm energy use was found to range from 3.7 to 15.2 GJ/ha costing $80 to $310/ha. Diesel energy inputs ranged from 95 to 365 litres/ha, with most farms using 120 to 180 litres/ha. (Source Development of Energycalc, 2007, G.Chen & C.Baillie NCEA,)

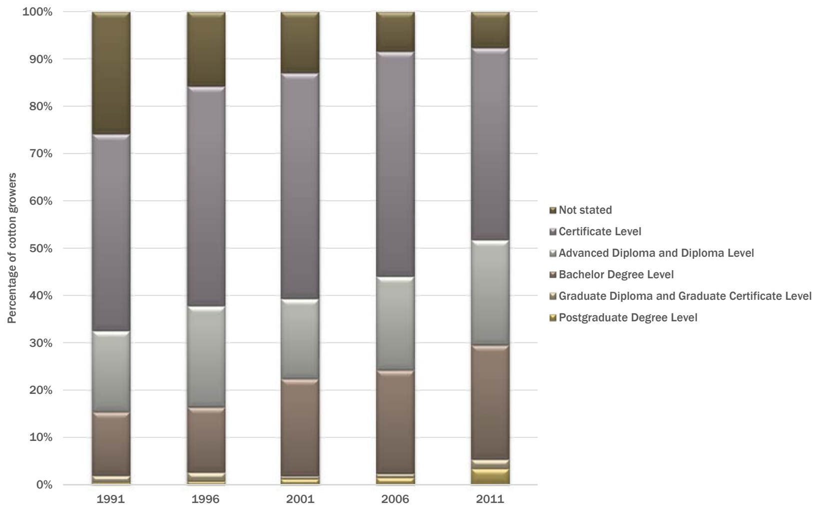


	Tillage method	Irrigation method	Water Sources
Farm A	Conventional tillage	Diesel pump	Surface water
Farm B	Conventional tillage	Diesel pump	Surface water
Farm C	Minimum tillage	Gravity feed	Surface water
Farm D	Conventional tillage	Diesel pump	Ground water
Farm E	Minimum tillage	Diesel pump	Ground water
Farm F	Conventional tillage	Electric pump	Surface water
Farm G	Minimum tillage	Electric pump	Ground water
Farm H	Minimum Tillage	Diesel pump	Surface water

	Preparation	Establishment	In Season	Irrigation	Harvest	Post Harvest
Farm A	15%	4%	8%	40%	24%	9%
Farm B	14%	7%	3%	39%	27%	10%
Farm C	4%	5%	21%	0%	54%	16%
Farm D	7%	1%	4%	70%	14%	3%
Farm E	5%	2%	4%	62%	19%	7%
Farm F	32%	7%	7%	9%	38%	7%
Farm G	12%	4%	4%	51%	21%	8%
Farm H	19%	2%	6%	52%	13%	8%

SOCIAL

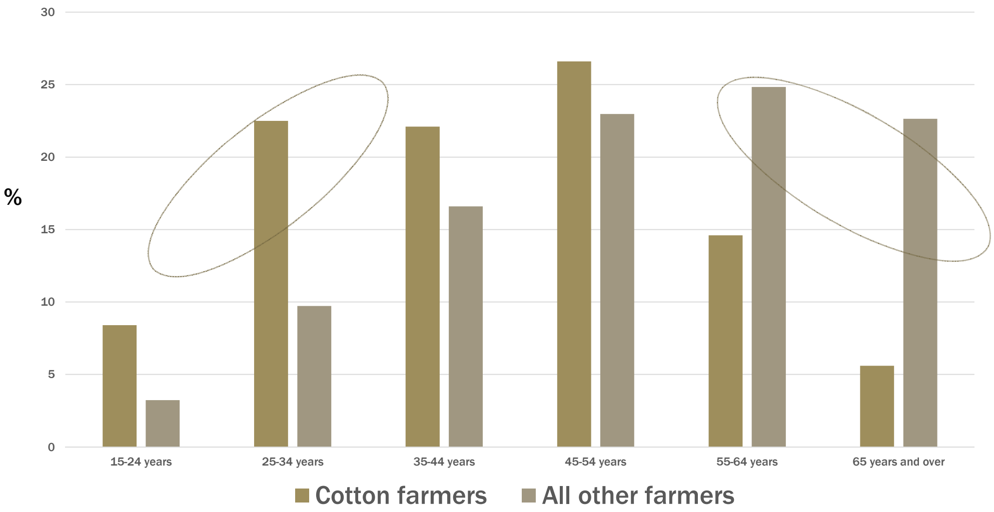
HIGHER EDUCATION QUALIFICATIONS OF COTTON GROWERS



Rising number of cotton growers with degrees.

Data obtained from various ABS cenus data

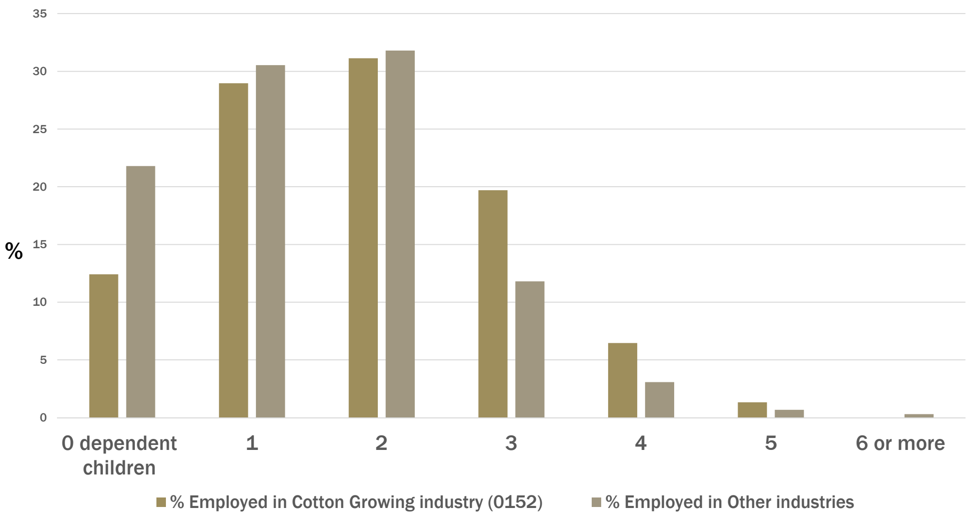
AGE OF COTTON FARMERS



Cotton farmers are younger than other farmers in Australia.

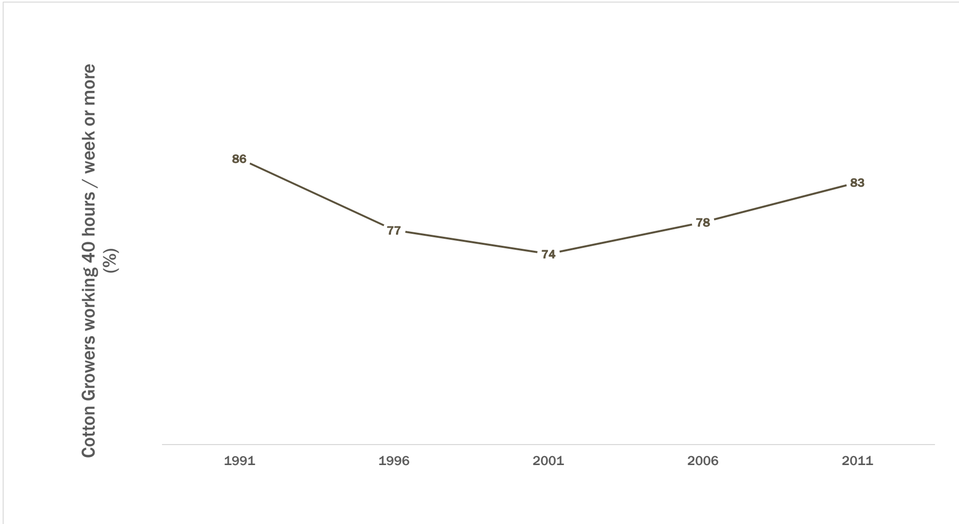
ABS 2011 cenus

FARMING FAMILIES



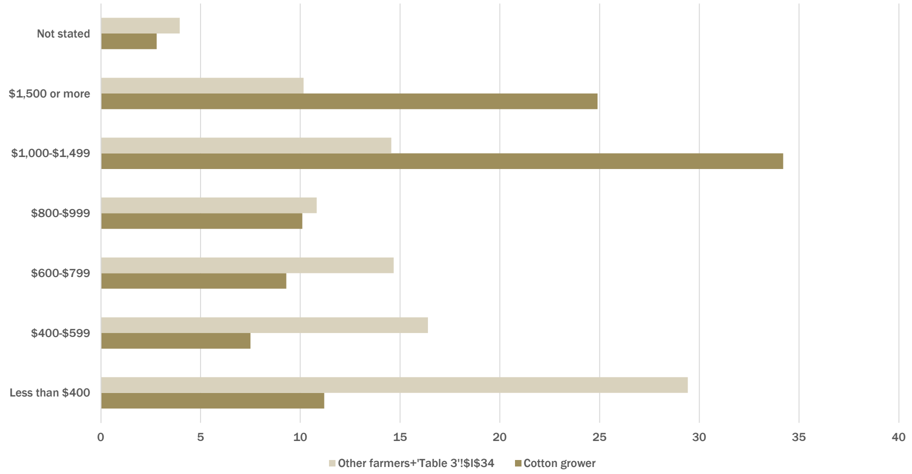
Count of Families where the Reference person or Partner is employed in Cotton Grower industry (0152) by Count of Dependent children, Australia, ABS 2011 Census. More families with 3 children than average of other industries.

COTTON GROWERS WORKING > 40 HRS /WEEK



Data compiled from ABS Census 1991, 1996,2001,2006

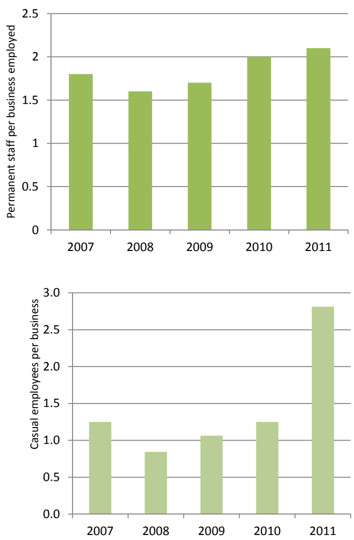
WEEKLY INCOME



Cotton growers weekly income higher than other farmers

Personal Income (weekly) by Industry of Employment (ANZSIC 06) and Occupation (ANZSCO), Cotton farmers and other farmers, Australia, ABS Cenus 2011

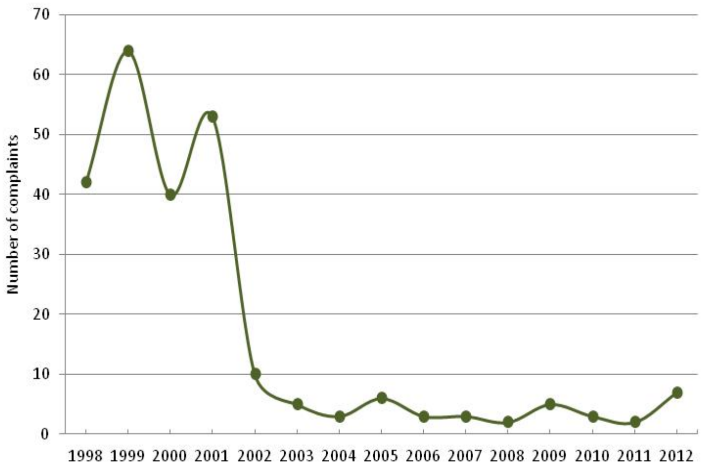
EMPLOYMENT TRENDS IN COTTON AGRONOMY BUSINESSES



Employment numbers recovering after the drought, especially casuals.

Modified from CCA

COMPLAINTS TO EPA



Number of complaints received by NSW EPA on cotton remains low

RESEARCH PEOPLE

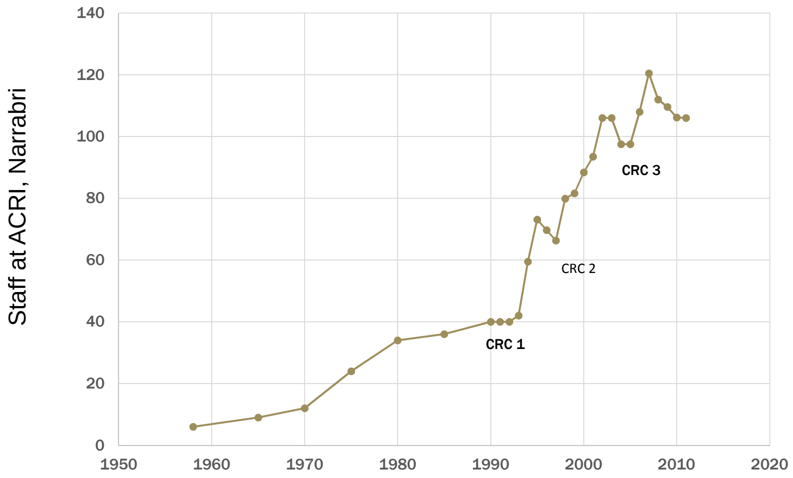


Table 1: A summary of economic sustainability indicators for the cotton industry October 2012

(Key - ↓/● falling/bad, ↑ /●rising/good, - /● no trend/ OK , ●●● easy/high → ○○○ difficult/low)

Economic Function	Economic Indicator	Current trend of indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
Cotton industry demographics	Planted area (ha)	↑	●	●	●●●	●●●	●●●	Irrigated & dryland proportions are available. Project has updated all these figures	Cotton Australia Cottonmaps.com.au Cotton year book ABARES Crop reports Monsanto data CSD
	Yield (bales/ ha)	↑	●	●	●●●	●●●	●●●	Need confirmation of 2012 yields. Project has updated all these figures	Cotton Australia, ABARE,
	Quality	↑	●	●	●●●	●●●	●●●	Aust. Cotton shippers have information on their web site. Difficult for layperson to understand. Project has updated all these figures	Aust Cotton Shippers Website. CSIRO
	Bales produced	↑	●	●	●●●	●●●	●●○	Straight forward. Convert to tonnes or kg for external stakeholders Project has updated all these figures	CA, ABARES.
	Grower numbers	↓	●●	●	●●●	●●●	●●○	Grower numbers are more elusive to find. Good data up to 2007, a number of different sources post 2007 and really a decision needs to be made whose figures to use. Whilst Cotton Australia may want to know the exact figure, most stakeholder	Cotton Australia Cottonmaps.com.au Cotton year book ABARES Crop reports Monsanto data CSD

								don't, they only need a ballpark figure. Getting grower numbers by valley is more challenging.	
	Cotton price per bale	↓	🔴	🟢	●●●	●●●	●●○	Price is very volatile (daily). It is a function of currency rate and physical price. Price is captured in gross margins.	Merchants.
	Cotton seed price	↓	🔴	🟢	●●●	●●●	●○○	As above	Excellent data and information on cotton seed in presentations at cotton conference in Aug 2012.
Gross value	Gross value ($) (industry scale)	↑	🟢	🟢	●●●	●●●	●●●	updated all these figures up to 2012	ABARES/CA
	Gross value (regional scale)	↑	🟢	🟢	●●●	●●○	●○○	Straight forward for gross value. Very complex for the regional economic multiplier contributions.	ABS farm finances MDBA recent studies ABARES water reports Stubbs & Powell et al reports
	Gross value (local government regions)	↑	🟢	🟢	●○○	●○○	●●○	Harder to collect than at the industry and regional scale, but local government is a key stakeholder for communities.	As above
	Cotton exports % or $ by country		🟢	🟢	●●●	●●●	●●●	Updated project data using ICAC data	ICAC & ABARES

Economic returns	Income / ha	-	● (red)	● (green)	●●●	●●●	●●○	Strongly influenced by yield and price.	
	Costs / ha	↑	● (red)	● (light green)	●●●	●●●	●●○	Boyce have 2012 data, smallish data set, but robust	Others Agririsk insurance?
	Gross margin / ha	↓	● (red)	● (light green)	●●●	●●●	●●●	As above	Boyce
	Profit / ha	↓	● (red)	● (light green)	●●●	●●●	●●○	As above	
	Income per ML water	↑	● (green)	● (green)	●●●	●●●	●●●	Updated data including data from other crops to compare to cotton now over 10 years.	DPIs, Boyce
	Return on investment (%)	?		● (red)	○○○	○○○	○○○	Very little data. Difficult to collect due to private wealth sensitivities. Government surveys do not segment the cotton farmers from beef, grain, sheep etc.	
	Equity / interest cover	?		● (red)	○○○	○○○	○○○	As above.	

Table 2: A summary of environmental sustainability indicators for the cotton industry.
(Key - ↓/● falling/bad, ↑ /●rising/good, - /● no trend/ OK , ●●● easy/high → ○○○ difficult/low)

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
Soil structure	Plant available water (soil moisture deficit)	↑	●	●	●○○	●○○	●●○		Encourage more cotton growers to compile their soil records over time such as the case study in this project. It could be necessary for industry leadership to assist this by initiating at least 10 case studies.
	Soil Compaction (SOILpak score)	?	●	●	○○○	○○○	●○○	expensive to collect., also subjective	
	Soil erosion	?	●	●	○○○	○○○	●○○	Very little data on erosion. There is information on management practices related to erosion. myBMP good source	
Soil fertility	Organic carbon %	↓	●	●	●●○	●○○	●●●	Decreasing and low levels. No industry wide data, although some good case studies. Carbon programs should change this	Grower surveys also have info.
	Soil phosphorus	-	●	●	●●○	●○○	●●○	Fertiliser replacement increasing.	
	Soil potassium and other cations	-	●	●	●●○	●○○	●●○	Fertiliser replacement increasing for potassium (K).	
	Fertiliser rates (N, P, K)	↑	●	●	●●●	●●●	●●○	Fertiliser use increasing. Good industry wide data. In grower surveys	
	Fertiliser Use Efficiency (Nutrient/yield)	↑	●	●	●●●	●●●	●●●	Eg N rate divided by yield.	Rochester, grower surveys

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
Soil salinity and sodicity	EC, Sodium, Chloride, ESP%	-	●	●	●●○	●●○	●●●	Soil salinity is generally low, soil sodicity high (sub soils) , no trend. Reasonable data available.	As above Triantafilis work in late 90s.NRM bodies
	Pesticide residues in soils	↓	●	●	○○○	●○○	●○○	Falling. Small data sets available in published papers.	?
Soil disease levels	Disease levels of major cotton diseases	↑	●	●	●●○	●●●	●●●	Good data available.	Research reports
Total water use by industry	ML (used)	↓	●	●	●●○	●●○	●●●	Each grower has their own records.	MDBA, ABS, grower surveys
	Compliance with law - Breaches of water legislation	?	●	●	●○○	●●○	●○○	Data is not available.	
	Trades - Number and volume	?	●	●	●○○	●○○	●○○	Increased trading of water, data quality is rapidly improving.	National Water Commission released a report in 2011. There was a cotton case study.
Water use efficiency on farm	Crop WUI Kg lint / mm /ha	↑	●	●	●○○	●●○	●○○	Improving. This index is usually used in research only.	Water Story 2012
	Gross Production WUI Bales per ML	↑	●	●	●○○	●●●	●●●	Most important, as includes rain and soil	Water Story 2012
	Irrigation WUI Bales per ML	↑	●	●	●●○	●●●	●●●		Water Story 2012
	Whole Farm irrigation efficiency (%)	↑	●	●	●○○	●●○	●●●	Large variations around the average figs.	Water Story 2012
	Crop water requirement bales / ML	-						6-8ml/ha figure often sought.	

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	% of irrigated agriculture	↓						Changes with crop area	MDBA ABARES Water reports
	WUE practice changes		●	●	●●●	●●●	●●●		Grower surveys myBMP case studies
Groundwater levels	Rising or falling	↑	●	●	●●○	●●○	●●●	Data is in most water sharing plans and monitored by agencies.	Data is in most water sharing plans and monitored by agencies. Also on line for some bores.
Irrigation scheduling	Method used for scheduling	↑	●	●	●●●	●●●	●●○	Increasing and high adoption of technology.	Grower survey
Water quality	Groundwater	-	●	●	●○○	●○○	●●●	Little data and varies from site to site.	Research reports
	Surface water	-	●	●	●○○	●●●	●●●	Water quality is improving. Excellent data sets in some areas.	State agencies Sustainable Rivers Audit (2012)
Biodiversity	Area of land cleared last 10 years (ha)	-	●	●	●○○	●○○	●●○	Trend of less and little clearing.	NRM groups / State Depts. Might be in a past grower survey.
	Area of land conserved (ha) last 10 years	↑	●	●	●○○	●○○	●●○		Grower surveys. NRM groups
	Breaches of land clearing regulations	?	?	●	●○○	○○○	●●○	No records.	As above
	% of farm managed as native vegetation	-	●	●	●●○	●●○	●●○	Some survey data, which could be easily improved.	Grower surveys

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	Vegetation quality index	?	🟢	🟢	○○○	○○○	●○○	Research is ongoing.	new carbon and biodiversity funding has created some new projects that could be followed up
	Bird species and numbers	-	🟢	🟢	●○○	●●○	●●○	Some scientific studies, but other studies needed in some regions. Birds Australia volunteers can do the monitoring.	Five CRC bird reports Birds Australia
	Fish species and numbers	?	🟢	🟢	○○○	●○○	●●○	Need improved data. Source State DPIs (fisheries)	Regional catchment bodies should have some funding or other government initiatives.
	Insect species and numbers	?	🟢	🟢	●○○	●●○	●●○	Many research studies that need reviewing by an expert entomologist. Probably an interesting story here.	
Riparian land management	Changes in riparian vegetation and landform condition	?	🟢	🟢	●○○	●○○	●●○	Some baseline data held by Murray Darling Authority	BMP scores Grower surveys,NRM bodies
Weeds	Density and distribution	↓	🟢	🟢	●○○	●●●	●●●	Falling weed density and distribution. Varies with species.	Research reports
	Herbicide resistance levels	↑	🔴	🟢	●●○	●●●	●●●	Low resistance. Research studies published.	Research reports
Pests (insects)	Density and distribution on insect pests	-	🟢	🟢	●●●	●●●	●●●	Highly variable with season and species dependent. Could segment species data. Research studies published.	As above

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	Level of resistance to key insecticides by pest species	↓	🟢	🟢	●●●	●●●	●●●		Research reports
Chemical use	Herbicide use	↓	🟢	🟢	●●●	●●●	●●●	Increasing glyphosate use, but decreasing use of other more toxic herbicides.	Chemical use figures various CAA reports. AVPMA, Croplife ? CRDC
	Total pesticide risk load	↓	🟢	🟢	●○○	●○○	●●○	Total pesticide usage weighted by environmental risk. Can be calculated by experts. Better Cotton Initiative require this see separate report	Kennedy et al ?
	Insecticide use	↓	🟢	🟢	●●●	●●●	●●●	Decreasing use.	Chemical use figures various CAA reports. AVPMA, Croplife ? CRDC - ICAC report
	Compliance with resistance management plans. (%)	-	🟢	🟢	●●○	●●○	●●●	High compliance.	myBMP
Transgenic crop trait stewardship	Resistance trends Insects	↑	🟢	🟢	●●○	●●●	●●●	Possible increasing trend, which is under close scrutiny.	CSIRO reports
	Resistance trends Herbicide (glyphosate)	↑	🔴	🟢	●●○	●●●	●●●	Possible increasing trend, which is under close scrutiny.	Research reports Werth, Thornby, Powell Cotton Conference 2012.
	Compliance with management plans	-	🟢	🟢	●●○	●●○	●●●	High but no published data	
	Area planted by	↑	🟢	🟢	●●●	●●●	●●●		Monsanto.

Environmental Function	Environmental Indicator	Current trend for indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	trait (ha) or % of growers using technologies								
Greenhouse emissions and energy	Nitrous oxide and CO_2 emissions	**?**	●	●	●○○	●○○	●●●	Very little data other than a few case studies. Techniques to calculate not fully developed.	Grace Rochester/MacDonald
	Energy use	**?**	●	●	●●○	●○○	●●●	Could look at renewable and non renewable energy use in the future	NCEA King ?, new projects
Carbon footprint	CO2 e/ ha	**?**	●	●	●○○	●○○	●●●	828 -4703 CO2e	F. Visser doing an investigation. Published paper 2012 cotton conference. CSIRO/IPCC ?
	Life Cycle Analysis	**?**							CRDC
Farm practices	Crop rotations	**↑**	●	●	●●●	●●●	●●○		Grower surveys
	Tillage (minimum) Area or %	**↑**	●	●	●●●	●●○	●●○		Grower surveys myBMP
myBMP	Bales produced	**↑**	●	●	●●●	●○○	●●●		Cotton Australia
	Investment in	**↑**	●	●	●●●	●○○	●●●		Cotton Australia / CRDC
	Farms participating	**↑**	●	●	●●●	●○○	●●●		Cotton Australia
	myBMP Rankings	**↑**			●●○	●○○	●○○	Average rankings of farm practices.	Cotton Australia
% of catchment cotton	% of catchment cotton	**-**	●	●	●●○	●●○	●●○	Better data in some catchments	CMAs / NRM CRC reports MDBA / ABARES 2012

Table 3: A summary of social sustainability indicators for the cotton industry.
(Key - ↓/● falling/bad, ↑ /●rising/good, **-** /● no trend/ OK , ●●● easy/high → ○○○ difficult/low)

Function	Indicator	Current trend of industry for the indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
Education	Highest post school qualification of cotton growers	↑	●		●●●	●●●	●●●	High and improving qualifications for agricultural industries. Data is in census classifications.	Census
	Highest post school qualification of service industry	↑	●		●●○	●●○	●●●	High and improving qualifications. Non census classification thus requires industry survey. Service industry is not necessarily specific to cotton.	Census
	Highest post school qualification of cotton ginners	↑	●		●●●	●●●	●●●	Improving qualifications. Data is in census classifications.	Census
	Vocational training of farm staff (& service industries)	↑	●		●●○	●○○	●●○	A lot of industry training, but hard to get data	Industry records Agrifoodskills ?
	Apprenticeships of farm staff	**?**	●		●○○	●○○	●●○	No data	
Employment	Number of people employed on farms	↑	●	●	●●○	●○○	●●●		Grower survey 2011 Boyce figs small sample. grower survey 2013. Melb uni project
	Number of people employed	↑	●	●	●○○	●○○	●●●		Estimated /calculated figures

Function	Indicator	Current trend of industry for the indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	(industry)								for CRC bid, which were published and have since become a fact. Stubbs & Powell reports have data.
	Number of people employed (indirectly)	↑	🟢	🔴	●○○	●○○	●●●	Improved data required.	Several reports Stubbs Powell, MDBA
	Income per week	-	🟢	🟢	●●●	●●●	●○○	High for agriculture. Question the census data as high number of self-employed people.	Census
	Hours worked	-	🟢	🟢	●●●	●●●	●○○	Well above national average	Census
Health	Deaths on farms and cotton gins	↓	🟢	🟢	●●●	●○○	●●●	Very low death rates.	Word of mouth.
	Accidents / injuries / Workers compensation claims	↓	🟢	🟢	●●○	●●○	●●●	Falling trend. However needs monitoring as crop area increases.	Moree Ag health unit get it from somewhere.
Demographics	Grower age	-	🟢	🟢	●●●	●●●	●●○	Younger compared to the balance of agriculture.	Census every four years. Last 15 years, Also some info in some of past grower surveys.
	Gender participation in industry	-	🟢	🟢	●●●	●●○	●●○	For agriculture, reasonable gender balance in organisations. More males working on farms. Many females in service sector.	Organisational annual reports CCA membership
	Aboriginal participation in	-	🟢	🟢	●○○	●●○	●●○	Need better data, trend of less manual work such as	?

Function	Indicator	Current trend of industry for the indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
	industry							cotton chipping and module building, more traineeships being offered?	
Attitudes	Local community attitudes	↑	●		●●●	●●●	●●●	Strong and improved local support for industry	Past surveys
	Non local community attitudes	-	●		●●●	●●●	●●●	Mixed attitudes, mostly negative towards industry	
	Industry attitudes	-	●	●	●●●	●●●	●●●	There are high levels of social capital	CA past surveys
Social capital	Memberships of ACIC	-	●	●	●●●	●●●	●●○	There is strong industry social capital	
	CCA memberships	?	●		●●●	●●●	●●○	There is strong industry social capital	
	WinCott memberships	↑	●		●●●	●●●	●●○	There is strong industry social capital	
	Conference delegates	↑	●	●	●●●	●●●	●●○	There is strong industry social capital	
	Internet usage	↑	●	●	●●●	●●●	●●○	High and rising usage	Grower surveys
	Other local cotton industry interactions with other industries such as beef cattle etc. or community	-	●	●	●○○	●○○	●●○	No data, but scope to strengthen linkages with other industries and organisations. Best done with case studies. Signposts 2006 report had a figure of 56% of growers volunteer.	
Research & Development	Investment levels (culture and impacts)	↑	●	●	●●●	●●●	●●●	There is a very strong culture of R&D and its adoption. Have data tracking staff numbers at ACRI.	CRDC annual report CRC exit report
Legal	Complaints	↓	●	●	●●○	●●●	●●●	Number of complaints	EPA

Function	Indicator	Current trend of industry for the indicator		Confidence In data	Ease of collection	Current information quality	Priority	Comment	Sources
compliance & responsibility	received by regulatory authorities about cotton industry							about industry practice is falling	
	Fines imposed on cotton growers for natural resource management breaches	**?**	●	●	○○○	●○○	●●○	No data.	? EPA
Ownership	Foreign ownership (ha or % or entity number)	↑	●	●	●●○	●●○	●●○	New indicator. Become a hot topic in last 12 months.	CA, NFF
Farm size	Average farm size	↑	●	●	●●○	●●○	●●○	New indicator. Aust provides data to ICAC.	CA

Priority indicators (Tables 1-3 contain further details):

i. profitability (gross margin);
ii. yield /fibre quality
iii. economy (gross value of production and employment);
iv. water use ;
v. water quality ;
vi. pesticide use and technology stewardship (transgenic traits, chemistry resistance);
vii. soil quality;
viii. energy, greenhouse and carbon balance;
ix. regional biodiversity;
x. industry demographics;
xi. community attitudes and
xii. workplace health and safety.

Outcomes

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

This project has contributed to;

- Better and longer term data sets on economic, environmental and social performance of the cotton industry (science outcome)
- New knowledge is available for stakeholders (Government, industry, scientists and community and markets)
- Improved evidence based data for CRDC, Cotton Australia, Cotton CRC and others to report on their strategies and operations
- Cotton industry is well prepared for the many emerging sustainability frameworks and markets such as ICAC SEEP, Better Cotton Initiative, Australian Government Sustainability Council,
- Better reporting of the public benefits of R&D
- Increase in social capital of the cotton industry to discuss the entire economic, environmental and social systems that make up the cotton industry
- Cotton industry being a leader amongst rural industries on sustainability, which is a priority activity of the NFF.

This report has been commonly cited by others researching Australian Cotton Industry, Murray Darling Basin Plan, Cotton Industry Environmental Review and Rural Communities researchers as well as attending to adhoc requests (about one per week) for information from a range of stakeholders.

From the project application: As a result, this will allow the cotton industry to:

- Demonstrate its economic, environmental and social credentials to a wider range of stakeholders, using reputable and independent data sources. In other words communicate its story with facts and figures.
- It will use the Global Reporting Initiative framework of triple bottom line reporting now being adopted by corporate Australia and the globe *(Note: This has not been achieved).*
- Identify potential areas for improvement in industry performance in relation to economic, environmental and social parameters.
- Be a leader amongst rural industries in measuring, demonstrating and communicating sustainability reporting
- Have the information at hand to report on CRDC's and Cotton Australia strategic plan as well as allow the industry to contribute better information to Government reviews and processes
- Build industry human capacity and knowledge across the breadth of economic, environmental and social disciplines that make up the cotton industry

Conclusion

The importance of sustainability reporting continues to strengthen driven by market demands, community values and government responses. The NFF blueprint for agriculture has sustainability indicators work as a priority action. The 3rd Environmental review recommended enhanced reporting by the Australian cotton industry. Other examples include, for example, in October 2012, the International Cotton Advisory Committee 71st plenary meeting theme was on "Shaping sustainability in the cotton value chain". The Member Countries made several commitments related to sustainability. Australia is well positioned to meet these and this project is contributing to that.

Worldwide demand for food and fibre is increasing to service the needs of a growing population and higher standards of living. At the same time, communities are striving for more sustainable management of natural resources. Agriculture will need to achieve both the demands for increased output of agricultural products and those for sustainability. For this to be possible, it is important for farming industries to measure and understand their current sustainability trends and adapt practices as required.

"Sustainability" is a commonly used word, but its actual meaning is subject to differences in interpretation. This is in part because of discrepancies with short and longer term timeframes, the influence that personal values play in the perceptions of sustainability and the challenges managing the trade-offs associated with decisions. For the purpose of this project, sustainability includes three distinct, but related economic, environmental and social parameters.

The project has updated most economic data sets with data from ABARES, Cotton Australia, International Cotton Advisory Committee etc. There is excellent economic data including trends over time. Information at the local government scale has been updated from the 2011 census. There is a gap in the profitability figures of farm business such as return on equity and interest coverage, which are sometimes requested by stakeholders. This information is difficult to collect due to private business (wealth) sensitivities, and government surveys do not segment the cotton industry figures as opposed to larger industries such as grain and beef cattle.

An important gap was employment data, which was not well quantified on farm, in the service industries and value chain. A few projects have addressed this in recent years (University of Melbourne, CRDC project, 2011 grower survey).

The project has updated economic indicators with data from ABARES, Cotton Australia, and the International Cotton Advisory Committee, etc. There is excellent economic data allowing long term trends to be monitored over time. Information at the local government scale has been updated from the 2011 census. There is a gap in the profitability figures of farm business such as return on equity and interest coverage, which are sometimes requested by stakeholders. This information is difficult to collect due to private business (wealth) sensitivities, and government surveys do not segment the cotton industry figures as opposed to larger industries such as grain and beef cattle.

A few years ago an important gap was employment data, which was not well quantified on farm, in the service industries and value chain. A few projects have helped addressed this in recent years (University of Melbourne, CRDC project, 2011& 2012 grower survey).

Key environmental indicators include soil, water, pesticide and transgenic crop trait stewardship, biodiversity, carbon and greenhouse emissions. Environmental indicator data is patchy. There are some excellent data sets available from case studies, research reports and the two industry environmental audits and the 2012 environmental review. However, these generally provide a 'point in time' story rather than a long term trend and are rarely provide an industry wide coverage.

There is data over a reasonable timeframe for fertiliser rates, disease levels, river water quality, pest (weeds and insects) density and distribution and their resistance levels to various chemistries to manage them. Water use data has improved significantly in recent years. Notable environmental data gaps include soils (physical, chemical and biological status), biodiversity, and greenhouse emissions/carbon balances/energy use.

A key issue for the cotton industry is understanding river health and environmental flows. This knowledge is linked to water sharing plans and monitoring outcomes related to these plans. Improved monitoring of river health is needed and will need to be resourced by Government.

Insecticide resistance is a major sustainability risk for the cotton industry. The management of insect resistance to transgenic cotton traits is perhaps the greatest potential immediate sustainability risk perceived by cotton industry stakeholders. Non cotton stakeholders are possibly focused on water and chemicals, while on the international stage labour working conditions is a key issue.

Key social sustainability indicators include education levels, demographics, employment, health, community attitudes, social capital, research and development and compliance with the law.

Gaps in the social data include; vocational training and other non-degree capacity building measures such as apprenticeships, number of deaths, and measures of social capital related with other local industries such as grain production, bee keeping, cattle or fruit production. Another notable gap for social responsibility and environmental management is data related to compliance with legislation related to natural resource management. Government agencies do not provide this information and it is unlikely they will into the foreseeable future.

The 2011 ABS Census data has been obtained and compiled into the older data sets to provide trends over time. It includes data such as age, education levels, salaries, and some other demographics of cotton growers and ginners that can be added to current data sets between 1995 – 2006. Contact was also made with NSW EPA to update the complaints received data.

There are many indicators for different audiences and they can be used on different timeframes. While there are over 100 possible sustainability indicators applicable to cotton in this study, it is recommended only 10-20 are a priority. A few priority indicators are:

Indicator	Status of data availability
Profitability (gross margin)	Good, although gross margin not the best measure of profit.
Yield & fibre quality	Good
Economy (gross value of production and employment)	Good, regional employment more challenging
Water use efficiency and productivity	Good
Water quality	Good
Pesticide use and technology stewardship (transgenic traits, chemistry resistance)	Good
Soil quality or health	Lots of data, but not easy to compare over time other than data at ACRI
Energy, greenhouse and carbon balance	Should improve with current projects
Regional biodiversity	A challenging indicator. Need to obtain from NRM bodies.
Industry demographics	Good
Community attitudes	Not measured since the Roy Morgan Study
Workplace health and safety	Some data.

Sustainability reporting is the practice of measuring and disclosing economic, environmental and social performance. Sustainability reporting is now entering the main stream of business operations with the Global Reporting Initiative being the most widely used framework. The cotton industry is striving for the sustainable development and its key organisations include reference to it in their strategic plans. A number of economic, environmental and social indicators can be used to measure progress towards the sustainability goal. Sustainability should be considered a journey. Many data sets exist as well as some gaps and opportunities for improvement, which are discussed in the next section.

Extension and Research Opportunities

There are *extension opportunities* to present or extend the outputs of the project. For the cotton industry, these could include the cotton conference, cotton researcher's conference, cotton grower magazine or CRDC spotlight

In terms of research, alignment with the growing interest in International and National sustainability programs such as the International Cotton Advisory Committee SEEP, Better Cotton Initiative, Cotton Leads, National Farmers Federation Agricultural Blueprint, and broader programs such as Global Reporting Initiative and Sustainable Agricultural Initiative. These opportunities could be pursued in the subsequent project.

In terms of industry development: a sustainability five year plan. A Policy Statement / Commitment is one of the founding principles of any sustainability program. The starting point could be:

A Sustainability Framework or Sustainability Charter

Australian cotton could benefit from a sustainability framework/charter. Sustainability is core business and forms part of the strategic plan and statements of most peak cotton bodies. The International Cotton Advisory Committee recently put cotton sustainability front and centre of its vision. Publishing a framework or charter would elevate and make a more transparent commitment to continual improvement, which is at the heart of the sustainability concept committed to by ICAC and Australia.

A simple one page statement…….

> *For example:* Australian cotton is committed to advancement in sustainability of its production throughout the value chain both in Australia and abroad.. We are committed to achieve sustainable economic development, enhancing the environment of its area of influence and contributing to improved wellbeing of our communities…….
>
> Add a few detailed commitments around enhancing ecosystems, economic prosperity, improving knowledge and innovation, collaboration, stakeholder consultation, capacity building, lawful compliance, supply chains, develop standards, adaptive and evolving, myBMP, reporting……..
>
> Framework around: Industry prosperity, supporting communities, health and safety, enhancing environmental well-being. The environmental policies have been covered in the past,
>
> A social responsibility statement (governance, human rights, OH&S, labour conditions) is of growing important to cotton consumers and the framework would strengthen Australia's position.

There is a need for an industry wide framework that the variety of industry organisations could sign up to possibly under the ACIC banner. It would add some meat to the bones of Vision 2029 and strategic plans of their organisations, as well as Australia's commitment to ICAC. Such a charter could map out existing initiatives. The good news is there is plenty going on, but it is difficult for people, especially non cotton industry stakeholders to see this.

Other future research could include;

- The Cotton BMP farm practice rankings be used to monitor sustainability trends.
- Cotton industry establishes a formal stakeholder consultation roundtable that convenes annually to discuss sustainability matters.
- The cotton industry undertake scenario planning activities to explore future key drivers of change.
- Cotton industry produce a social responsibility statement for the cotton industry.
- The cotton industry formally approach the Queensland and NSW Government agencies to establish what environmental data they may be able to provide and their monitoring intentions for the future.
- The Global Reporting Initiative should produce a specific sector supplement for agriculture at the industry level for a region/country. This should be pursued via the NFF blueprint process.
- A better understanding of the materiality issues / indicator needs of external stakeholders
- Publish a paper in the scientific literature
- Investigating and pulling together the soils data
- Explore the natural resources data with regional NRM bodies
- Re visit community attitudinal data. This has not been measured since the Roy Morgan study about 10 years ago.
- Investigate "e portal" data management systems.

6. **List the publications arising from the research project**.

A. Publications

- Roth G, Harris G, Gillies M, Montgomery J, and Wigginton DW (2013) A review of water use efficiency and productivity trends in Australian irrigated cotton. *Journal of Crop and pasture Science (in press).*

- Roth G (2012) Sustainability indicators for cotton. A poster for the Australian Cotton Conference, August 2012 and included in the conference proceedings.

- Roth G (2012) A review of social indicators of the cotton service sector, Proceedings Australian Cotton Conference, August 2012 pp76-79.

- Trindall J, Roth G, Williams S, Wigginton D, Harris G, (2012) The Australian Cotton Water Story. Cotton Catchment Communities CRC, Narrabri, 132pp.

- Roth G (2012) Riparian area – arteries of the cotton landscape. *In* Trindall J, Roth G, Williams S, Wigginton D, Harris G, (2012) The Australian Cotton Water Story. Cotton Catchment Communities CRC, Narrabri, 132pp.

- Roth G (2012) Coordinating deep drainage research. *In* Trindall J, Roth G, Williams S, Wigginton D, Harris G, (2012) The Australian Cotton Water Story. Cotton Catchment Communities CRC, Narrabri, 132pp.

- Roth G and Harris G (2012) Water management for irrigated cotton research and development outcomes. A science review and future directions. Paper presented, Irrigation Australia Conference, Adelaide, 27th June 2012

- Roth G (2011) The cotton industry social licence. In Defending the Social licence of farming. Issues, Challenges and New Directions for Agriculture. Ed J Williams and P Martin. CSIRO Publishing. pp69-82

- Roth GW (2010) Economic, environmental and social indicators for the Australian Cotton Industry. Cotton Catchment Communities CRC http://www.cottoncrc.org.au/general/Research/Projects/3_03_09

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

- Roth GW (2010) Economic, environmental and social indicators for the Australian Cotton Industry. Cotton Catchment Communities CRC http://www.cottoncrc.org.au/general/Research/Projects/3_03_09
  Expectations for industries to manage resources in a sustainable manner raise the question of how industries can demonstrate their sustainability credentials. This thesis reviews the question of sustainability monitoring and reporting in relation to the Australian cotton industry. Principals of sustainability reporting in business and agriculture were reviewed. A set of sustainability indicators has been developed and economic, environmental and social data compiled. A specific analysis of the cotton industry's environmental management system, the Cotton Best Management Practices program was completed to investigate its potential to track and report farm management practice change over a 10 year period.

Presentations of cotton industry data at Cotton CRC Science forums, Irrigation Australia Conference 2010 & 2012, Poster for Global Reporting Initiative Australian Conference 2012, article Australian Cotton grower magazine 2012, article in CRDC Spotlight magazine 2012.

Part 4 – Final Report Executive Summary

The importance of sustainability reporting continues to strengthen driven by market demands, community values and government responses. The International Cotton Advisory Committee Member Countries have made several commitments related to sustainability recently, including reporting metrics. Sustainability performance includes three distinct, but related economic, environmental and social parameters.

The project identified 110 possible sustainability indicators applicable to the cotton industry, however recommends only 10-20 are a priority for reporting. The project compiled updated economic, environmental and social sustainability indicator data sets including trends over time where possible. In particular, all the economic data sets, water use efficiency and soil nutrition data, and social metrics from the 2011 ABS Census. Several of the environmental indicators are challenging to collect meaningful data over extended timeframes. These include soil health and biodiversity.

Other project activities included: technical input into the Cotton CRC impact reports, sustainability project collaborations, an investigation of the Global Reporting Initiative, collaboration and production of The Cotton Water Story, publication of water use efficiency trends in the scientific literature, a book chapter on the social licence of farming using cotton as a case study, and provision of data and information to a range of stakeholders.

This project has contributed to;

- ✓ Better and longer term data sets on economic, environmental and social performance of the cotton industry
- ✓ New knowledge is available for stakeholders (Government, industry, scientists and community and markets)
- ✓ Improved evidence based data for CRDC, Cotton Australia, Cotton CRC and others to report on their strategies and operations
- ✓ The cotton industry being well prepared for the many emerging sustainability frameworks and markets such as International Cotton Advisory Committee SEEP, Better Cotton Initiative, Australian Government Sustainability Council Reporting
- ✓ Better reporting of the public benefits of Cotton R&D&E
- ✓ Increase in social capital of the cotton industry to discuss the entire economic, environmental and social systems that make up the sustainability challenge
- ✓ The cotton industry being a leader amongst rural industries on sustainability, which is a new priority activity of the NFF/DAFF.

Priority indicators include:

- *Economic*: profitability (gross margin), yield /fibre quality, economy (gross value of production and employment);
- *Environment*: water use efficiency and productivity, water quality, pesticide use and technology stewardship (transgenic traits, chemistry resistance); soil quality; energy, greenhouse and carbon balance; regional biodiversity;
- *Social:* industry demographics; community attitudes and workplace health and safety.

The cotton industry is striving for the sustainable development and its key organisations include reference to it in their strategic plans. A number of economic, environmental and social indicators can be used to measure progress towards the sustainability goal. Sustainability should be considered a journey rather than a destination. Many excellent data sets exist as well as some gaps and opportunities for improvement.

Appendix

- Roth G, Harris G, Gillies M, Montgomery J, and Wigginton DW (2013) A review of water use efficiency and productivity trends in Australian irrigated cotton. *Journal of Crop and pasture Science (in press).*

- Roth G (2012) Sustainability indicators for cotton. A poster for the Australian Cotton Conference, August 2012 and included in the conference proceedings.

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A review of water use efficiency and productivity trends in Australian irrigated cotton.

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A review of water use efficiency and productivity trends in Australian irrigated cotton.

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Abstract

Water is the major factor limiting cotton production in Australia, with 70-90% of the cotton production area usually managed under an irrigated system. The Cotton Catchment Communities Cooperative Research Centre (Cotton CRC) placed a major emphasis on improving water use efficiency and productivity of irrigated cotton farming systems in Australia. This paper reviews the research and trends in the water use efficiency and productivity of irrigated cotton.

Cotton CRC research from 2006 – 2012 focused on promoting measurement of water use efficiency, optimising the performance of surface irrigation systems, investigating alternatives irrigation systems to the conventional furrow irrigation systems, understanding the movement of water through the soil and the potential of deep drainage, reducing water losses from on farm storages and better understanding of plant water relations

Surface irrigation systems are used on 80% of the irrigated Australian cotton crop and utilise 6-7 ML/ha depending on the amount of seasonal rain received. Over the past decade water use efficiency by Australian cotton growers has improved by 3-4% per annum, or by 40% increase in the water use productivity. This has been achieved by both yield production increases and more efficient use of applied irrigation water. The whole farm irrigation efficiency has improved from 57% - 70%, while crop water use index is above 3 kg/mm/ha and is high by international standards. The seasonal evapotranspiration of surface irrigated crops averages 729 mm over the last 20 years

Yield increases over the last decade can be attributed to plant breeding advances, the adoption of genetically modified varieties, and other agronomic research. There has been an increased use of irrigation scheduling tools and furrow irrigation system optimisation evaluations. This has reduced in field deep drainage losses. The largest losses of water on cotton farms is from evaporation from on farm water storages. Application efficiencies of over 90 per cent are achievable under well managed furrow irrigation. The greatest initial gains in water use efficiency can be achieved by improving the management of existing surface irrigation systems through this site specific optimisation. Growers are also making changes to alternative systems such as centre pivots and lateral move systems and it is expected there will be increasing numbers of these machines in the future. These systems achieve labour and water savings (30%), but have significantly higher energy costs associated with water pumping and machine operation.

The standardisation of water use efficiency measures and improved water measurement tools for surface irrigation have been important research outcomes to enable irrigation benchmarks to be established. While the Cotton CRC achieved important new research outcomes, its major effort was related to water extension projects, training of growers and advisers, capacity building, technology demonstrations and information packaging. The industry benchmarks indicate that Australian cotton irrigators should be producing >1.1 bales per ML water (total water, ie irrigation water applied, rainfall and soil moisture used) with surface irrigation systems and 1.3 bales/ML with centre pivots and lateral move machines.

Water use management performance is highly variable and site specific between cotton growers, farming fields and across regions. Therefore, site specific measurement is important. The range in the presented data sets indicates there remains potential for further improvement in water use efficiency and productivity.

Introduction

Water is critical to cotton production to maximise crop yields and fibre quality. In Australian cotton growing regions, crop water demand exceeds the rainfall supply. While dryland crops are successful in some regions and some seasons, irrigation enables cotton to be grown in a wider area to optimal yield. Variability in the availability of irrigation water is widely accepted as the most limiting factor in Australian cotton production systems. Increasingly water is becoming scarce due to the rising demand of alternatives uses such as the demand from other crops, mining, urban communities, environmental flows and climate change. Therefore, it is imperative that farmers continue to strive to improve water use efficiency and productivity. Increasing water scarcity and demand for water led to the Cotton Catchment Communities Cooperative Research Centre (Cotton CRC) goal of producing "more crop per drop" or more cotton per unit of water used.

The farm based Cotton CRC research focused on promoting measurement of water use efficiency, optimising the performance of surface irrigation systems, investigating alternatives irrigation systems to the conventional furrow irrigation systems, understanding the movement of water through the soil and the potential of deep drainage, reducing water losses from on farm storages and better understanding of plant water relations.

There has been a body of specific water research projects published in the scientific literature on various aspects of cotton agronomy, physiology and plant water relations. During the last decade there have also been many large Government and industry funded agricultural extension initiatives specifically aimed at improving water use efficiency on cotton farms. These include, for example, the Queensland Rural Water Use Efficiency Programs, NSW Waterwise on the farm, Commonwealth Government Rural Water Use Efficiency Fund, Cotton Research and Development Corporation Irrigated Cotton and Grains projects and programs of several regional natural resource management bodies such as Namoi Catchment Management Authority and Condamine Alliance.

An analysis of the Cotton Catchment Communities CRC Final Report (2012) publication list shows irrigation research publications made up only seven percent of the total peer reviewed scientific journal publications, while 31% of the publications in industry magazines were irrigation extension articles.

The objective of this paper is to report changes and trends in cotton water use efficiency and productivity from both the scientific literature and the unpublished reports form these extension programs.

Australian cotton and irrigation water management context

Market research on cotton growers found the key issues affecting their water management were the availability, continued security and cost of water, economic returns per megalitre, water quality and water scheduling (Callen *et al* 2004). Other important issues that have arisen since that research include rising energy costs of energy for pumping, labour shortages for irrigating, and uncertainty associated reforms of Government policy related to irrigation allocations.

The Australian climate and its variability is one of the major risks that farmers try to manage. In the last decade, the cotton industry has been subjected to the "millennium drought", arguably the worst on record. Australia is maybe one of the driest countries on the planet, but this cliché needs some interpretation. Cotton is mostly grown in the 400-800mm summer rainfall zone, which means cotton crops can receive significant amounts of their water needs from rain during the growing season. Likewise, the highly variable climate can lead to droughts and flooding rains and both extremes have been experienced in the last decade. The cracking clay soils where cotton is mostly grown can store up to 150-178mm of plant available water in a 130 cm profile (Cull *et al* 1981a, McKenzie 1998), especially following a wet winter prior to cotton planting.

For the last 10 years, dryland production has on average made up 17% of the total planted cotton area and 8% of the total Australian cotton crop production. The area of rain grown or dryland cotton fluctuates considerably in response to rainfall, seasonal conditions and prices of agricultural commodities. During the last decade, the dryland area ranged from 7370–206,250 hectares, with the average yields ranging from 1.87 – 5.76 bales /ha.

For the last 10 years, on average, 83% of the Australian cotton crop was irrigated and produced 92% of the national crop with an average yield of 9.59 bales/ha. Up to 400,000 hectares of irrigated cotton are grown in Australia depending on water availability. Australian average irrigated lint yields are now the highest of any major cotton producing country in the world, being about 2.5 times the world average. Yields have continued to edge upwards from 1200 kg/ha in the 1970s, through 1400 kg/ha in the 1980s to 1600 kg/ha in the 1990s and are now greater than 2270 kg /ha (10 bales/ha).

Most of this yield gain is attributed to plant breeding and exploiting genetic variation and genotype response to modern management (Liu *et al* 2013). They found the yield gain in a 30 year evaluation of cotton breeding trials was attributed to gains in cultivars, ie genetics (48%), management (28%) and cultivar by management (24%) interaction.

In addition to their influence on yield, water and irrigation can have a significant impact on cotton fibre quality. (Hearn 1976, Hearn and Constable (1984) and Hearn (1994). Water stress during the first one third of boll filling reduces fibre length when fibres are elongating, while it reduces fibre maturity and thickening if it occurs during the last two thirds of boll filling (Bange *et al* 2009). Irrigation scheduling and variety choice were rated by growers in 2011 as the most critical management tools for fibre quality (Roth 2011).

Farmers grow cotton because they believe it is the most profitable crop for them per unit area of land and water used. The gross margin of cotton in 2012 was $1192/ha (Boyce 2013) compared to corn, wheat and sorghum, which were considerably less. The International Cotton Advisory Committee (2010) provides a report on irrigation costs for most countries in the world. Australian irrigation costs are amongst the highest in the world. Irrigation costs represent between 3-11% of total costs for most countries and this was reported as 8% in Australia, compared to the USA for example, which is 3%.

The majority, at least 80%, of Australian cotton is irrigated using gravity surface irrigation systems. Hence, the focus of this review is on surface irrigation systems. The major recent trend is the rising use of the centre pivot and lateral move irrigation machine systems, up from 10% in 2008 to about 17% in 2013 (8% lateral move and 7% centre pivots). About 3% is irrigated with pressurised sub surface drip irrigation systems. Anecdotal evidence suggests that there has been little additional drip irrigation capacity added in this time but that the area under centre pivots and lateral move systems has increased considerably.

Australian Irrigation Cotton Plant Based Research

Many studies have investigated cotton plant water relations, agronomic variables, water use, yield and fibre quality relationships. It is not the intention of this paper to provide a detailed review of all the irrigation research that has been undertaken in Australia. As expected, there is considerable variability in project outcomes driven largely by climatic variability; wet, dry, hot, or cool seasons, as well as location specific factors such as variations in soil type and irrigation practices. Comprehensive discussions on the physiology of cotton plant water relations in can be found in Hearn (1979), Jordon (1981), Hearn and Constable (1984a), Turner *et al* (1986), and Hearn (1994).

Research in the 1970s examined irrigation scheduling regimes using water balance models, soil moisture monitoring to develop an understanding of seasonal irrigation requirements and establish crop factor relationships between evapotranspiration and leaf area index (Cull *et al* 1981a,b). At the time they recorded actual farm water use efficiencies were 30-50% in the Namoi Valley and concluded there was scope to improve. These projects led to the beginning of irrigation scheduling by farmers using neutron probes to measure soil moisture.

Other studies in a similar timeframe by Hearn and Constable (1984), which looked at irrigation strategies and Constable and Hearn (1981) examined the effect of irrigating at various water deficits at different times in the growing season. The best irrigation strategy varied from year to year due to the variable rainfall pattern. The plant growth stages sensitive to water and nitrogen stress and stress interactions through the season were identified and their impact on plant growth, yield and quality.

Using a rainout shelter and different irrigation treatments physiological and morphological responses to water stress were investigated (Turner *et al* 1986). They concluded soil water deficits reduced the capacity of the crop to carry fruit as a result of lower leaf photosynthesis.

Managing limited water scenarios during drought were reviewed by (Hearn 1995). At the time 5-6 ML/ha was considered the optimum, depending on the location and irrigation water allocation prior to planting. This finding is supported in a recent review by Quin *et al* (2013). Tennakoon and Hulugalle (2006) studied rotations and tillage practices on water use efficiency and found crop rotation with wheat and minimum tillage improved water use efficiency in some years in the vertisol soils of north western NSW. They also found average seasonal evapotranspiration was higher with minimum tillage in comparison to conventional tillage systems and that plant available water in minimum tilled cotton was increased by 18 mm over that of conventionally tilled cotton. Soil properties in irrigation furrows on vertisol soils were investigated by Hulugalle *et al* (2007). Hulugalle and Scott (2008) reviewed the research that has examined irrigated cotton crop rotations, including outcomes related to soil water management.

Partial root zone drying is an irrigation strategy which involves the alternate drying and wetting of sub sections of the plant root zone. The application of partial root zone drying irrigation strategies was investigated between 2002-05 and no significant difference in crop growth or yield was found in commercial field conditions. More effective WUE benefits were found with regulated deficit irrigation strategies around 80% of ET using centre pivot or lateral move irrigation systems, and the increased ability for capture of in crop rainfall. (White 2007, White and Raine 2009). They argued that deficit and regulated deficit irrigation strategies were already inadvertently applied within some parts of the Australian cotton industry as many of the centre pivots and lateral move systems had inadequate capacity to meet peak irrigation water requirements.

Prior to 2006 cotton irrigation research in Australia had been conducted using conventional varieties that had lower fruit retention, were subjected to frequent insect attack and often incorporated a period of water stress until squaring. Paytas (2009) demonstrated using rainout shelters and plastic inter-row covers the importance of maintaining adequate soil moisture during early growth phases of high fruit retention B*t* cotton (Bollgard II™) crops. Leaf area index, vegetative and reproductive biomass, number of squares, flowers and fruits were found to increase in well watered treatments. Modest water deficits pre flowering were found to reduce fruit retention, yield and lint quality (Paytas *et al* 2008).

The widespread adoption of transgenic varieties by Australian cotton growers meant it was important to investigate how these varieties respond to water stress and irrigation strategies. Yeates *et al* (2010) measured the effect of this increased insect protection on morphology, growth and response to water using Bollgard II™ and non B*t* cultivars with the same genetic background. Scheduling experiments showed that irrigating at smaller deficits than commonly used for cotton increased Bollgard II™ yield by 17% and WUE by 8%. In addition for Bollgard II™ crops the importance of avoiding stress in late flowering as the yield loss per day of stress was double that of conventional varieties at the same growth stage. They also found when insect damage occurs to conventional varieties, Bollgard II™ varieties mature earlier and used around 10% less water. Where there is no insect damage there was little difference in yield and water use between conventional and transgenic varieties due to little difference in morphology between the two varieties (similar looking plants).

Experiments to establish the response of cotton plants to soil water stress under different soil types, climatic conditions and fruiting loads were completed by Neilson (2006). This research was built on by (Broderick *et al* 2012) who are investigating irrigation strategies using dynamic deficits. That is, refining irrigation scheduling by dynamically changing soil water deficits during periods of high and low evaporative demand. Their study highlighted the need for a definitive measure of plant stress.

There have been a few studies on plant based sensors for irrigation scheduling in Australia. Pressure chambers or pressure bombs were used by farmers in the 1970s and 1980s and water stress thresholds were established (Browne 1986). Ground and airborne canopy spectral reflectance remote sensing techniques found that near infrared wavelengths could detect plant moisture stress, but found the thermal canopy temperatures were most successful for monitoring crop moisture status (Roth 1991, Roth 2002). Conaty (2010) examined the use of canopy temperatures and found reductions in lint yield above 28-29 degrees C and explored a stress time concept around these temperatures.

As part of a larger Cotton CRC project hyper spectral radiometer sensors were used to predict leaf water potential, but it was concluded a lower cost sensor was needed (Robson 2010). A machine vision system was developed to measure internode length of cotton, and had the capability to map internode length across a field, from which spatial trends in plant water stress maybe inferred (McCarthy *et al* (2010). In summary, these plant based sensors are effective at monitoring the water status of a crops in research trials, but they have not proven practical to schedule irrigations in a commercial modus operandi. This is largely due to high frequency of clouds changing solar radiation levels and the variable ambient air temperatures as well as technology costs.

Irrigation scheduling tools have been available for many years. The Australian cotton industry is one of the most advanced agricultural industries in terms of its use of irrigation scheduling tools. The cotton industry has the highest use of soil moisture monitoring probes of any agricultural industry in Australia (around 40%) compared to irrigated pastures which is less than 5% (Montagu *et al* 2006; ABS 2006, CCA 2007). In 2011 a survey of cotton growers found 57 % of growers used soil moisture capacitance probes, and 22% used neutron soil moisture probes for irrigation scheduling (Roth 2011). Greve *et al* (2011) investigated a 3D resistivity tomography moisture probe as a possible new irrigation scheduling technology.

Cotton is known to be poorly adapted to excess water and waterlogging. Waterlogging of cotton crops by inappropriate irrigation and /or excess rain has been identified as a major source of yield reduction (Hodgson 1982, Hodgson and Chan 1982, Hearn and Constable 1984b, Bange *et al* 2004, Conaty 2008, Milroy *et al* 2009). These studies have explored opportunities to reduce the impact of water logging such as the use of AVG ethylene inhibitor, correction of nitrogen, iron and other nutrient iron concentrations, hydrogen peroxide, plant genetics, irrigation systems and designs.

Hornbuckle and Soppe (2012) conducted research on weather based irrigation water management and crop benchmarking using satellite imagery and the Normalised Difference Vegetation Index (NDVI) index to better determine site specific crop coefficients to more accurately calculate crop water use for individual fields. This system, known as IrriSAT, was trialled for the first time in the Australian cotton industry in 2010. Developed primarily as an irrigation scheduling tool, it is finding more potential for growers to benchmark their water management performance between fields and across regions. Initial results showed there is wide variation in water use productivity, between fields, growers and regions.

Water Use Efficiency and Productivity Measures

Water use efficiency is a concept that has historically caused much confusion for scientists, extension officers and farmers. Much of this confusion is due to the range of terms available to describe water use efficiency and the difficulty in measuring aspects of the farm water balance, especially in surface irrigated fields that make up the majority (80%) of the Australian cotton industry. Adding to the complexity are different irrigation systems such as centre pivots, lateral move machines and drip irrigation as well as different agronomy systems such as row spacing, pests, disease, salinity, hail, soil types, waterlogging, and extreme temperatures.

An important part of improving water use efficiency is knowing how to measure it. There is a cliché "if you can't measure it you can't manage it". Most cotton growers measure their water use and calculate water use efficiency. In surveys when growers were asked if they measure water use efficiency, 60% said they did in 2005-06 (CCA 2007) and 76% measured it the following year 2006-07 (WRI 2007). However, in these surveys growers stated they found water use efficiency measurement a difficult task, which is why considerable emphasis was placed on measurement tools and training as part of the Cotton CRC activities.

Generally, farmers will refer to the amount of cotton grown per megalitre of irrigation water used in terms of cotton bales produced (227 kg of lint) per megalitre of water used. When comparing crop water use figures from cotton growers, it is critical to check whether the numbers include or exclude rainfall. Summer rainfall can be an important source of water during the crop growing season.

Water use efficiency is itself a generic label that encompasses an array of performance indicators used to describe water use within a cropping system. In order to achieve consistency of water use efficiency measurement, the cotton industry adopted standard measurements developed by Barrett, Purcell and Associates (1999). These are listed below and a detailed discussion on water use efficiency terms can also be found in Fairweather *et al* (2003) and Montgomery *et al* (2013). As explained by Barrett, Purcell and Associates (1999) many of these terms are not defined as efficiencies but instead are indices.

- Gross Production Water Use Index (GPWUI): is the gross amount of lint produced per unit volume of total water input. The total water input includes irrigation, rainfall, and total soil moisture used where the rainfall component can either be total rainfall or effective rainfall, but it must be defined Effective rainfall is the more typical and useful term. . There is still a little uncertainty as to how effective rainfall is calculated. The index can be applied at either a field or farm scale, and in Australia is usually discussed in bales (227 kg) of cotton lint per megalitre of total water used. The GPWUI is the most useful indicator for long term comparisons of industry performance and for comparisons between seasons, regions and farms as it accounts for the climatic rainfall variability between seasons and all sources of water.

- Irrigation Water Use Index (IWUI): is similar to the GPWUI, but relates cotton production to the amount of irrigation water used only. It relates the lint produced per ML of irrigation water applied to a field or supplied to a farm. It is commonly used to compare fields on one farm, since it only accounts for irrigation water and can therefore reflect differences in irrigation management. It is less useful for comparing different farms and regions as there is no accounting for differences in rainfall, which can obviously affect the amount of irrigation water required.

- Crop Water Use Index (CWUI): is the lint produced (kg) per millimetre of evapotranspiration from a field during the cotton growing season. It indicates the ability of the crop to produce cotton lint for the given water use.

- Whole Farm Irrigation Efficiency (WFIE): is the amount of irrigation water available and used by crops on the farm (for evapotranspiration) as a percentage of total water available to the farm. It is a measure of system efficiency and water losses as a percentage.

Water use productivity trends from national statistics

One way to assess the trend in cotton water use efficiency is to examine nationally collected statistics. The irrigated cotton production figures for each region in Australia can be obtained from a range of sources such as Cotton Australia Ltd, who supplied the figures used in this paper. The amount of irrigation water used in each valley can be obtained from the Australian Bureau of Statistics Water Accounts. From this data it is therefore possible to calculate the Irrigation Water Use Index at a national level.

The Irrigation Water Use Index (IWUI) is a coarse measure of the water productivity achieved by the cotton industry during the past decade which can vary from year to year in response to the amount of rainfall received. It should always be considered in context with other WUE indices which have been measured at the individual farm and field level.

Figure 1 shows the trend in Australian national cotton production between 2001 and 2012. During this decade the cotton industry experienced extreme climatic variability in droughts and flooding rains. The 2001 crop was a record production crop at the time. The "millennium drought" from 2003 to 2010 reduced the availability of water for irrigation and resulted in significantly reduced production levels that reached a record low in 2008. Since 2008, production rose to new record highs in 2011 and 2012 (4.5 million bales) as a result of drought breaking rains. Whilst every year is different, in 2011-12, the Australian Bureau of Statistics recorded 828 business irrigating cotton, on 397,221 ha, which used 2,068,908 ML of irrigation water, at an average rate 5.2 ML/ha (ABS 2012). Preliminary figures of the current 2012-13 crop is estimated at 4.4 million bales, with an average yield of 10.4 bales/ha (Adam Kay, CEO, Cotton Australia, pers comm).

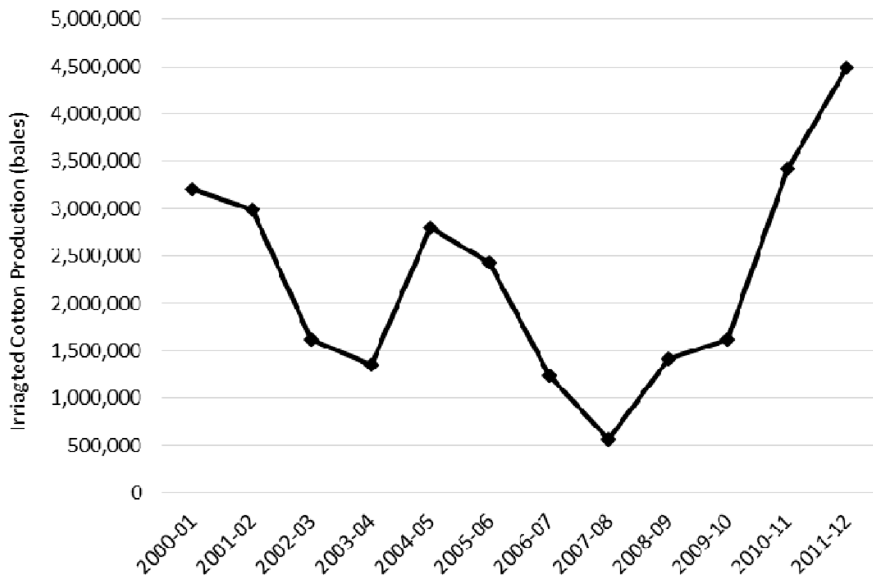

Figure 1: Irrigated cotton production in Australia 2001-2012.(227kg of lint per bale) (Source: Cotton Australia).

During the last decade the cotton industry experienced extreme climatic variability. This included dry years (2003, 2004, 2007, 2008) and wet years (2011, 2012). Figure 2 shows the lint yield per hectare of cotton has been increasing, whilst at the same time the average total amount of irrigation water applied has decreased.

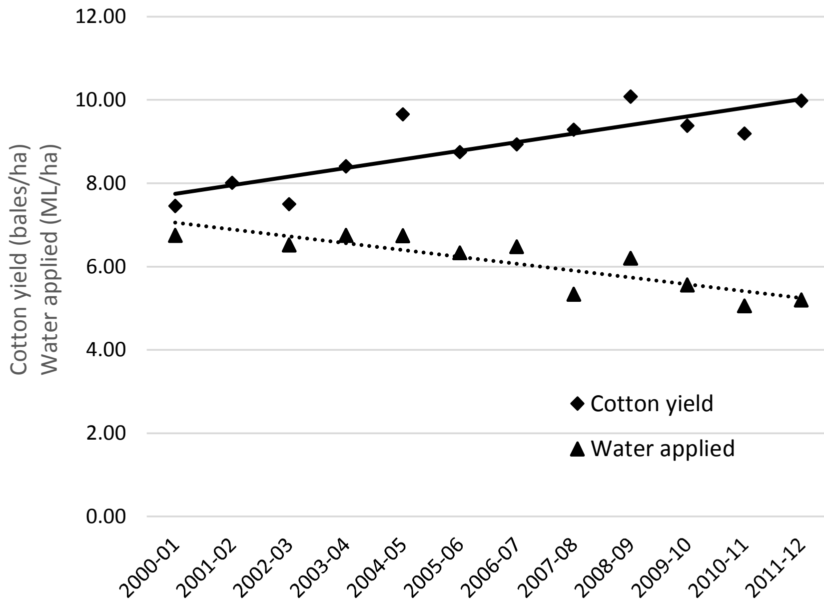

Figure 2: Irrigated cotton yields and water applied in Australia, 2001-2012 (227kg per bale).

Figure 3 shows there has been an upward trend in the Irrigation Water Use Index between 2001 and 2012. Despite the numerous climatic and water availability challenges during this time, the Irrigation Water Use Index has improved 97% from 1.10 bales per megalitre in 2001 to 2.17 bales per Megalitre in 2012. The drought resulted in the smallest crop ever in 2008, and it was also a dry summer yet the irrigation water use index was high, which could be attributed to growers being very focused on their irrigation management and water use efficiency.

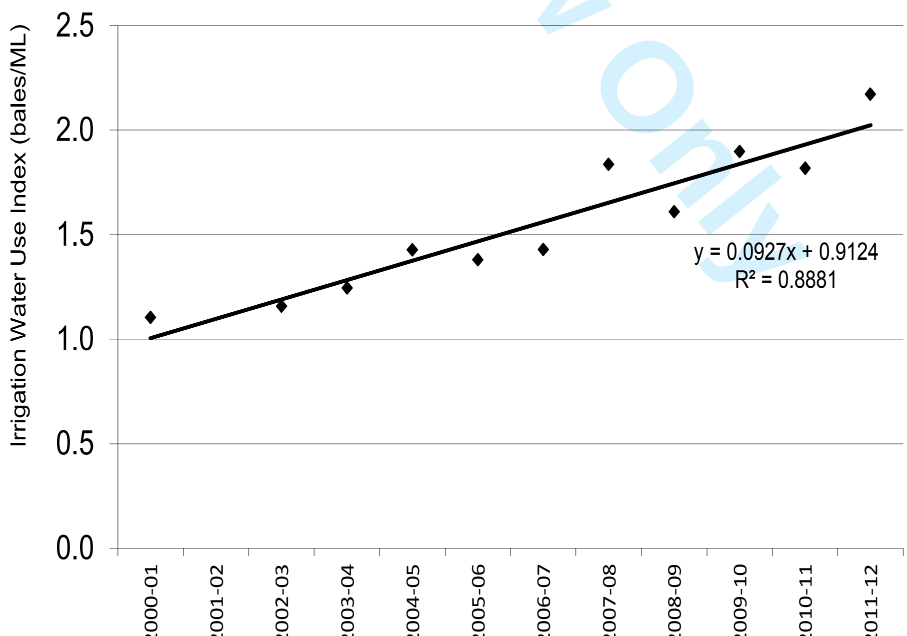

Figure 3 Irrigation Water Use Index for cotton productivity 2001-2012 (227 kg of lint bales/ML irrigation water applied).

The Irrigation Water Use Index is a coarse measure of water use productivity as it can vary from year to year in response to the amount of rain received. It should always be considered in this context. There are better WUE indices for comparisons across seasons, which will now be explored from measured data sets on commercial cotton farms.

Trends from irrigation benchmarking studies

The water use efficiency and productivity of the Australian cotton industry has been measured as part of several studies in the past 20 years and are summarised in Tables 1-3.

Each of the studies have used differing calculations, and in some cases represent a small number of growers. The studies also include different farms and have occurred on a range of soils types and climatic variability. The methodology each used can be found in the original reports. An important aspect of most of these studies is they have each measured the whole farm water balance on more than 10 commercial irrigation cotton farms.

The first major study of the cotton industry and whole farm water use efficiencies was completed by Cameron and Hearn (1997). They asked growers to provide data between 1988 and 1995. They collected data from 11 farms in the Macquarie, Namoi, Gwydir and Macintyre regions. They pointed out that some rainfall events and subsequent water storage data had not been well recorded, which may have inflated some of their water index data.

Between 1996 and 1999, Tennakoon and Milroy (2003) collected data from 200 fields from 25 growers from the six major cotton producing regions, which produced 80% of the national crop during those years. Their analysis included water pumped from rivers and bores, water stored on farm, rainfall, and soil water reserves used during the growing season. They calculated daily water balances for each crop to estimate ET. The irrigation efficiency was calculated as a proportion of irrigation water input to the farm.

Between 1998–2000, Dalton *et al* (2001) using engineering survey tools measured water use and losses on seven irrigation farms in the Macintyre region.

Between 2000-2003 the QRWUE (2003) monitored five major cotton growing regions on 29 farms in Queensland. Their analysis included water pumped from rivers and bores, water stored on farm, rainfall, and soil water reserves used during the growing season.

Between 2006–2011, Williams and Montgomery (2008), Montgomery and Bray (2010) and Wigginton (2011) collected data from irrigators and used the WaterTrack ™ water balance program to calculates water use indices. Their analysis included water pumped from rivers and bores, water stored on farm, rainfall, and soil water reserves used during the growing season. Montgomery and Bray (2010) and Williams and Montgomery (2008) included farms from NSW and Queensland, while in Wigginton (2011) farms were all in south western Queensland.

Table 1: A summary of key studies of the cotton industry between 1988 and 2011.

Year	*Number of Farms*	*Average amount of irrigation water applied ML/ha*	*Range of irrigation water applied ML/ha*	*ET mm*	*Lint yield bales/ha (227kg bale)*
1988-95[1]	11	5.37	0.52 - 10.9		6.73
1996 - 99[2]	25	6.96		735	7.96
1998- 00[3]	7	7.5			
2000- 03[4]	29	7.51	6.85 - 9.40	721	8.73
2006-07[5]	36	8.90	4.87 – 13.50	733	11.12
2008-09[6]	45	6.27	1.87 - 10.53	759	10.63
2009-10[7]	14	6.53	3.33 - 11.57	679	9.23
2010-11[7]	12	6.69	1.69 - 10.78	747	10.3

(Data is from; 1 Cameron Agriculture and Hearn (1997), 2 Tennakoon and Milroy (2003), 3 Dalton *et al* (2001), 4 QRWUE (2003), 5 Williams and Montgomery (2008), 6 Montgomery and Bray (2010),7 Wigginton (2011)).

The average amount of irrigation water used for all the studies in Table 1 was 6.97 ML/ha and had a range of 5.37 – 8.90 ML/ha. There was also a large range between the farms in any given year. The amount of irrigation water used depends on rainfall received and the farm irrigation system efficiencies. Seasonal variability between the seasonal average results is evident and expected. For example. 2009-10 and 2010-11 were wet seasons, while 2006-07 was a hot dry year. These figures have led to the farmers rule of thumb, that typically, 6 -7 ML/ha of irrigation water is required to maximise cotton production.

The seasonal evapotranspiration (ET) figures range 679-759 mm, but are reasonably consistent around the average of all the studies, 729mm. Higher values would be expected in hotter years/ regions such as 2010-11 where 10 of the 12 farms were located at St George, while lower values in cooler years such as 2009-10 where 10 of the 14 farms were on the Darling Downs, which is also one of the cooler cotton growing regions. These figures are similar to other research reports in that crops need to use between 700-800 mm of ET of water for high yields. Table 1 shows the average cotton yield is rising, which is consistent with the trend shown in Figure 2.

Table 2 shows key water use indices figures from research studies on commercial cotton farms between 1988 and 2011. As expected there is some variation over time in the IWUI data. As previously discussed it is strongly influenced by the amount of seasonal rain. That is, lower numbers in wet years and higher numbers in dry years. By way of example the 2006-07 season was extremely dry with little in crop rainfall and irrigation water made up on average 88% of the total water supplied to the crop, whereas in 2008-09 the average irrigation water supplied was only 64% of the total gross available water (Montgomery and Bray 2010). The differences in the IWUI between these two seasons (1.30 and 1.99) illustrates the influence rainfall has on this index. It is a more useful index when comparing fields or farms within the same season.

The range in IWUI in any one season is also significant, the IWUI in 2008/09 ranged from 0.80 – 5.75bales/ML. The farm with an IWUI of 5.75bales/ML only grew a small area of 36.5ha of irrigated cotton and applied only 1.8ML/ha of irrigation water, with rainfall meeting the rest of the crop water requirements. This farm received 416mm effective rainfall during the growing season which is equivalent to 4.16 ML/ha and it obviously fell at the right time as this farm yielded well at 10.75bales/ha. The minimum IWUI 0.8 bales/ML occurred on a farm where they also on grew a relatively small amount of cotton, 68ha, however yields were lower at 8.15bales/ML and a large amount of irrigation water applied. This farm applied 10ML/ha of irrigation water, and on top of this received 176mm of effective rainfall. It's likely this crop was impacted by waterlogging, resulting in reduced yields. This along with a high application of irrigation water resulted in a low IWUI.

IWUI is the figure usually quoted by growers when referring to the water use efficiency of their crops because it is easy to measure and calculate. However, this data shows it must be used with some caution due to the influence of rainfall and it is best used only when comparing nearby fields or farms within the same season.

Table 2: Key water use indices figures from research studies on commercial cotton farms between 1988 and 2011.

Year	*Average IWUI bales/ml*	*Average GPWUI bales/ml*	*Average CWUI kg/mm/ha*	*Range IWUI bales/ml*	*Range GPWUI bales/ml*	*Range CWUI kg/mm/ha*
1988-95[1]	1.48	0.82	2.9			
1996 - 99[2]	1.32	0.79	2.52			2.0-3.2
1998- 00[3]						
2000- 03[4]	1.16	0.93	2.79			
2006-07[5]	1.30	1.13	3.47	0.9-1.92	0.82-1.71	2.66-4.31
2008-09[6]	1.99	1.14	3.20	0.8-5.75	0.64-1.58	2.29-4.36
2009-10[7]	1.47	0.93	3.11	0.96-1.89	0.78-1.14	2.20-4.04
2010-11[7]	1.84	0.94	3.14	0.97-3.17	0.64-1.33	1.73-3.56

(Data is from; 1 Cameron Agriculture and Hearn (1997), 2 Tennakoon and Milroy (2003), 3 Dalton *et al* (2001), 4 QRWUE (2003), 5 Williams and Montgomery (2008), 6 Montgomery and Bray (2010),7 Wigginton (2011)).

The more meaningful water use index for comparing water use between seasons is the GPWUI. The GPWUI includes irrigation, rainfall and water stored in the soil and is the best measure for long term seasonal comparisons. There is an improving trend in this index the average GPWUI shows a 40% improvement over the decade between Tennakoon and Milroy (2003) (0.79/bales/ML) and Williams and Montgomery (2008) and Montgomery and Bray (2010) (1.13 & 1.14 bales/ha) who all sampled farms from most cotton growing regions in Australia.

Wigginton (2011) found slightly lower GPWUI numbers on his sampled farms, which was attributed to some bias in the types of farms as they were all located on the Darling Downs and St George in Queensland. In both years several farms were affected by flooding and subsequent lower cotton yields. As these farms are located in only 2 cotton regions these figures provide benchmarks at a regional basis only, The indices cannot be compared to the industry wide data collected by Tennakoon and Milroy (2003), Williams and Montgomery (2008) and Montgomery and Bray (2010) to gauge industry changes in these indices over time. Farmers within the St George and Darling Downs can however compare their own performance to the regional benchmarks established by Wigginton (2011) and also compare their individual indices to the industry benchmarks established in 2006/07 & 2008/09 to gauge their own changes in WUE.

The influence of varying seasonal conditions and differences in crop management highlights the importance of the continued collection of irrigation benchmarking data. Ideally irrigators should be benchmarking annually while industry benchmarks should be established every 2 to 3 years to better track water use performance overtime. The established industry benchmarks indicate that Australian cotton irrigators should be producing >1.1 bales per ML water (total water, ie irrigation water applied, rainfall and soil moisture used).

The CWUI averaged 2.95 kg/mm/ha between 1988 and 2011. There is also an increasing trend in the CWUI, prior to 2003 it was less than 3 kg/mm/ha while post 2003 it has mostly been above this. However, like the other performance indices there is a large range in CWUI within any given year. The CWUI is rarely calculated by cotton growers due to the difficulty in measuring seasonal crop evapotranspiration, but is more commonly used in research trials. It is the efficiency with which the cotton crop converts water supplied to lint yield or production per unit of crop ET. It is mostly dependent on agronomy inputs that affect yield rather than irrigation efficiencies.

Whole Farm Irrigation Efficiency (WFIE) reflects the productivity of the plant and irrigation system efficiencies (Table 3). That is, it shows the amount of irrigation water that was used productivity by the plant as a percentage of total water available to the farm. Therefore, the inefficiencies an irrigation system will result in a percentage of total water, not being consumed by the crop. No surface irrigation system will ever achieve a WFIE of 100 per cent as there are always losses in evaporation and seepage across the fields, distribution system (channels) and on farm storages. The aim is to reduce these losses to maximise the WFIE.

The WFIE figures show there is a wide range in the data. However, the yearly averages show a significant improvement over time. During the late 1990's, the WFIE was around 57 per cent, whereas in the latest industry wide data collected 10 years later who the WFIE has risen to around 70 per cent. This indicates that there were less on-farm water losses and more of the water used on farm was used productively through the crop. Differences in seasonal conditions can also influence this performance indicator. For example, the highest WFIE was achieved in 2006/07 which was a very dry season. Soil profiles were dry and few irrigation storages were used. There was little to no in-crop rainfall across all regions and surface water allocations were very low or non-existent, so the area planted to cotton on any farm was significantly reduced. This meant that the opportunity for water losses was also reduced and management would have been tight with a smaller area to water. Irrigators would have planted fields closest to on-farm storages or water extraction points to reduce conveyance losses.

The WFIE performance indicator provides an initial look at on-farm irrigation efficiency, but does not tell you where the water losses and inefficiencies are occurring. Further investigations are required to determine this.

Table 3: A summary of key water use figures in the cotton industry between 1988 and 2009

Year	*WFIE Average %*	*WFIE range %*
1988-95[1]	63	49-78
1996 - 99[2]	57	20-85
1998- 00[3]		21-65
2000- 03[4]	58	50-74
2006-07[5]	71	33-99
2008-09[6]	69	39-100
2009-10[7]		
2010-11[7]		

(Data is from; 1 Cameron Agriculture and Hearn (1997), 2 Tennakoon and Milroy (2003), 3 Dalton *et al* (2001), 4 QRWUE (2003), 5 Williams and Montgomery (2008), 6 Montgomery and Bray (2010),7 Wigginton (2011)).

International water use efficiency information from commercial cotton farms in other countries is scant. Data collection challenges, accuracy, and variance in data assumptions make it difficult to make explicit international comparisons. International comparisons also vary because of the climatic differences between countries such as the significance of the amount rain received, different irrigation application systems or other underlying regional production problems such as extreme temperatures, disease, insect pests or soil problems like salinity.

Reviews have attempted to compare crop water use figures between countries around the world (Gillham *et al* 1995, Grismer 2002; Hearn 1994; Payero and Harris 2007). These reviews show that Australia is amongst the higher performing countries in the world.

Cotton production globally uses 3% of the world's agricultural water while the largest three crop water users are rice (21%), wheat (12%) and maize (9%) (Hoekstra and Chapagain 2007). Zwart and Bastiaanssen (2004) reviewed 84 studies on irrigated wheat, rice, cotton and maize. They reviewed 16 publications on cotton from nine countries, which included one study from Australia (Tennakoon and Milroy (2003) and found that crop water productivity had increased from a similar global review by FAO in 1979 (Doorenbos and Kassam 1979). The data had a large range, which they attributed to climate, irrigation water management and soil fertility management as well as other variables.

Where are the water losses on farm?

The fore-mentioned data leads to the question of; Where are the major water losses on surface irrigated cotton farms in Australia? Several studies have attempted to quantify the specific loss components associated with the whole farm water balance.

An example of the variation in whole farm water irrigation efficiency was quantified by Dalton *et al* (2001) (Table 4). They found for the seven farms measured, on average, 43% of the total water extracted was used for crop production. The major water losses were storage evaporation 30%, field seepage 10%, channel distribution seepage 6%, storage dam seepage 5%, channel distribution evaporation 4%, and field evaporation 2%, which in total was 57%.

Table 4 shows the more recent studies found smaller average losses were in 2006-07, 25%, 2008-09, 20% and 2009-10 31% and 2010-11 30%. Wigginton (2011) also reported the largest loss of water was through the on farm storage, which account for on average 19% of the total water, followed by in field application loss, which accounted for 10% of the total available water. Channel and drain losses were minimal relative to other water balance components. Again, all the studies reported large variances in the farm water loss data, 5-45%, reinforcing the importance of individual site specific measurements.

In a separate study, Wigginton (2011) reported measurement of 136 on farm water storages across the cotton industry ranging in size from 75ML to 14,000ML and depths from 1-9 metres. Evaporation losses were the largest component of loss in most storages. Seepage losses averaged 2.3 mm per day and was less than 2mm per day for 75% of these storages. These studies support earlier research that evaporation loss is a significant issue for the Australian cotton industry as it has been shown to exceed 40% of the total available (Sainity 2006, Dalton *et al* 2001, Craig *et al* 2007).

Table 4: Water loss components and crop use of the total available water.

Water balance loss area	*1998- 00*[3]	*2006/07*[5]	*2008/09*[6]	*2009-10*[7]	*2010-11*[7]
	%	%	%	%	%
Storage Dam evaporation	30			20	18
Storage Dam seepage	5				
Channel Distribution evaporation	4			1	1
Channel Distribution seepage	6				
Field evaporation	2				
Field seepage	10			9	10
Field tail water				1	1
Total Losses	**57**	**25**	**20**	**31**	**30**
Crop Use	43	75	80	69	70

Evaporation losses depend on the surface area of the water storage, ambient air temperature, wind speed and other factors. Craig *et al* (2005) assessed the effectiveness of many methods of reducing evaporation such as shade cloth, floating covers and chemical film monolayers and summarised practical and technical limitations. An online tool (Ready Reckoner) has since been developed to help farmers calculate evaporation losses (Schmidt 2012). Evaporation mitigation measures continue to be explored, but at present there are no commercially viable options for cotton growers evidenced by the current low uptake of postulated solutions.

Recent research on the development of new chemical monolayers has shown to reduce evaporation in the laboratory (Prime *et al* 2012a, Schouten *et al* 2012, Tran *et al* 2012) and in field trials (Prime *et al* 2012b). Further modification of the chemical monolayer properties to improve surface film properties for large water storages found on cotton farms has led to development of a novel duo layer surface film system, which have significant advantages over all polymers previously investigated (Prime *et al* 2013). Further field trails are currently being undertaken.

The second largest loss of water on irrigated cotton farms are the losses which occur within field, namely the deep drainage and tail water losses, both of which are more prevalent in furrow irrigated fields. The types of improvements growers are making include objective irrigation scheduling, surface irrigation evaluations, storage efficiency calculations, installation of water meters, EM surveys and changing irrigation systems. Between 2006 and 2011 half of the cotton irrigators made changes to their siphon flow and or size (Roth 2011).

Application efficiency is a volumetric term indicating the percentage of water applied that remains in the root zone at the end of the irrigation event and is available to the crop. Most cotton growers use surface irrigation and there is scope to improve its application efficiency. The majority of growers practice some form of tail water recycling and hence runoff is not strictly a loss to the production system as it may be used for subsequent irrigations. For this reason application efficiency is sometimes modified to account for the fact that a proportion (e.g. 75%) of the runoff is not lost.

Techniques for modelling and evaluating surface irrigation have been reviewed by Raine (1999), Dalton *et al* (2001), Raine *et al* (2005) and Gillies (2008). Measuring and modelling the infiltration characteristics of the soil under surface irrigation was hindered by the lack of reliable equipment and procedures to measure the many variables involved and this held back the adoption of technology to optimise this simple form of irrigation (Purcell and Fairfull 2005). To address this problem the Irrimate™ monitoring hardware and software tools were developed by the National Centre for Engineering in Agriculture and Aquatech Pty Ltd.

These tools and software gained popularity during the mid 2000's after commercialisation and with further exposure by way of on-farm demonstrations of the Irrimate suite of tools by NSW and Queensland Departments of Primary Industries. A description of these tools can be found in Purcell and Fairfull (2005) and Dalton *et al* (2001). The system is based on the use of a hydraulic model (e.g. SIRMOD) which is calibrated to field conditions using infield measures of inflow rates and water advance times. Once calibrated the model can be used to (a) evaluate the performance of the measured event and (b) optimise application rates and times.

Dalton *et al* (2001) monitored 70 irrigations over two seasons on 11 fields. Individual irrigation application efficiencies ranged from 37-100%. Average seasonal efficiencies ranged from 70- to 90%, assuming full tail water recycling. Tail water runoff ranged from 4 to 32% and deep drainage 11-30%. Raine and Foley (2002) found application efficiencies of single irrigations ranging from 35-100 per cent for 180 irrigations. Smith *et al* (2005) examined 79 surface irrigation events and found efficiencies ranged from 17-100% with an average of 48%. They calculated irrigation losses of 1.6 -2.5 ML/ha. Raine *et al* (2006) reported average savings of 0.15 ML/ha/irrigation when irrigators adjusted siphon flow rates and irrigation times.

In 2006-07 the Cotton CRC water extension team conducted 47 furrow irrigation evaluations across 9 farms in the Gwydir and Namoi Valleys using the Irrimate system (Montgomery and Wigginton 2007). While about 35% of the irrigation events had an application efficiency that could be considered below standard (80 per cent), importantly they also found that applications greater than 90 per cent can be achieved under furrow irrigation. Furthermore irrigation performance could be improved with simple changes such as reducing the time siphons are running and/or increasing the rate at which irrigation water is applied to the field. In their performance evaluation the amount of water applied was reduced by 0.18 ML/ha for each irrigation event.

QDPI&F (2009) evaluated 100 furrow irrigations in Queensland. They found a significant spread in the performance of furrow irrigation across Queensland with an average application efficiency of 65%, which they then optimised to increase this to 81%, mostly by increasing flow rate and reducing cut off time changes.

The NCEA were commissioned by the Cotton CRC to develop the Irrimate Surface Irrigation Database (ISID). The completed database enables performance benchmarking and ongoing analysis of future data. Gillies (2012) compiled and analysed data from 631 surface irrigation events measured by commercial consultants and researchers between 1998 and 2012. The average application rate for the typical 2m alternate row irrigation is 4.4 L/s for 12.5 hours resulting in a 1.3 ML/ha applied with an application efficiency of 64.6%. The losses are almost evenly split between runoff, 0.253 ML/ha and deep drainage 0.274 ML/ha per irrigation. Correctly accounting for the tail water recycling common place in the industry increases this efficiency to 76.1 % representing a 11.5% water saving.

For growers, the major purpose of these field evaluations is identification of strategies to improve or optimise surface irrigation performance through measures such as run times, flow rates, siphon sizes. Despite considerable advances growers can make from these single furrow optimisations, there is considerable field variability of infiltration characteristics and further research is being undertaken to improve modelling (Gillies *et al* 2008).

The data within ISID was optimised in order to identify the potential irrigation performance with minimal changes to application time and or inflow rate (Gillies 2012). The results indicate that the average application efficiency can be increased to 84.7% which represents potential water savings of 0.155 ML/ha per irrigation (or 0.226 ML/ha neglecting tail water recycling) corresponding to a halving in drainage and runoff losses.

In-field deep drainage has been the focus of much research in recent years and this has been summarised by Silburn and Montgomery (2004) who found typical figures were 100-200 mm/yr with a very large range 0-900mm/yr. Silburn *et al* (2013) in this edition of Crop and Pasture Science have completed a review of four decades of deep drainage research in the cotton industry. They have reported more recently deep drainage is being better managed, while some deep drainage is needed to avoid salt build up in the profile. Gunawardena *et al* (2011) reported deep drainage information from seven farms in Queensland where they found deep drainage varied along the length of the field and most deep drainage occurred during pre-irrigation or the first two or three in crop irrigations. They also reported almost zero deep drainage under the lateral move irrigation system. Deep drainage was measured under furrow irrigated cotton at Narrabri by Ringroase-Voase and Nadelko (2013) who found that drainage accounted for up to 11% of the water applied. They observed that in cracking soils, drainage water may bypass the subsoil without fully wetting these layers. They also concluded that significant quantities of nitrogen were lost with this drainage.

Efficient management of furrow irrigation faces two major issues, firstly that field conditions vary spatially and throughout the season thereby altering the optimal application rate and time and secondly that the high level of control involves increased labour requirements. Adaptive real time control of furrow irrigation combined with automated application systems offers the potential to overcome both of these problems. Prototypes of these systems are described by Koech *et al* (2012) and McCarthy *et al* (2012). The system is capable of monitoring, simulating and formulating the optimisation and controlling the application whilst the event is still underway. Commercial development of this "smart automation" for furrow irrigation is underway.

Correct management of soils to achieve good soil structure is fundamental to achieving water efficient crops. There has been a body of research, which is summarised in the Soilpak manual (McKenzie 1998) aimed at reducing compaction to increase the plant available water holding capacity of soils. Any program aimed at improving water use efficiency and productivity should focus on soil management.

Alternative irrigation systems to surface furrow

In the last decade there has been increased interest in alternative irrigation systems to surface furrow irrigation. These include bankless channel surface irrigation, drip irrigation, centre pivot and lateral move machine systems.

The bankless irrigation system is an alternative method of surface irrigation being considered by some cotton growers as it provides significant labour savings as well as some energy savings. Field trials are currently being conducted by many growers to evaluate this system and more information on their operation can be found in Grabham (2013).

Drip irrigation has been evaluated in the Australian cotton industry for 30 years. One of the first was in 1983, where a buried sub surface drip trial was established on a commercial farm near Narrabri (Warnock 1983), and there have since been many other examinations (Table 5). In general, drip irrigation saves 20-30% water, and yields are often 10-20% higher, but there are also many examples where yields have been less than a comparable surface irrigation system.

Table 5 Drip irrigation trials results compared to surface furrow irrigation in Australian cotton fields.

	Year	*Water saved by drip compared to surface irrigation (%)*	*Yield response drip compared to surface irrigation*	*(%)*	*Source*
Narrabri, NSW	1984-1987	yes	Decreased		Hodgson *et al* (1990)
Survey of 26 farms	2000	38	Increased		Raine *et al* 2000
Boggabilla, NSW	1999-2000	35-40	Increased	10	Cross (2003)
Dalby, Qld	2001-2003	29-31	Increased	10	Harris (2007)
Dalby, Qld	2002-2007	27	Decreased	13	Harris (2007)
Macalister, Qld	2003-2007	15	Increased	20	Harris (2007)
Narrabri, NSW	1996-1999	20-30	Increased	5	Anthony (2008)
Warren, NSW	2001-2003	40	Increased	20	Anthony (2008)
Moree, NSW	2011-2012	38	Decreased	7	GVIA (2012)
Emerald, Qld	2004-2012	yes	Increased		Pendergast (2012)
NSW (5 farms)	2010-2011	yes	Increased		Montgomery (2011)

The high capital cost and high energy costs associated with the pumping to create adequate pressure remain the main constraints to drip irrigation adoption in Australia. As water costs rise in theory there may be wider adoption of drip irrigation, but this is unlikely given the rapidly rising energy costs associated with the pumping of water and the higher level technical support required. Drip irrigation maybe the most appropriate tool in very specific circumstances. This is a conclusion van de Kooij *et al* (2013) also reached after reviewing 49 published studies on drip irrigation around the globe between 1974 and 2011.

Aeration of the irrigation water in sub surface drip irrigation systems has been investigated in a long term trial from 2004 to 2012 on a vertisol soil near Emerald Queensland (Pendergast 2012b, Midmore and Bhattarai 2010). Positive effects (on average 15%) of the aerated water treatments were noted consistently on lint yield over a number of seasons. An increase in WUE was associated with the higher yield as well as improved soil biological properties.

The most important irrigation system change occurring on Australian cotton farms is the Increasing areas of cotton being grown under centre pivot and lateral move irrigation machine systems. Survey interviews have been conducted of cotton growers in 2001 (whole industry, Foley and Raine 2001) and in 2011 in Queensland Murray Darling Basin (Wigginton et al 2011).

Growers in both these surveys cite labour savings and water savings as their main motivation for installing these systems. Other major advantages with these systems compared to furrow irrigation include reduced water logging, ability to apply fertiliser and chemicals in the irrigation water, improved capture of rainfall, and the ability to germinate crops with less water and improved minimum tillage practices.

In terms of water use, growers in the 2001 study found greater improvements in the IWUI of these machines compared to surface irrigation than the 2011 study. This maybe because furrow irrigation performance across the cotton industry has also improved over the last decade with improved management practices (Foley *et al* 2013). Wigginton *et al* (2011) found growers indicated water savings around 30% compared to traditional furrow irrigation systems. These savings are usually from increased ability to capture rainfall and less in field deep drainage below the root zone. Table 6 shows both higher IWUI and GWUI of these machines compared to surface irrigation benchmarks in Table 2. The average GPWUI in Table 6 of 1.33 bales/ML would serve as a useful benchmark index of these systems.

Table: 6: Summary of the Irrigation Water Use Index and Gross Production Water Use Index Benchmarks for the Centre Pivot & Lateral Move irrigation systems for Australian Cotton – 2010/11 and 2011-12.

Year	*IWUI*	*GPWUI*	*Sample size*	*Source*
2009-10		1.28	1	GVIA (2012)
2010-11	4.62	1.2	23	WaterBiz 2012 / Wigginton *et al* 2011
2010-11	4.25	1.37	40	Modified from Montgomery 2011
2011-12	4.01	1.43	29	WaterBiz 2012
2011-12		1.35	1	GVIA (2012)
Average		1.33		

Baillie *et al* (2010) surveyed 150 irrigators in Queensland and found farmers had generally focused on the adoption of low capital, low technology on farm water use efficiency options. A similar finding was found by Roth (2011) from a survey of 177 growers in both NSW and Queensland. There is evidence that the current Government co-investment schemes have increased the uptake of centre pivot and lateral move machines, but not drip irrigation. It is expected that there will be a greater conversion of furrow irrigation to other systems such as centre pivots, lateral moves in the future. The major barriers to changing application methods include water allocation uncertainty, cost of the system upgrade and the energy pumping costs. A number of resources have been developed to help growers with the management of these systems, such as a DVD Growers Guide to Centre Pivots and lateral Moves (Pendergast 2012a)

As mentioned earlier, the majority of the Cotton CRC effort, was on extension and knowledge management delivery to growers and advisers. Growers and crop agronomists' needs in terms of irrigation knowledge were explored through a convergent interviewing process (Callen *et al* 2004). Wigginton and Smith (2008) implemented the recommendations of that study that included focusing on building capacity of the advisory sector and improving grower based peer learning knowledge sharing and specifically designed training workshops. An extensive range of activities were undertaken such as field days, technology demonstrations, water use efficiency benchmarking, cost benefit analyses, workshops, case studies, media articles and e-information, by subsequent projects (Jackson 2008, Harris and Brotherton 2009 and Montgomery 2011).

The latest management practices of water application continue to evolve and were complied in the WATERpak – a guide for irrigation management in cotton and grain farming systems (Dugdale *et al* 2008, Wigginton 2013).

Conclusion

The cotton industry adopted a goal in 2006 to double its water use efficiency by 2015. The precise measurement of this goal is more challenging than the statement, however the intent of the goal is clearly to significantly improve water use efficiency and productivity. Water is the major limiting factor of production for the Australian Cotton Industry, so growing "more crop per drop" has been an important goal for cotton water research. A decade of drought provided a strong driver for growers to improve irrigation management and some large regionally based extension activities provided the link between research and on farm implementation.

An important part of improving water use productivity is knowing how to measure it. A significant effort was devoted to developing better tools, creating confidence and promoting measurement of water use efficiency, optimising the performance of surface irrigation systems, investigating alternatives irrigation systems to the conventional furrow irrigation systems, understanding the movement of water through the soil and the potential of deep drainage, reducing water losses from on farm storages and better understanding of plant water relations.

Research projects are not serving their purpose unless their outputs are delivered to farmers as the end users of the information and put into practice. Evidence of changes to irrigation management include, a 40 % increase in cotton water productivity over the last decade, cotton yields 2.5 times the world average of high quality product, new water measurement tools being used by farmers and their advisers and changed attitudes on issues such as deep drainage and furrow irrigation practices. The most recent survey of Australian cotton growers found that 70% of irrigators used soil moisture probes for irrigation scheduling, which is up from 40% in 2006, 62% of groundwater irrigators regularly monitor water quality, which is up from 20% in 2006 and 96% of irrigators had made improvements to their furrow irrigation systems (Roth 2011).

There is strong evidence that growers have improved their water use efficiency by 3-4% per annum. There are also many individual examples of even more significant improvements in one year as a result of irrigation system improvements. There is a large range and variability in reported water use figures and significant room for growers at the lower end to improve their practice. The industry benchmarks indicate that Australian cotton irrigators should be producing >1.1 bales per ML water (total water, ie irrigation water applied, rainfall and soil moisture used) with surface irrigation systems and 1.3 bales/ML with centre pivots and lateral move machines.

The data shows that most water losses occur in on farm storage through evaporation losses. Seepage losses are relatively small, but can be significant in some cases. This review has highlighted the greatest improvements for WUE can be made by targeting\reducing losses from on farm water storages and improving in field irrigation application. Application efficiencies of over 90 per cent are achievable under well managed furrow irrigation. The greatest initial gains in water use efficiency can be achieved by improving the management of existing surface irrigation systems through this site specific optimisation.

Growers are making changes to alternative systems such as centre pivots and lateral move systems and it is expected there will be increasing numbers of these machines in the future. These systems achieve labour and water savings (30%), but have significantly higher energy costs associated with water pumping and machine operation. Other major advantages with these systems compared to furrow irrigation include reduced water logging, ability to apply fertiliser and chemicals in the irrigation water, improved capture of rainfall, and the ability to germinate crops with less water and improved minimum tillage practices. Drip irrigation has been extensively tried in a variety of locations where it has resulted in 20-30% water savings, but yield results have been shown to both increase and decrease compared to surface irrigation systems. It is unlikely there will be significant adoption of drip irrigation due to high capital and energy costs in Australia in the foreseeable future.

Research and development priorities continue to evolve. This should include a continued focus on plant breeding, agronomy, soil and irrigation management, both in fully irrigated, partly irrigated and rain fed environments. A major focus, whilst challenging should be aimed at reducing the major losses related to evaporation form storages, and improving application efficiency and uniformity. Improved technologies for soil moisture monitoring and better crop coefficients for irrigation scheduling are required. Individual growers must be encouraged to measure aspects of the water balance on their farms and calculate efficiencies. Further improvements in surface irrigation through automation, real time control and optimisation. Better weather forecasting remains high on priorities list.

Changing irrigation systems is step change in terms of capital investment. Better information is needed on the optimisation of water, carbon, energy, and labour interactions of alternative systems to surface irrigation. While some systems are more water efficient, they often require more energy for pressurised pumping. Specific agronomy packages for alternative irrigation systems will also need to be developed. Farmers learn by doing, and trust farmers more than any other source. Therefore, an even greater emphasis on people, farm demonstration and local learning sites should be implemented as a partnership between farmers and scientists.

Irrigation water availability will remain the most limiting factor to cotton production in Australia. The main steps forward to improve water use productivity include; good agronomy, good soil management, improved water measurement tools, improving the delivery of water to the field, maximising storage and distribution efficiency, reducing evaporation and drainage, maximising application efficiency, achieving uniform application, and the use of alternative irrigation systems such as centre pivots and lateral moves machines where applicable.

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DEFENDING THE SOCIAL LICENCE OF FARMING

Issues, Challenges and New Directions for Agriculture

Editors: Jacqueline Williams and Paul Martin

Australian Centre for Agriculture and Law, University of New England

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7

Retaining the social licence: the Australian cotton industry case study

Guy Roth

The Australian cotton industry has been no stranger to community and social anxiety. This was particularly evident throughout the 1980s and early 1990s, with outcry about the industry's pesticide usage and its impact on community health, water quality, fish kills and pesticide residues in beef cattle. Other aspects of cotton growing, such as fertiliser use, alteration to river flows, soil degradation and vegetation clearing, had also attracted the attention of the environmental regulatory agencies. In the late 1990s, the use of genetic modified traits in varieties kept cotton in the media headlines, while in more recent years during the ongoing drought public attention largely shifted to the industry's use of water for irrigation.

This chapter outlines proactive initiatives, and their outcomes, of the Australian cotton industry that enabled it to defend its *social licence to operate* when, in the early 1990s, community pressure went close to forcing the federal government to impose a regulatory regime that may have proven uneconomic for the industry.

Background to the Australian cotton industry

Cotton is the most commonly produced natural fibre in the world and represents just under half of the world textile market. On a global scale, Australia is a relatively small producer of cotton, growing about 3% of the world's cotton. The largest producers are currently China, India, USA, Pakistan, Brazil and Uzbekistan.

There are around 800 cotton farmers in Australia and approximately 10 000 people employed by the industry. Seventy per cent of Australia's cotton is typically grown in New South Wales, with the remainder grown in Queensland (Figure 7.1). Cotton is a major source of regional economic activity where it is grown, and usually generates 30–60% of the gross value of all regional agricultural income where it is produced, which makes up 10–30% of the gross regional product (Roth 2010). Its indirect impact on local economies is high.

Depending on water availability, up to 400 000 hectares of irrigated cotton can be grown in Australia. The area of rain-grown or dryland cotton changes considerably from year to year, depending on rain and cotton prices. The dryland area ranges from 5000–120 000 hectares, and this cotton is produced by up to 450 growers. Since 1980, the value of Australian cotton produced annually has increased dramatically to around \$1.4–\$1.6 billion per annum. In recent years, this gross value of production fell to less than \$1 billion because of drought conditions. As in some of its competitor's market places, there is no direct government intervention or market support mechanisms applied to the growing or marketing of cotton in Australia. Australian cotton yields have increased significantly each year (Figure 7.2). During the last 20

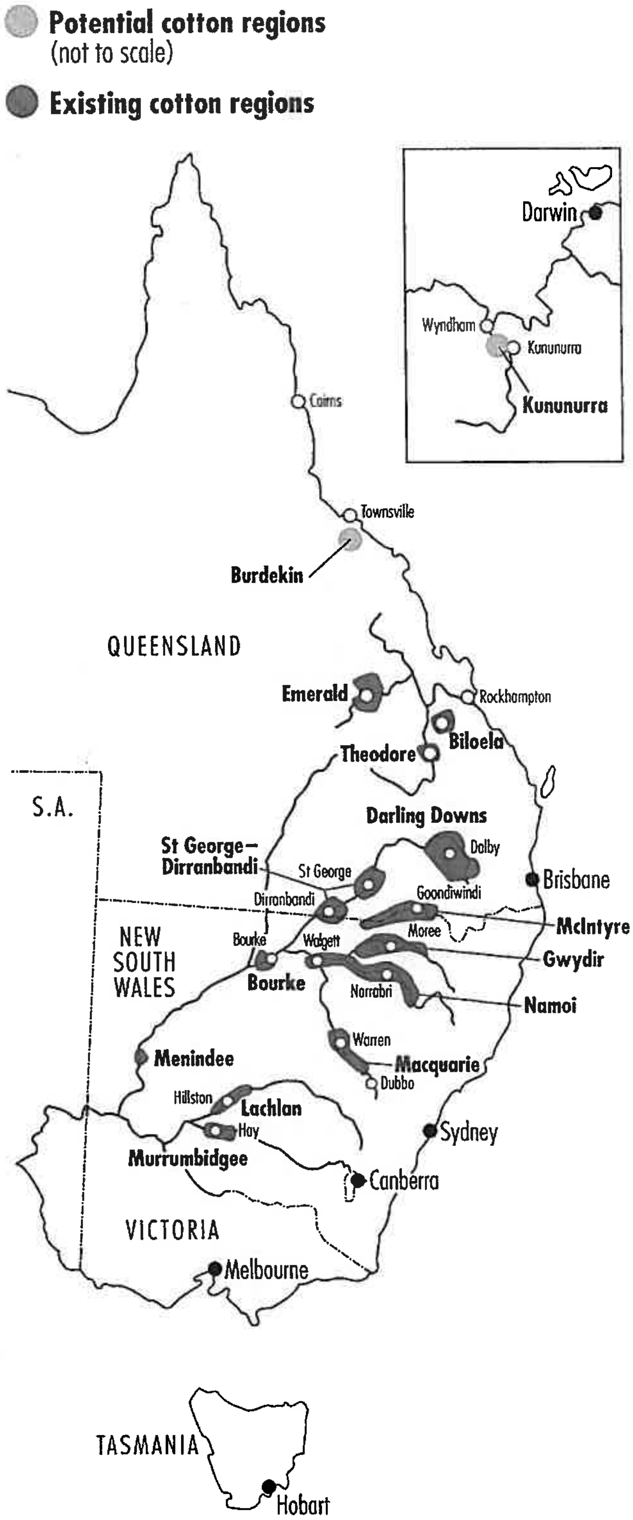

Figure 7.1: Existing and potential cotton regions in Australia (Source: Roth 2010)

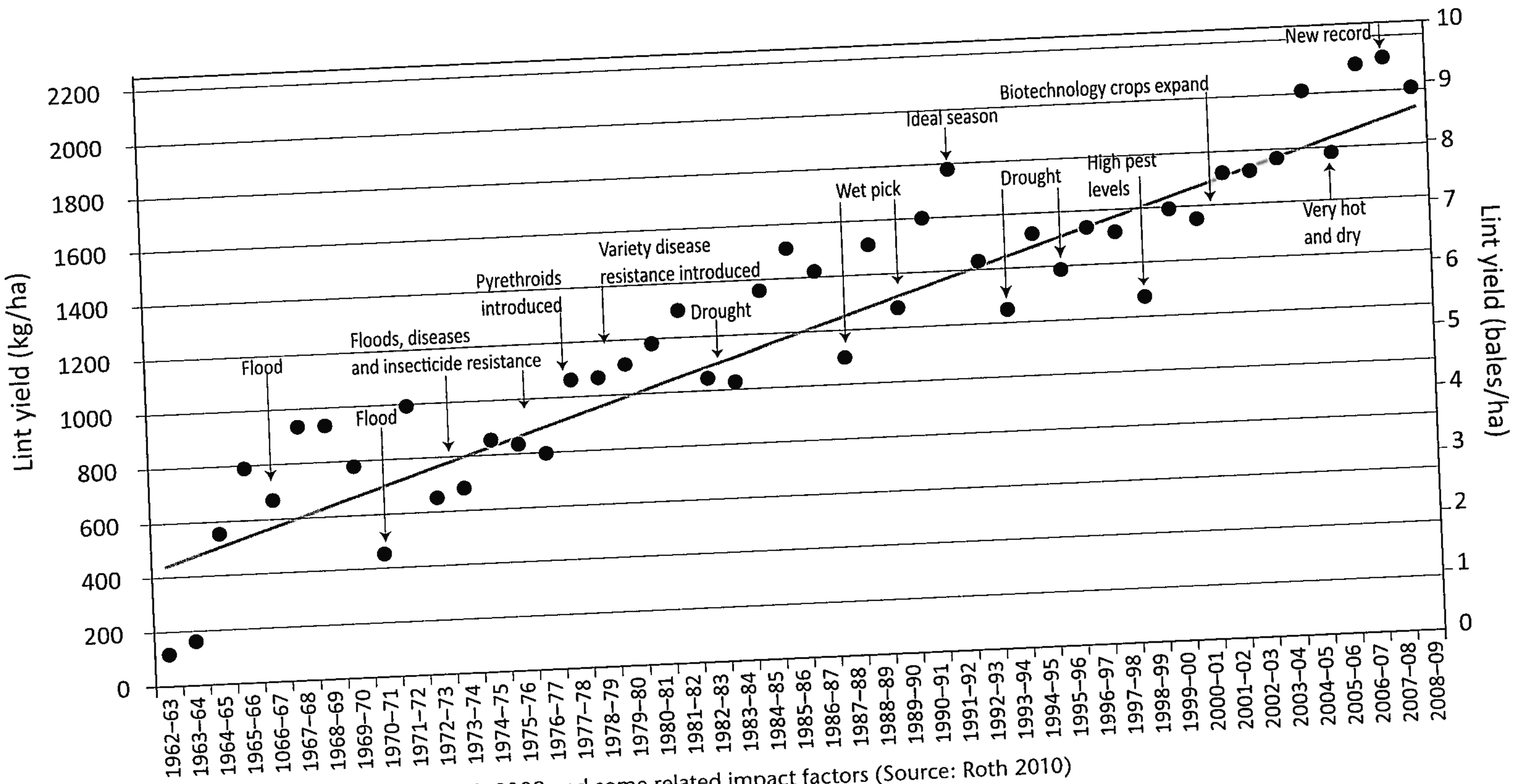

Figure 7.2: The rise of cotton lint yields 1962–2009 and some related impact factors (Source: Roth 2010)

years, cotton yields have increased on average at 32.9 kg of lint per hectare per year. Australian cotton yields are about three times greater than the world average (Roth 2010).

Australia has a reputation for producing high-quality cotton. This quality generally compares very favourably with that from other cotton-producing nations (Vijayshankar 2006; Dall'Abra 2006; Van der Sluijs *et al.* 2004; Shimazaki 2008; Yung 2008). The major buyers of Australian cotton are China, Indonesia, Thailand, South Korea and Japan. Australian cotton is increasingly considered a niche product because of its high quality in the world market, but the industry agrees that there are still opportunities for improvement. In this high-end market, Australia's major competitors are Texas and California in the USA and other longer staple producers such as China, India, West Africa, Uzbekistan and Brazil.

Customer demand is a key determinant of the type of cotton grown in Australia. An important trend in the world textile market is environmentally friendly cotton or 'eco cotton' (Fitzpatrick 2008; Spellson 2008; Yung 2008). Organic cotton is part of the 'eco cotton' theme, but cannot be produced in a cost-effective manner in large quantities. Hence, what has emerged is the importance of cotton produced according to environmental standards that have market traceability. Australia is one of the few countries where this can be delivered to market with complete reliability and transparency (Shimazaki 2008).

Responding to community concerns to regain the social licence

The cotton industry recognised it needed to be proactive in tackling environmental and community concerns, which had risen to a critical point in the early 1990s. It was considered important not to rush into a strong regulatory response because of concern of severe impact to the cotton industry economically (Schofield 1998). The cotton industry therefore initiated several key actions:

- It funded an external environmental audit of the industry in 1991. It commissioned an industry-wide environmental audit using independent international consultants Gibb Environmental Science and Arbour International. The audit report identified a suite of opportunities for improvement.
- It commissioned a scientific review on the effects of pesticides on the riverine environment (Barrett *et al.* 1991).
- It conducted a series of workshops with a range of stakeholders to identify research and development opportunities.

The urgent need for research and development solutions was led by the Cotton Research and Development Corporation (CRDC) who, in collaboration with the then Land and Water Resources Research and Development Corporation and the Murray–Darling Basin Commission, conducted a research program titled 'Minimising the impact of pesticides on the riverine environment using the cotton industry as a model'. This research program ran from 1993 to 1998, investigating the ways in which pesticides could move off the farm and the best ways of managing this movement, so that contamination risks could be minimised. A detailed description of the program can be found in Schofield *et al.* (2005).

Armed with more detailed knowledge, the cotton industry moved to identify solutions by holding a workshop. Somewhat surprisingly, 70% of the potential solutions were drawn from farmer knowledge (often comprising straightforward actions) while 30% came from new research (Schofield *et al.* 2005). These actions were then compiled into a formal Best Management Practices (BMP) Manual for managing pesticides. This BMP Manual has since been expanded to cover issues other than pesticides, such as water, soil and other natural resources.

The Cotton Best Management Practices Program

The cotton industry's BMP Program is a voluntary environmental risk management program based on a process of continuous improvement using a 'plan–do–check–review' management cycle. Cotton Australia (2006) describes it as a 'functional environmental management system'. An overview of the Cotton BMP program by Cotton Australia (2006) outlined the program goals as:

> *'To see the development of the cotton industry:*
> - *whose participants are committed to improving farm management practices*
> - *whose participants have developed and follow policies and farm management plans that minimise the risk of any adverse impacts on the environment or human health*
> - *which can credibly demonstrate to the community stewardship in the management of natural resources and farming operations.'*

The Cotton BMP Program was introduced to primarily improve the management of pesticides (Williams and Williams 2001; Williams *et al.* 2004; Ross and Galligan 2005; Schofield *et al.* 2005). The BMP program then evolved to consider broader natural resource management issues related to land and water management. Now, with the launch of the revised program in 2010, it seeks to provide a whole-of-farm tool for growers to manage their enterprises and the everyday risks of farming. The Cotton BMP Program presents the opportunity for the cotton industry to provide more confidence to the community, governments and cotton markets in its ability to use and manage various technologies such as pesticides and gene technology (Anthony 2004).

The BMP Program also provides a systematic process for the cotton industry and its growers to contribute to the catchment planning and natural resource management goals of government. It is a proactive initiative that is enhancing cotton growers' social licence to farm (Higgins and Adcock 2008).

In 2005, the industry embarked on the legal process to acknowledge the social licence afforded to industry by BMP. The industry embarked on the unique pathway of attempting to have the BMP Program formally recognised by the Queensland Government as delivering outcomes consistent with its statutory Land and Water Management Plans. These have the purpose of 'providing individual landholders with a practical management plan that demonstrate that water use practices are ecologically sustainable, both on and off farm' (Department of Natural Resources and Mines 2001). This achievement was realised in December 2008, with the Cotton BMP Program currently being the only voluntary on-farm management system recognised by a government in Australia as an alternative pathway for landholders to achieve a regulatory requirement. The importance of a social licence in the industry was reiterated in 2008, by the Chairman of the Australian Cotton Industry Council BMP Committee who stated that the program was a proactive initiative to help maintain its social licence to farm (Cotton Australia 2008).

Most recently, the cotton industry has been investigating the application of BMP in the post-farm-gate sectors of ginning and transport. The implementation of BMP at the grower level and the use of it throughout the post-farm-gate supply chain provides a vehicle and standards for the improvement of Australian cotton product (Dall'Alba 2006). The cotton industry has investigated the cotton market requirements of retailers (Williams 2007), with work continuing by the Australian Cotton Shippers Association and Cotton Australia to evaluate the promotion and marketing of 'BMP cotton' as environmentally responsible cotton

(Spellson 2008) and capitalise on this global focus of environmentally sound production of food and fibre.

Monitoring of Cotton BMP outcomes

Since the introduction of the Cotton BMP Program in 1997, independent reviews have found that at least 85% of cotton growers have changed their practices as a result. In May 2006, Cotton Australia undertook a survey of 70 growers, including levy and non-levy payers, BMP participants and non-BMP participants (Cotton Australia 2006). The result showed that 79% of the growers felt that BMP had improved the environmental performance on their farm, 31% of growers felt BMP had improved the financial performance of their farm, and 46% indicated it had improved staff management.

Cotton Australia also asked the growers what they thought the industry could do to get other growers to adopt BMP. Growers identified the key ways for industry to support growers in adoption of BMP is to demonstrate its benefits and develop grower champions and grower-to-grower encouragement, as well as providing incentives and discounts.

The voluntary audit process has posed challenges in its management (Hassall and Associates 2006), implementation and adoption. Auditing is often stated as a barrier and unnecessary aspect of the BMP program. However, a review by Holloway and Roth (2003) of grower feedback on audits found that 90% of respondents felt an audit was of significant benefit. Some grower comments on the benefits of the audit program included: '... it makes you aware of your obligations, it focused on the issues we overlooked, it gave us the push to do things we have been putting off.'

In 2003, CRDC commissioned GHD Pty Ltd to conduct the second environmental audit of the Australian cotton industry (GHD 2003) and to assess the industry's response to the previous environmental audit in 1991 (Gibb 1991). The second environmental audit involved a review of the literature, workshops with stakeholders and visits to 32 farms. It noted significant improvements in farm management practices.

As noted in the second *Environmental Audit of the Cotton Industry:*

> *'One of the most significant environmental improvements in the Australian Cotton Industry was the development of the BMP program. The audit identified a direct link between areas of improvement observed on the properties and the BMP modules. Farms that had undertaken their second BMP audit showed real improvements in environmental management and the auditing process provided a benchmark to indicate that progress had been made. The BMP audits were found to give a good assessment of the environmental farm practices currently covered by the manual.'*

In 2003, Macarthur Agribusiness was commissioned by CRDC and Cotton Australia to undertake an evaluation of BMP outcomes. The evaluation involved 10 farm visits, 65 telephone interviews and focus groups in five cotton regions. The findings of the report are as follows:

- Significant beneficial change in cotton farm practices had taken place since the manual was introduced in 1997, such as improvements to IPM, pesticide application, communication, weather monitoring, reduced pesticide use, reduced spray drift and odour complaints, improved water quality and a reduction in fish kills and cattle contamination.
- On-farm economic outcomes were difficult to quantify. This finding was similar to a conclusion reported by Cotton Australia (2006). Actions undertaken were often viewed as things growers would have done anyway.

- External stakeholders regarded the audit program as important.
- It was recommended that audit data be used for triple bottom line reporting.

Hassall and Associates (2006) evaluated the implementation of the BMP process and in particular the BMP Land and Water Module. The study found that growers and stakeholders considered the BMP process and the Land and Water Module to be effective, with well-developed tools for reviewing and planning changes to activities on farm. It also found the Land and Water Module effectively deals with most key natural resource management issues relevant to the cotton industry and made several recommendations to improve BMP uptake by growers. Likely outcomes include changes in attitude, knowledge and aspirations, as well as natural resource management outcomes such as water use efficiency and soil health. Protection of the right to farm and continued access to water were found to be the largest potential benefits for production and profitability.

An example of a cotton grower quote from Hassall's report (2006) highlights the feeling that growers understand it is important to demonstrate externally that they are being responsible, which in turn helps to support a social licence to operate: 'BMP is important so that cotton can demonstrate that they're doing things well as an industry'.

A farm agronomy adviser noted that BMP was not about reducing costs or increasing production, but rather about being able to continue farming: 'We need to keep growers in business – BMP helps to do that'.

Roth (2010) completed an analysis of the Cotton BMP program farm practice audit criteria for the 10 years between 1999 and 2008. Results show it is possible to quantify how cotton growers have implemented changes to a wide range of their farm management practices. The analysis showed there was a very high standard of legal compliance on farms during 1999–2008 where the BMP program was adopted. Figure 7.3 shows the mean BMP ranking for all 47 farm practice criteria from the pesticide application, pesticide storage, integrated pest management, farm design and farm hygiene modules for the 10 years between 1999 and 2008. The rankings averaged 1.46 (scale 1–4) and showed a 29% improvement over the decade. It showed a 45% improvement between 1999 and 2006. The fall in the mean BMP farm practice standards between 2007 and 2008 was attributed to the ongoing drought, which reduced expenditure, action and motivation.

Despite the drought, the BMP farm practice standards for the five years (2004–2008) were on average better than the previous five years (1999–2003). The analysis showed the mean BMP ranking for certified audited farms between 2006 and 2008 was 24% better than the non-audited farms. This supports the premise that the extra rigour associated with external audit does lead to additional on farm improvements in practice.

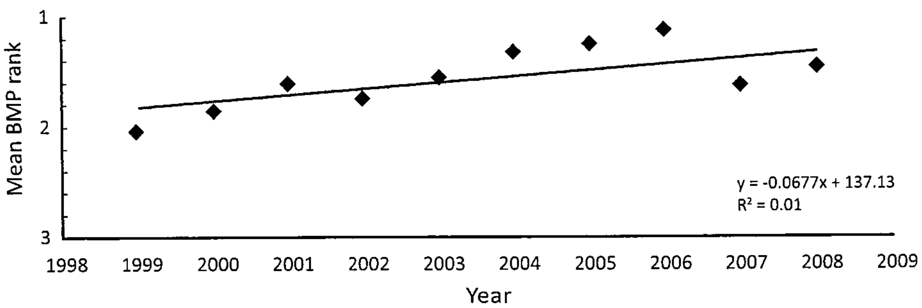

Figure 7.3: The mean Cotton BMP audit rankings for all 47 farm practice criteria between 1999 and 2008 from the pesticide application, pesticide storage, integrated pest management, farm design and farm hygiene modules (Source: Roth 2010)

Figure 7.4 shows significant improvements were made between 1999 and 2008 in pesticide spill containment (69%), storage ventilation (49%), security (51%), work procedures (19%) and emergency procedures (39%). Figure 7.5 shows significant improvements were made between 1999 and 2008 related to pesticides in signage on chemical storages (38%), mixing and loading sites (62%), mixing and loading systems (65%), worker safety (22%) and waste disposal (35%). Trends for equipment maintenance and safe transport are not clear, but were of a high standard.

Reduced insecticide use

Endosulfan is an organochlorine insecticide used to control sucking, chewing, and boring insects and mites in a range of crops, including cotton and sorghum. Figure 7.6 illustrates that endosulfan concentrations, which were very high in 1991, have been below the Australian and New Zealand water quality guideline trigger value for 99% ecosystem protection (ANZECC and ARMCANZ 2000) for the last seven years (Mawhinney 2008). The adoption of the Cotton BMP Program improved tail water return systems. Restrictions placed on endosulfan use and the introduction of genetically modified 'Bt' cotton has all contributing to the reduced movement of endosulfan into river systems. Similar results have been reported in the Gwydir and Macintyre Valleys during 1992–2003 (Mahwinney 2004) and in the Queensland Murray–Darling Basin during 1994–2001 (Waters 2004).

Number of complaints to the EPA

Complaints to the Environment Protection Authorities (EPA) are a good indicator of the absence of strong community dissatisfaction in relation to industry performance. There has been a dramatic drop in the number of complaints to the NSW EPA since 2001, which were down to three per year for 2006 and 2007. This can been attributed to a number of linked factors including the implementation of the Cotton BMP program, greater use of transgenic cotton varieties and a reduction in the crop area due to the drought. Fewer complaints lead to greater social harmony in the community, which in turn leads to less threats to the farmers' social licence to operate.

Community attitudes and the social licence

Community attitudes are important because they influence the social licence to farm. Between 1995 and 2004, Cotton Australia commissioned five studies that investigated community attitudes towards the Australian cotton industry. The studies were carried out by professional attitudinal research companies, namely Stollznow Research and Roy Morgan Research (Stollznow 1995a, 1995b, 1997, 1998; Roy Morgan Research 2004). The issues raised in these studies included:

- community health: harmful chemicals, chemical smells, aircraft noise and spraying, beef cattle contamination by Helix and endosulfan, and soil contamination
- pesticides, herbicides and defoliants: excessive use and spray drift
- river water: chemicals in the water and run off, high water use and salinity
- groundwater: excessive use drying up stock bores and entry of chemicals
- soil: exploiting soils, chemicals and residues
- land clearing and laser levelling
- cotton growers: perception of being greedy, arrogant, irresponsible and only in it for the short term
- cotton industry: perceived as all powerful, secretive and dishonest
- the Cotton industry was rated consistently low in surveyed attributes compared with other industries

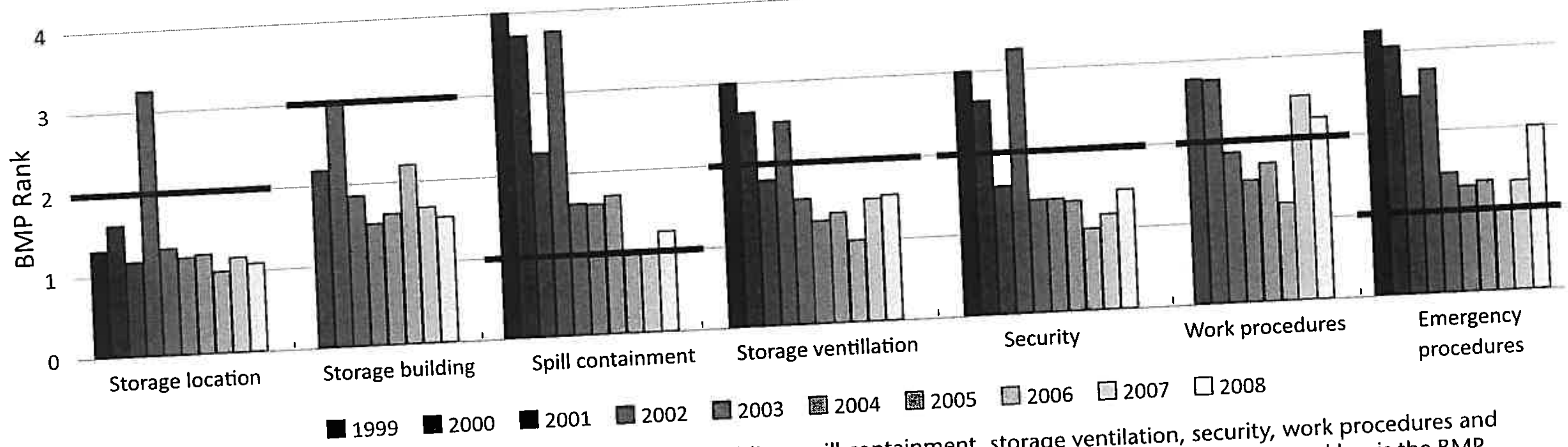

Figure 7.4: The mean BMP rankings for storage location, storage building, spill containment, storage ventilation, security, work procedures and emergency procedures on BMP audited cotton farms over 10 years between 1999 and 2008 (Source: Roth 2010). The horizontal bar is the BMP compliance standard. Rank 1 is excellent. Rank 4 is poor.

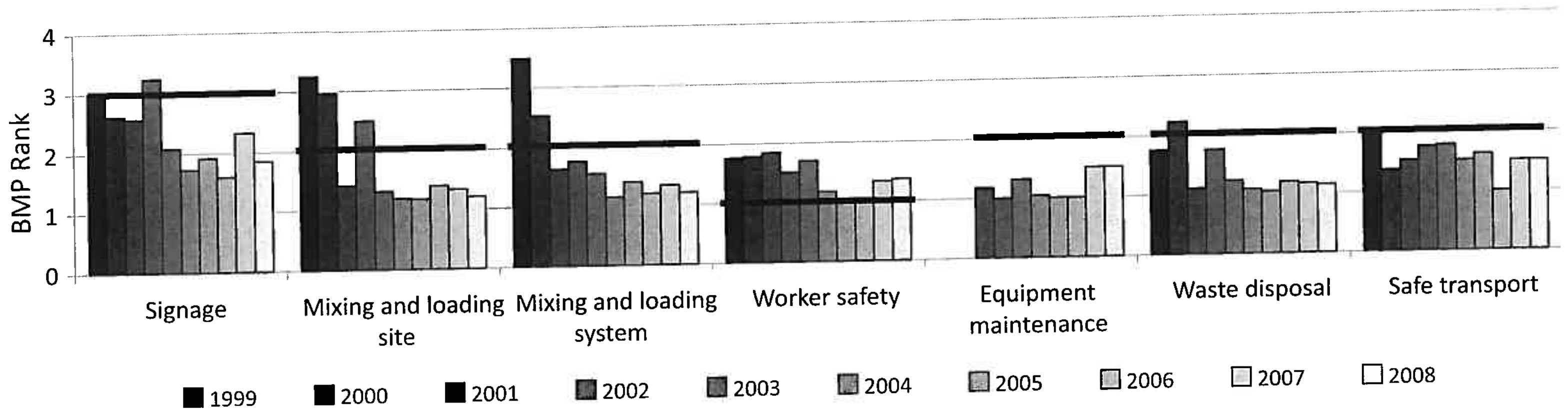

Figure 7.5: The mean BMP rankings for signage, mixing and loading sites and systems, worker safety, equipment maintenance, waste disposal and safe transport on BMP audited cotton farms over 10 years between 1999 and 2008 (Source: Roth 2010). The horizontal bar is the BMP compliance standard. Rank 1 is excellent. Rank 4 is poor.

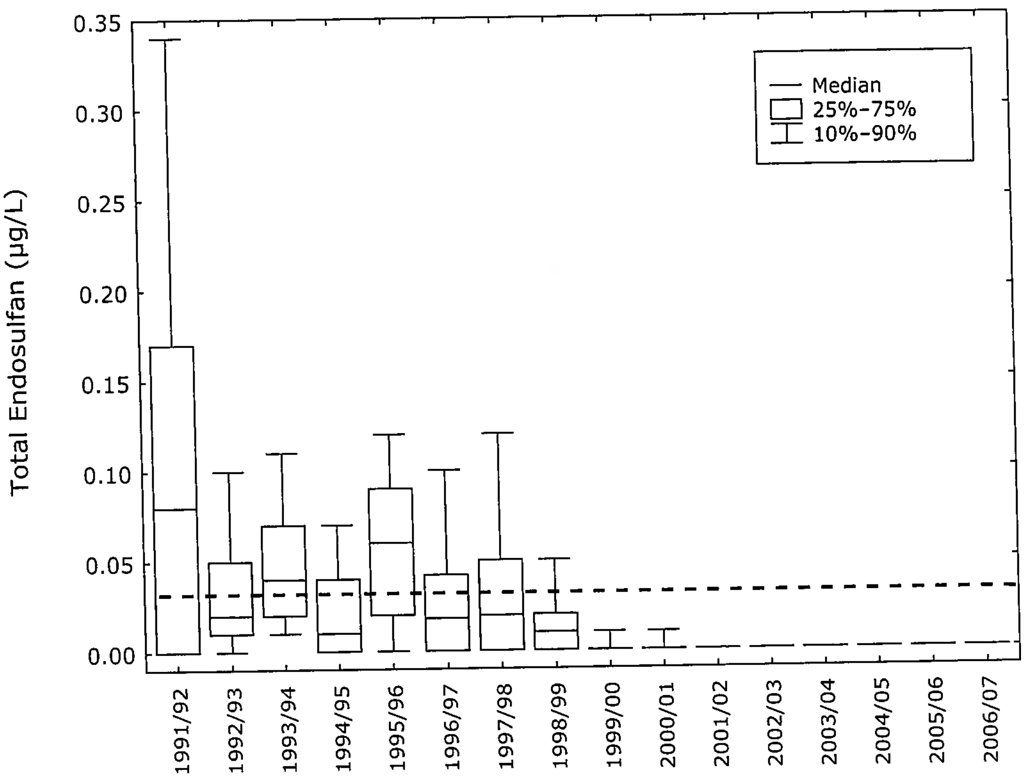

Figure 7.6: Total endosulfan concentrations in the Namoi Catchment from 1991–1992 to 2006–2007 (Source: Mawhinney 2008). The broken line represents the Australian and New Zealand water quality guideline trigger value (ANZECC and ARMCANZ 2000) for 99% ecosystem protection (0.03 µg/L). Each box represents the middle 50% of the data collected for each year. The middle line in each box represents the median (or 50th percentile) value, which is the most useful when assessing water quality.

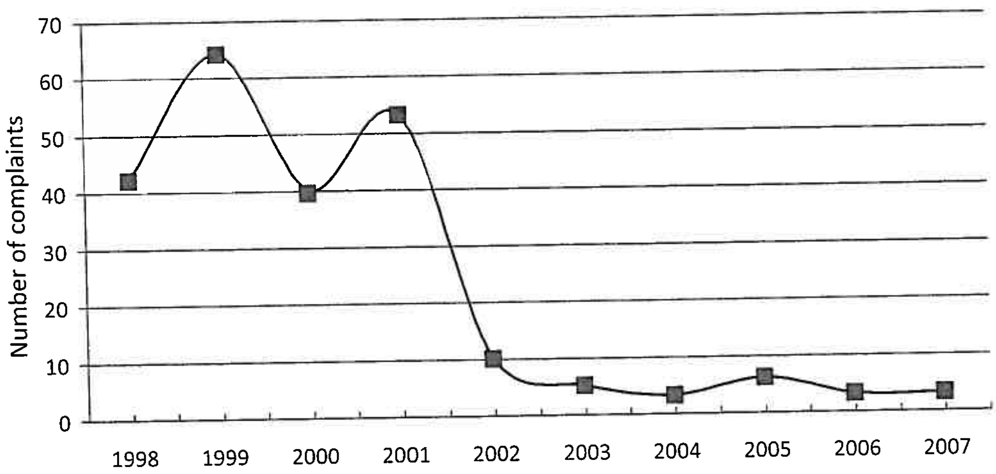

Figure 7.7: Number of complaints received by the NSW EPA 1998–2007 (Source: NSW EPA *pers. comm.* 2007)

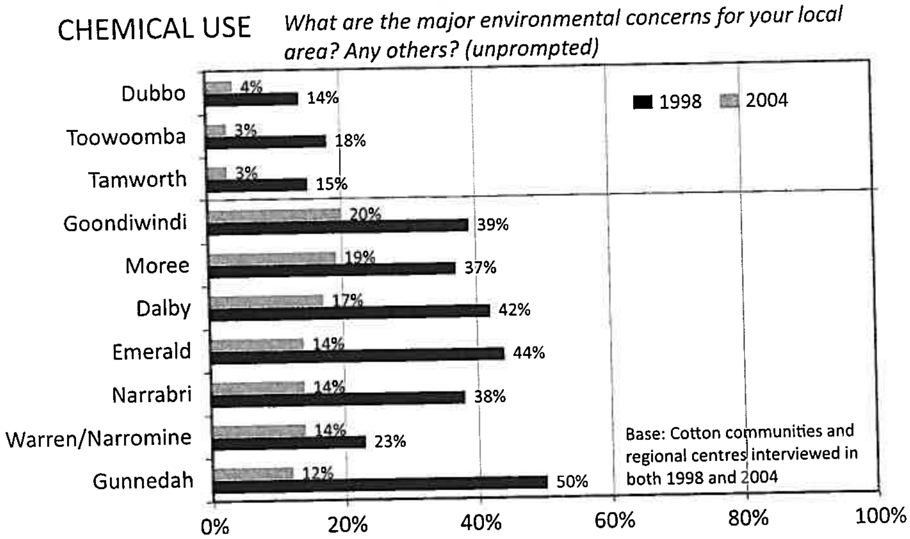

Figure 7.8: A comparison of community concerns in cotton growing regions regarding agricultural chemical use between 1998 and 2004 (Source: Roy Morgan Research 2004)

- Moree and Gunnedah were noted as towns where there was most community negative orientation towards the cotton industry.

In 2004, Cotton Australia and CRDC commissioned further attitudinal research into the cotton industry by Roy Morgan Research (2004). This study included major cotton towns, a number of large regional centres nearby the cotton communities, but themselves not cotton towns (Dubbo, Toowoomba and Tamworth) . Community member's responses to the cotton industry in both 1998 and 2004 were reported. In 1998, chemical use was still a major concern, but by 2004 this had reduced significantly in all centres (Figure 7.8). This research also showed that community concerns about the cotton industry's chemical use, spray drift and water use had reduced significantly between 1998 and 2004.

It should be noted that these changes in community perceptions, do, in principle, mirror actual improvements in cotton farming practices that have been demonstrated through on-farm audit and farmer surveys.

Looking to the future

The Australian cotton industry, like any other industry, will need to balance economic, environmental and social sustainability issues. The cotton industry has a number of initiatives underway aimed at better managing these competing pressures to improve its public standing and maintain its social licence to operate. Research and development and the systematic implementation of better practices by farmers via the BMP Program are the central planks of the strategy. Marketing or spin campaigns are not part of the strategy.

The cotton industry has produced a vision strategy out to the year 2029 (CRDC 2010), which was launched at the 2010 Australian Cotton Conference. A key element of this vision is being a responsible producer and supplier of the most environmentally and socially responsible cotton in the globe. Other key elements of the 'Preferred Future for 2029' envisage an industry that represents 'Australian cotton, carefully grown, naturally world's best': an industry that is differentiated, responsible, tough, successful, respected and capable. To achieve this, the industry needs good measures of its economic, environmental and social performance for the community to deliberate.

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A REVIEW OF SOCIAL INDICATOR TRENDS OF THE COTTON SERVICE SECTOR

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SUMMARY

- 66% of business owner consultants are aged between 35-49
- 81% have a bachelor level degree or higher postgraduate qualification
- The majority of their employees (65%) also have a Bachelor degree
- permanent staff employed per business increased from 1.6 in 2008 to 2.1 by 2011
- casual staff employed has increased from 1.1 in 2009 to 2.8 employees per business in 2011
- In 2011, the average number of hectares of cotton serviced per employee was 1969 ha (dryland & irrigated)
- In terms of recruitment, 32% of respondents said it was more difficult than past experience to find suitable applicants to fill positions in 2011, while 42% said it was similar to past experiences
- Of the staff recruited into the businesses in 2011 one third were "return employees"
- Consultants viewed their largest OH&S risks as driving accidents, chemical exposure, & sun/heat exposure
- zero workers compensation claims had been made in the last 12 months and only two in the past five years
- 72% of consultancy income of these businesses is derived from cotton crops.
- 58% of consultancy time services is for cotton pest monitoring and recommendations
- Major external factors that influence business planning include chemical supply and commodity price fluctuations.

INTRODUCTION

As part of the cotton industry sustainability understanding it is necessary to understand social indicators of the industry's human resources. An analysis was undertaken of the raw data from the Crop Consultant's Australia survey of its membership after the 2010-11 cotton season.

Thirty two crop consultants provided responses. The area of cotton these consultants provided agronomic advice covered 308,692 ha, of which 215,110 ha was irrigated cotton and 93,582 ha was dryland cotton. This represented 59% of the industry irrigated area and 62% of the dryland area. The respondent's services covered 455 cotton farm businesses.

The majority of respondents, 77% or 24 respondents, were from independent crop consultancy businesses not associated with reselling agronomic input products.

The average number of farms serviced by each consulting business was 14. The median number of farms serviced was 12.5 farms. There was a wide range in the number of farms the consulting business serviced ranging between 1 and 51 farms.

RESULTS

Age of the Business Owner

Figure 1 shows the age of the cotton consultant business owners that responded to the survey. The majority (66%) were aged between 35 and 49, with 47% aged between 35 to 44. Only 13% of the business owners were aged over 55, while 19% were aged less than 35 years. These figures are consistent (almost identical) with the WRI (2008) survey of cotton consultants. The data indicate that owners of cotton agronomy businesses would generally be considered a young person's industry.

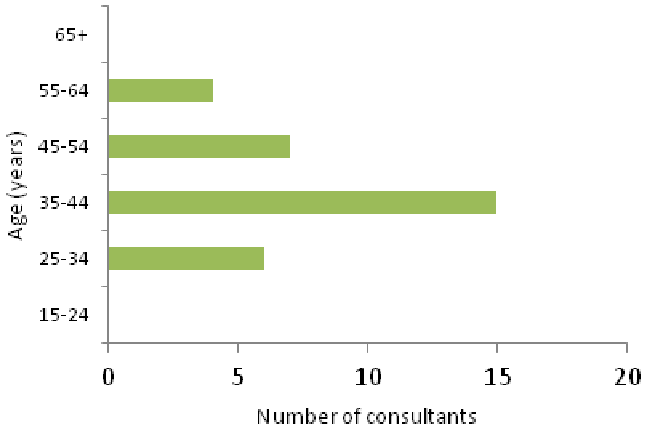

Figure 1: Age distribution of cotton consultants

Education levels - Highest post school qualification

Education levels are usually measured with the highest post school qualification. Education is a measure of human capital of the cotton industry.

Business owners

The highest post school qualification of the business owner is shown in Figure 2. The majority (65%) have a bachelor level degree, while 81% have a bachelor level degree or higher postgraduate qualification. In 2007, 64% of the Cotton Consultants Australia total membership had a bachelor degree or higher. The difference is likely due to differences in the sample size and more data is needed before drawing a conclusive comment that education levels have risen between 2007 and 2011. The key message is that the business owner members of Crop Consultants Australia have high post school qualification levels.

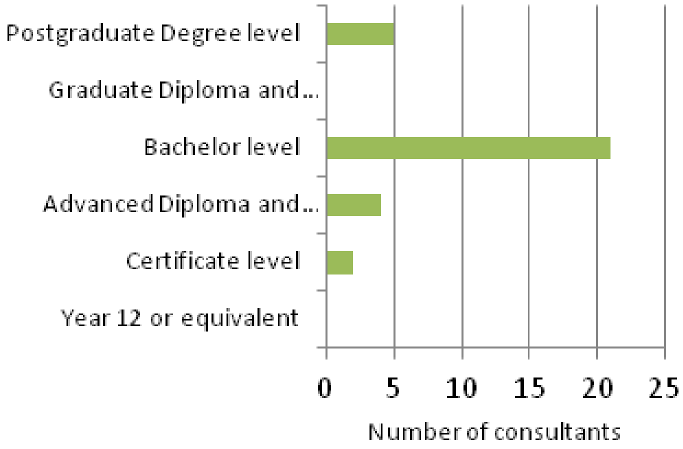

Figure 2: Qualification of cotton consultants

Permanent employees

The highest post school qualification of permanent employees is shown in Figure 3. The majority of employees (65%) also have a Bachelor degree. A small number of employees only have Year 12 or equivalent as their highest post school qualification, which would be expected as these businesses recruit young staff.

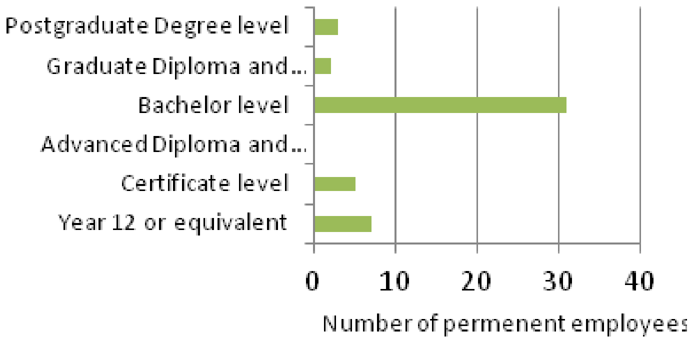

Figure 3: Qualification of cotton consultant's permanent employees

For cotton growers, the number with a bachelor degree has risen 8.4% from 13.5% to 21.9% between 1991 and 2006. The majority of cotton growers highest post school qualification is an advanced diploma (2006 – 19.8%) or certificate level (47.5%) qualification. 15% of cotton ginners had a bachelor degree or higher (Roth 2010).

<u>Employment</u>

Permanent staff

A social metric to compare employment over time is the number of permanent staff employed per business (Figure 4). In 2008 when cotton production area was at a record low, 1.6 permanent staff employed per business. By 2011, 2.1 permanent staff were employed per business as the cotton area increased following good commodity prices and widespread rain. (Note: These figures include the business owner.)

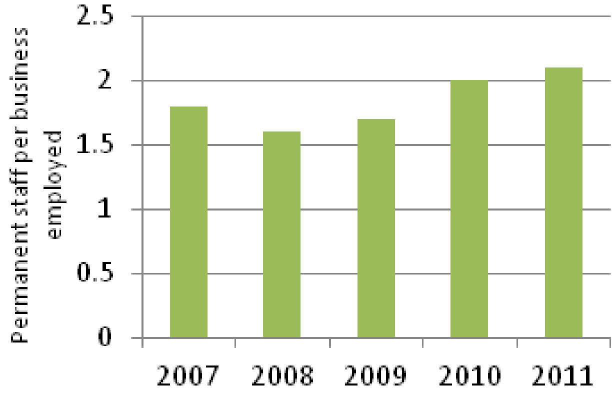

Figure 4: Permanent staff per business

Casual staff

The number of casual staff employed per business during January each year between 2007 and 2011 is shown in Figure 5). There was a significant increase (about 250%) in the number of casual employees hired in 2011 in response to the record area of cotton planted. On average, the number of casuals employed has increased from 1.1 per business in 2009 to 2.8 casual employees per consulting business in 2011.

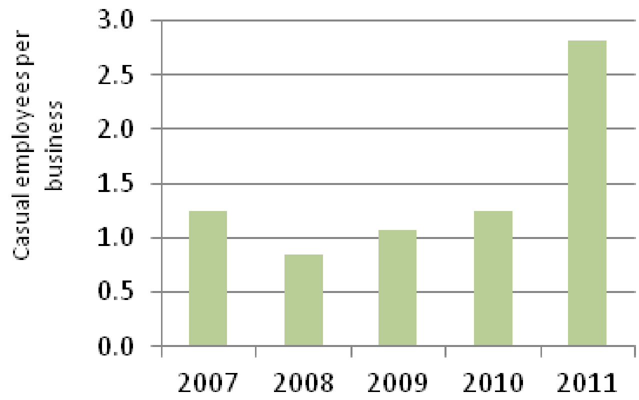

Figure 5: Casual staff per business

<u>Hectares of cotton serviced per employee of the agronomic consulting business</u>

In 2011, the average number of hectares of cotton serviced per employee (permanent and casual) of the agronomic consulting business was calculated as 1969 ha. (Note this area includes irrigated and dryland cotton).

<u>Recruitment challenges</u>

In terms of recruitment, 32% of respondents said it was more difficult than past experience to find suitable applicants to fill positions in 2011, while 42% said it was similar to past experiences.

<u>Business Income</u>

Figure 6 shows 72% of consultancy income of these businesses is derived from cotton crops. Other summer crops contribute 5%, winter cereals 9%, winter pulse crops 6%, pastures and natural areas <0.5%).

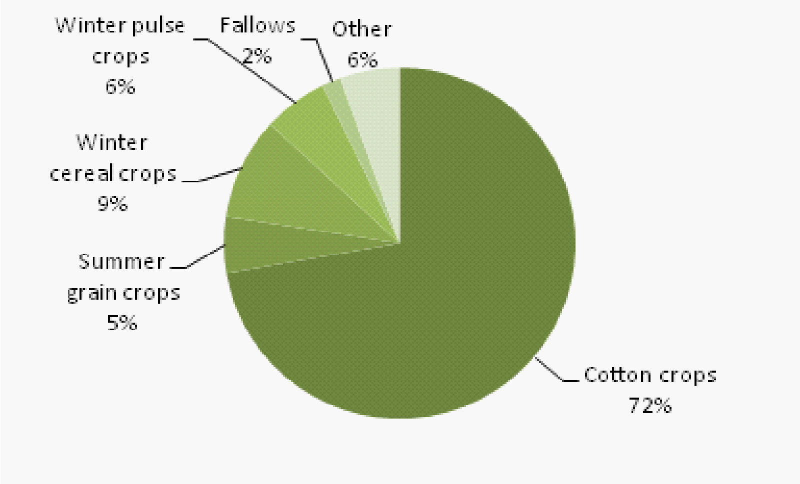

Figure 6: Business income

In terms of cotton work, Figure 7 shows the percentage of consultancy time derived from services includes cotton pest monitoring and recommendations 58%, cotton weed monitoring and recommendations 12%, cotton irrigation scheduling and recommendations 13%, cotton nutrition monitoring and fertiliser recommendations 13% and other 4% (defoliation, pix, diseases etc).

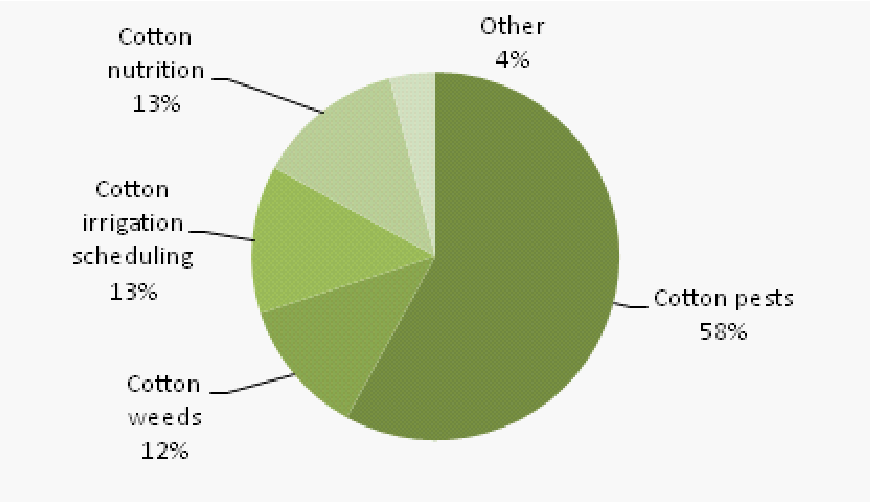

Figure 7: Consultancy business time

Most businesses (25) have not been involved with their local CMA or NRM body. The few that have been involved have been associated with water use efficiency (5) and water quality projects (2), as well as conservation farming (2).

ACKNOWLEDGMENT

Funding from CRDC.

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Sustainability Indicators for cotton

Guy Roth
Roth Rural and Regional Pty Ltd, Narrabri, NSW

The Cotton Industry needs to demonstrate that its practices are sustainable (and communicate this to the community and government).

Sustainability involves an understanding of economic, environmental and social attributes.

This project compiles these attributes into a one stop shop.

A full report is available at www.cottoncrc.org.au (communities publications)

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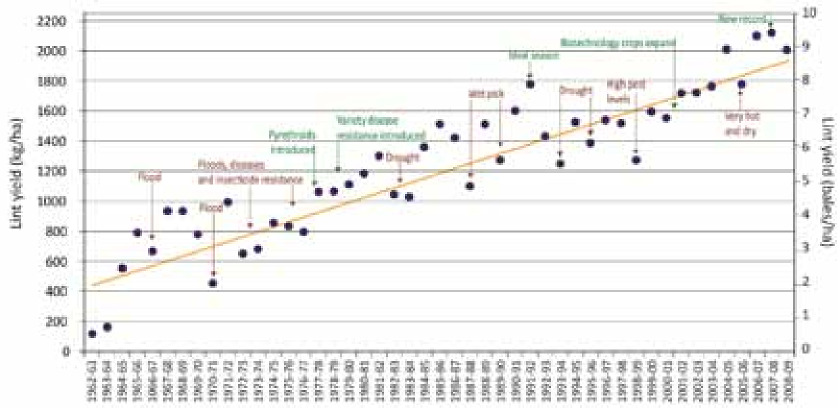
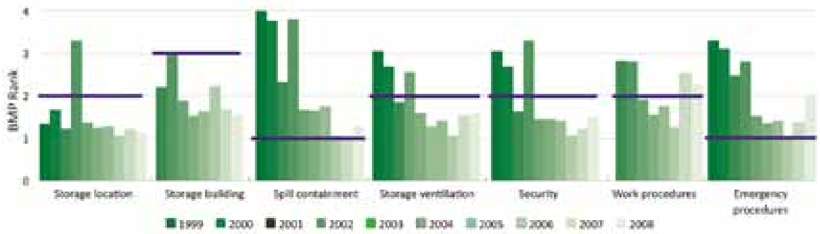
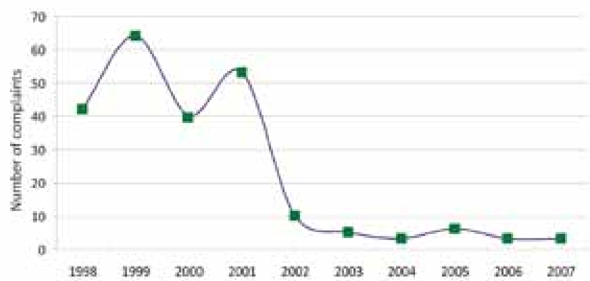


Economic indicators of sustainability include yield, production levels, profit, and fibre quality. This graph shows the rising yield of cotton in Australia.



Environmental indicators include: water use, water quality, pesticide use and stewardship, soil, energy, biodiversity. This graph shows pesticide stewardship using BMP rankings from farms. The blue line is the industry or legal requirement and improved practice is evident as the rankings trend to lower than the blue line.



Social indicators include employment, OH&S, education, attitudes and demographics like age and gender. This graph shows the number of complaints about cotton to the NSW EPA was falling.

Irrigation & Cotton

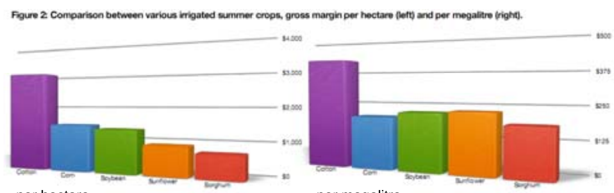
Guy Roth

Irrigation Australia
and International Committee on Irrigation and Drainage
Conference, June 2012, Adelaide

Advancing Australian Cotton

COTTON AUSTRALIA

Gross margins - irrigation

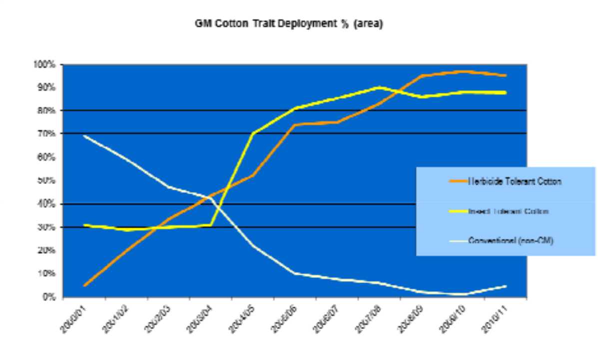


per hectare

per megalitre

Cotton Seed Distributors Ltd.

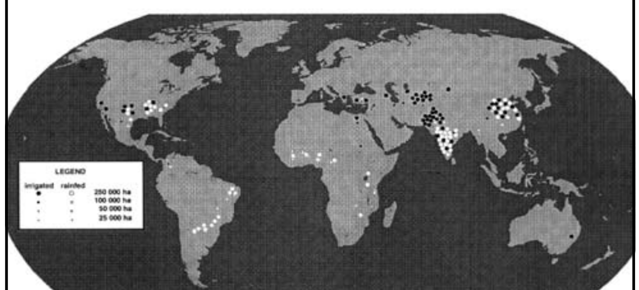
2



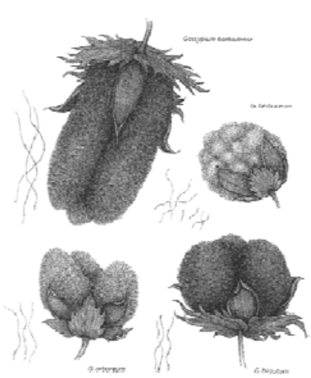
Cotton Australia 2012

3

World Production Areas



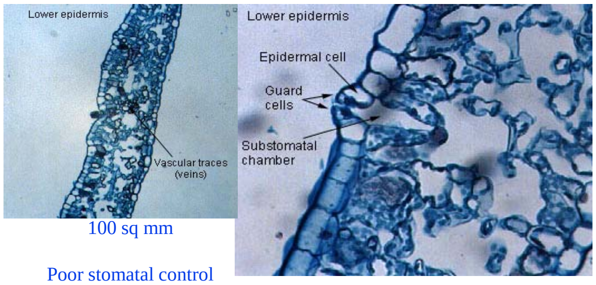
Hearn 1984



How does cotton grow ?

- Perennial
- Indeterminate
- Xerophytic plant
  - Survive along time without water

Cotton leaf



100 sq mm

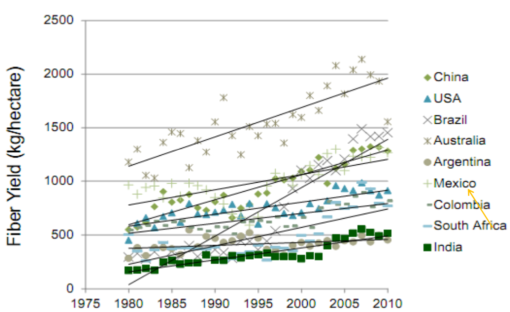
Poor stomatal control
Stay open until severe stress
Transpiration compromised

Biotechnology for irrigation?

- Complex subject but a few groups working
- As an indeterminate plant, cotton is more complex than grains.
- Decreasing water use may increase leaf temperature and increase stress.
- What variety type; what management system?

(Constable 2011)

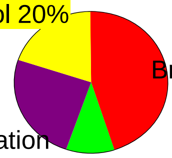
World leader – yield & quality



David Zilberman, Univ. of Calif. Berkeley

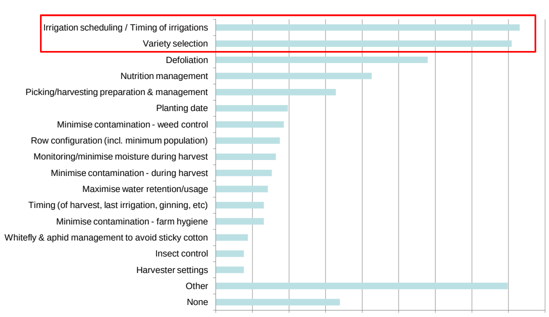
9

Components of yield level and progress in Australia



Source:Constable 2000

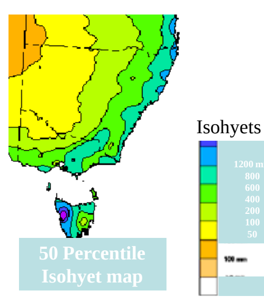
Fibre quality – Growers are saying



11

Roth 2011

Driest continent cliché needs interpretation.

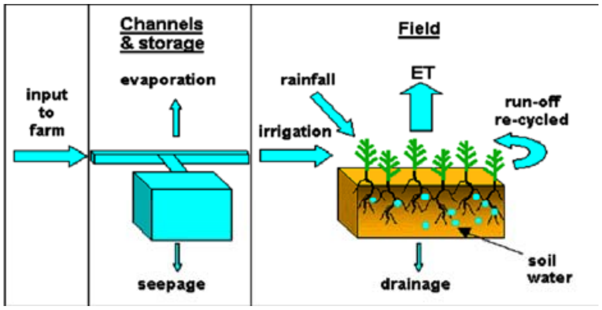


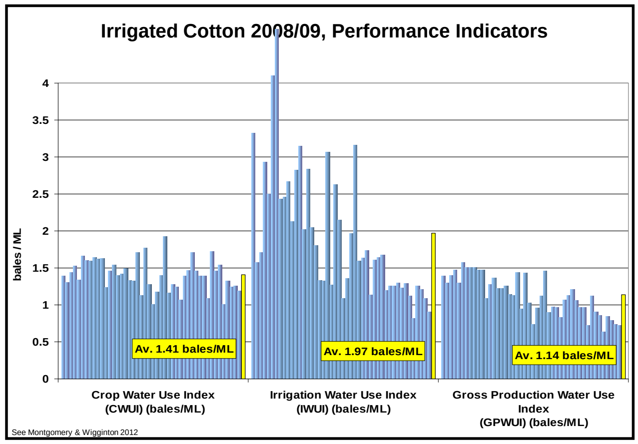
Most of key agricultural production is in 400 to 800 mm rainfall zone (not arid)

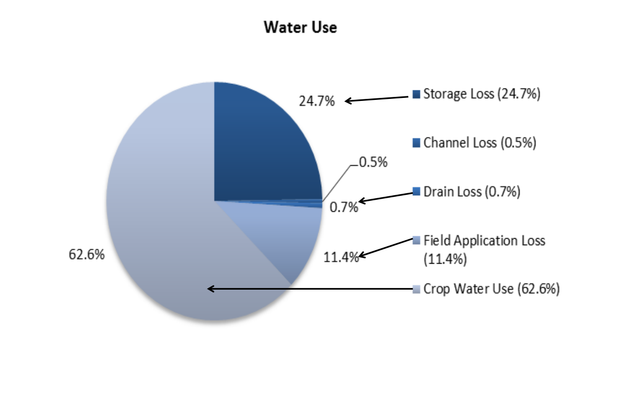
Managing variability is a critical issue

Rainfall can be a significant component of irrigation system

D Anthony pers comm



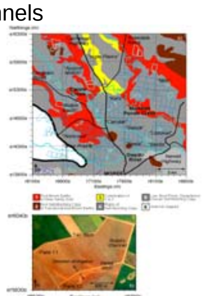




16

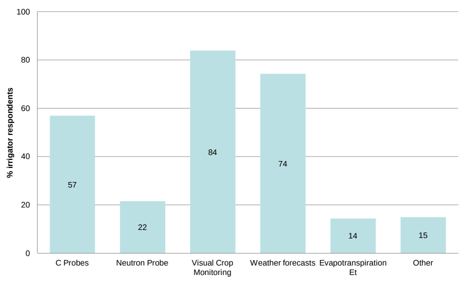
EM38 surveys of storages and channels

Identification of seepage from storages and distribution channels



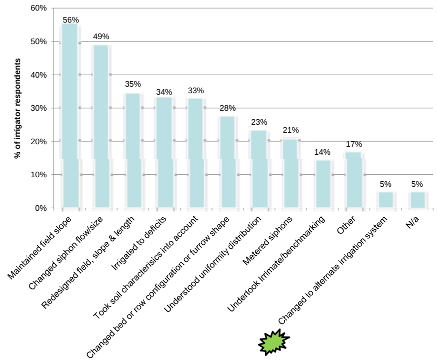
Tools

Irrigation scheduling - growers are…..



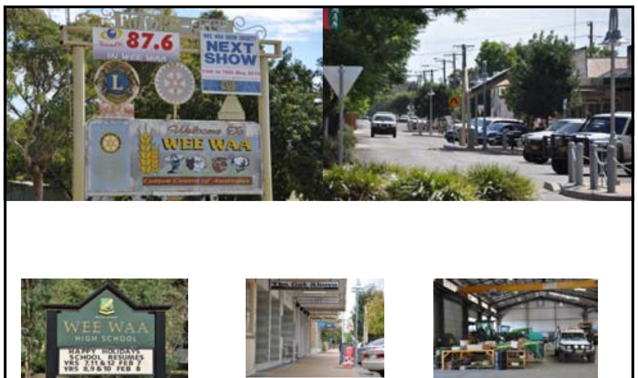
Roth 2011

Growers have …….. to improve WUE



Roth 2011

20



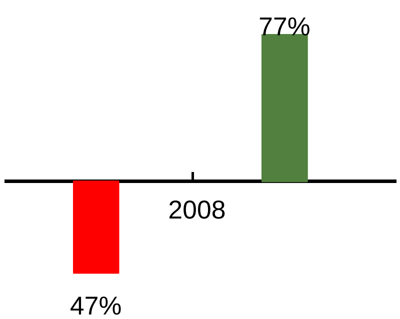
Communities

LOCAL GOVERNMENT AREA	1997[1] % of agricultural production ($)	2001[2] % of agricultural production ($)	2006[3] % of agricultural production ($)
Emerald	37.5	23.6	
Bananna	22.2	13.7	
Balonne	53.1	59.4	
Wambo	29	25.9	
Dalby	49.4		
Jondaryran	27.3	18.7	
Pittsworth	44.2	44	
Chinchilla	8	4.8	
Milmerran	35.8	20.5	
Waggamba	30	35.2	
Moree	55	62.6	43.7
Walgett	28.6	41.8	
Gunnedah	33	26.8	
Narrabri	60.2	63.8	28.4
Narromine	26.1	37.5	34.8
Warren	49.7	57.3	44.2
Bourke	66.4	61.7	
Carathool	0.6	n/a	
Lachlan	n/a	n/a	
The Darling Downs			17.6

Roth 2010

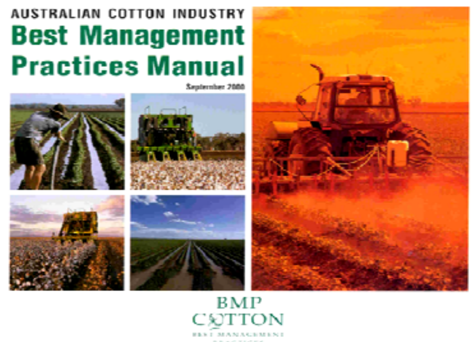
22

Business turnover up

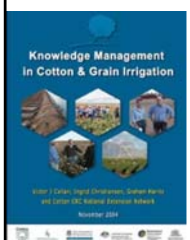


Employment

	2008	2011	2012
Large business	34	37	38
Small business	3	3	3

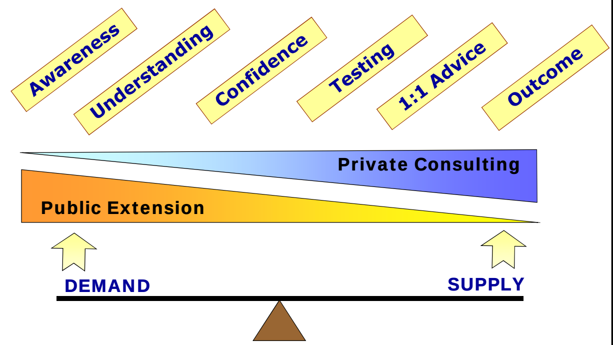


What farmers want ?

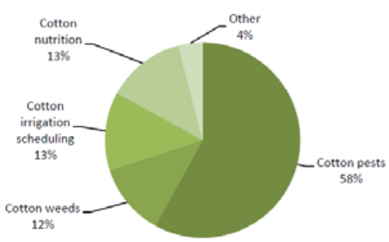


- Personal contact (where possible one-on-one)
- Regional research
- Detailed, practical irrigation training for consultants
- Better target consultants in extension activities
- Concise practical information (esp. Cotton Tales)
- Potential for cross-industry co-operation
- Develop integrative information tools (e.g. WATERpak, trial books)

Partnering public and private sector knowledge services



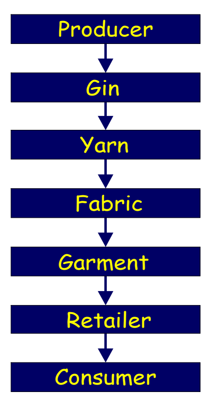
Private crop consultants income

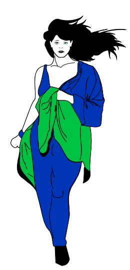


CCA 2010 survey

29

Cotton belongs to the Fashion Industry





Life cycle and/or CSR

31

A few RD&E prorities

- Yield and quality - varietal selection, nutrition, crop protection and irrigation management to name a few
- Storage, distribution & application efficiency
- Monitoring water use and calculating efficiencies
- Alternative irrigation systems (where applicable)
- Water, carbon, energy, labour interactions
- People
- Adoption, Adoption, Adoption
- Key learning sites
- (Environmental water & SW & GW & CSG & WQ)
- (Social and economics)

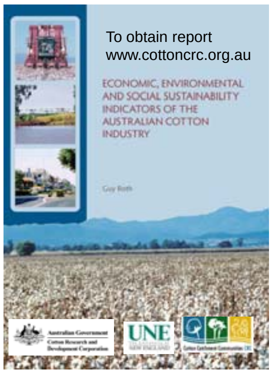
Dr Guy Roth, Roth Rural & Regional, guy@roth.net.au , 02 6792 5340

Economic, Environmental & Social Sustainability Indicators of the Australian Cotton Industry

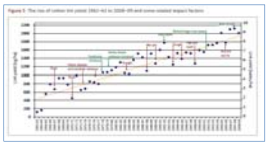
Australian Government Cotton Research and Development Corporation

Cotton Catchment Communities CRC

Dr Guy Roth, Roth Rural & Regional & Cotton Catchment Communities CRC , guy@roth.net.au , 02 6792 5340



To obtain report
www.cottoncrc.org.au



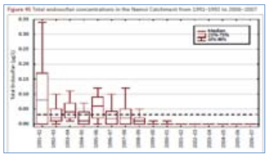
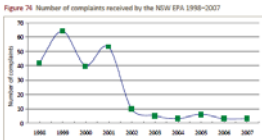
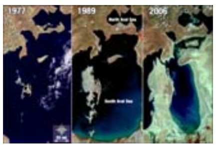
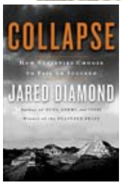


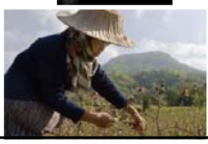
Figure 74 Number of complaints received by the NSW EPA 1998–2007



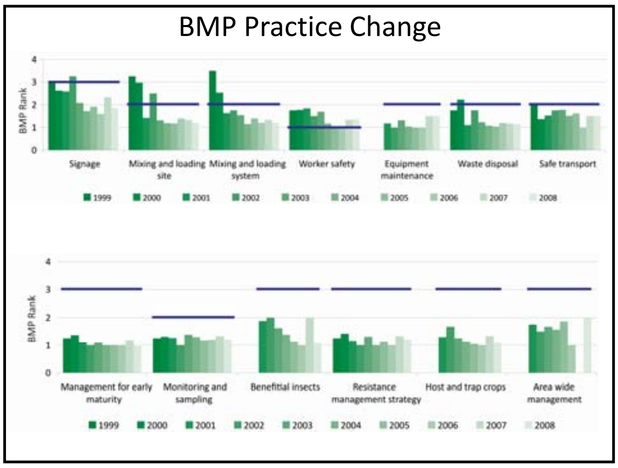
Source: NSW EPA, pers. comm. 2007

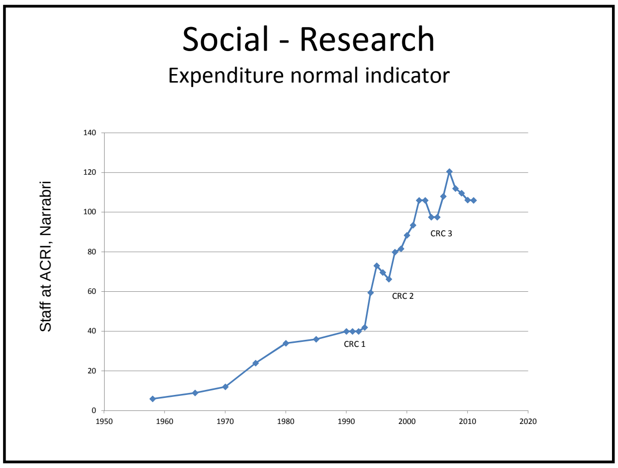






OUTCOME	POSSIBLE INDICATORS
Economic	
Regional and export income	• Value of production • Export income
Regional employment	• People employed • Productivity per man hour • Hours worked per bale
Industry trends	• Farm numbers / area
Profitable farming	• Gross profit • Farm income diversity (including off farm) • Costs • Capital investment and return
Continual improvement in production	• Yield
Accountability to taxpayers	• Funding received from Government programs
Environmental	
Water: Explaining trends of water quality in catchments	• Quality (turbidity, N&P, EC, pesticides) • Access/fairness • Efficiency of use and comparisons
Land: Sustainable soils, responsible pest management, responsible transgenic crop stewardship	• Soil health (nutrients, EC, structure, sodicity, Organic C) • Weeds (and escapes) • Pest management (spray drift implications) • Transgenic or genetically modified traits (resistance, stewardship)
Biodiversity: Contribution to ecology of region and nation	• Environmental weeds • Riparian health including connectivity • Aquatic biodiversity • Native vegetation (spray drift impacts, quantity, quality) • Native fauna / bugs
Climate Responsible energy use, compliance with Government policy and contributing to climate change mitigation	• CO_2 Emissions • Carbon storage • Energy use
Social	
Measure of the human capital of the industry. The capacity of the workforce to achieve tasks and adopt new practices.	• Education • Training • Education • Qualifications of farmers and people in the industry
Explaining trends of how people are involved in the cotton industry	• Demographics • Age • Distribution • Gender • Population
Value of the workplace and industry to the community	• Employment / unemployment • Numbers • Income levels • Hours worked • Turnover of employees • Distribution
Healthy and safe industry and work practices	• Health • Farm accidents (deaths, injury) • OH&S
Reputation of the cotton industry by stakeholders. It provides the "social licence" to farm.	• Community attitudes / perceptions • Pesticides • Water • Transgenic cotton technologies
Playing a part in the community, knowledge diffusion and cooperative behaviour for mutual benefit.	• Social capital and fabric • Industry networks • Memberships • Participation in activities
Innovation & desire to improve practices, human and social capital	• Research and development • Investment and priorities
Evidence of doing the right thing	• Number of prosecutions • Water and land management offences / fines • Complaints


BMP Practice Change
BMP Rank
Signage
Mixing and loading site
Mixing and loading system
Worker safety
Equipment maintenance
Waste disposal
Safe transport
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
BMP Rank
Management for early maturity
Monitoring and sampling
Beneficial insects
Resistance management strategy
Host and trap crops
Area wide management
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


Social - Research
Expenditure normal indicator
Staff at ACRI, Narrabri
CRC 1
CRC 2
CRC 3
1950 1960 1970 1980 1990 2000 2010 2020


87.6
NEXT SHOW
Welcome to
WEE WAA
WEE WAA
HIGH SCHOOL

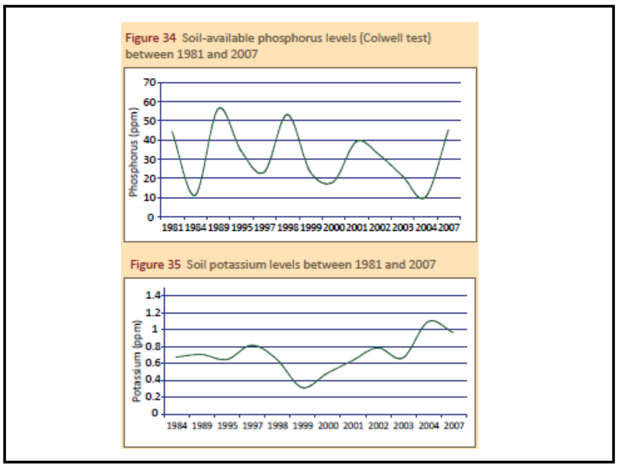
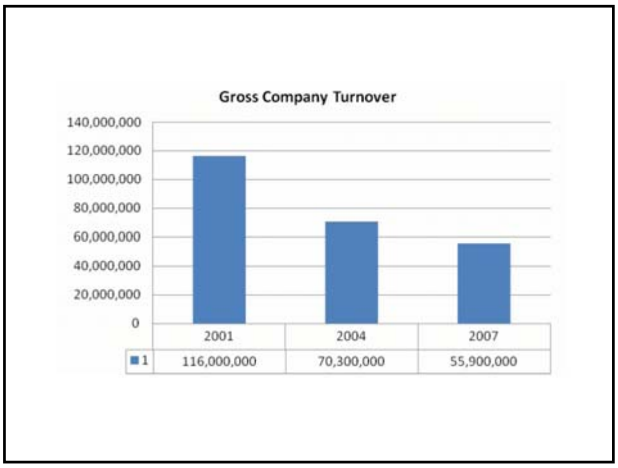


Figure 34 Soil-available phosphorus levels (Colwell test) between 1981 and 2007
Phosphorus (ppm)
1981 1984 1989 1995 1997 1998 1999 2000 2001 2002 2003 2004 2007
Figure 35 Soil potassium levels between 1981 and 2007
Potassium (ppm)
1984 1989 1995 1997 1998 1999 2000 2001 2002 2003 2004 2007

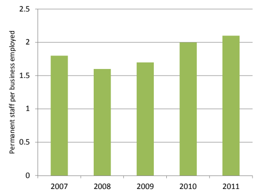

Gross Company Turnover
2001 2004 2007
1 116,000,000 70,300,000 55,900,000

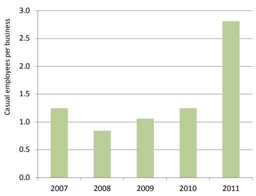
Full time employment

2007 (WRI)		2011 (GHD)
4.8		4.01

Sustainability Reporting

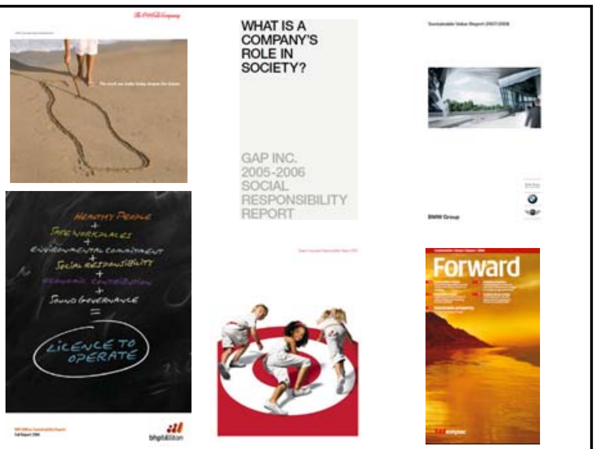
Global Reporting Initiative™





Next

- One stop shop online.
- 10 key indicators
  - (profit, employment, economy, water use, WQ, pesticide use & stewardship, soil, energy, biodiversity, demographics, attitudes, OH&S.)
- Formal stakeholder consultation roundtable
- Produce a social responsibility statement



Economic, Environmental & Social Sustainability Indicators of the Australian Cotton Industry

Dr Guy Roth, Roth Rural & Regional & Cotton Catchment Communities CRC , guy@roth.net.au , 02 6792 5340

Sustainability reporting for agriculture

- Agriculture is spatially the world's biggest industry

- Agricultural industries want to demonstrate that their practices are sustainable.
- The GRI could work with Australian agricultural industries . A sector supplement or case studies would provide global leadership in agricultural sustainability reporting .

Dr Guy Roth, Roth Rural & Regional & Cotton Catchment Communities CRC , guy@roth.net.au , 02 6792 5340

Industries have their data – they need help getting started with GRI

To obtain report
www.cottoncrc.org.au

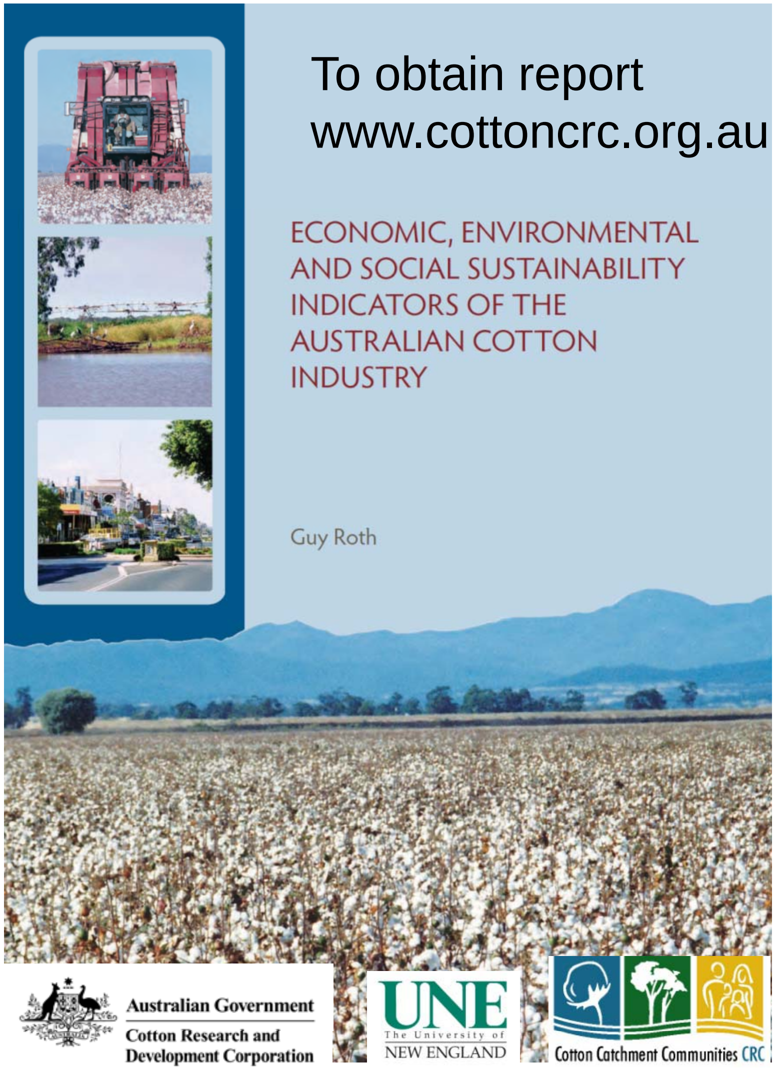


Figure 5 The rise of cotton lint yields 1962–63 to 2008–09 and some related impact factors

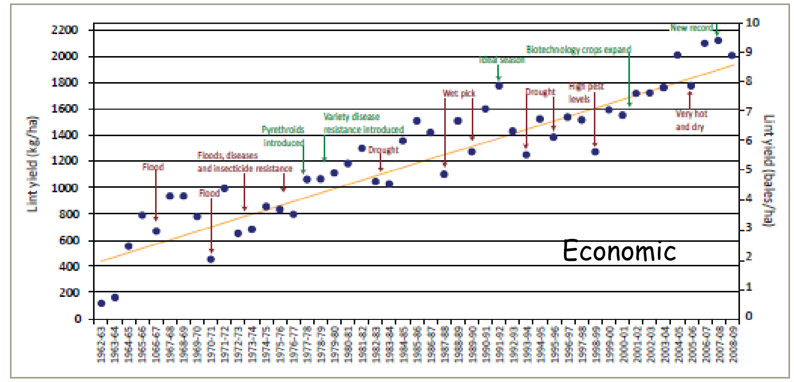


Figure 45 Total endosulfan concentrations in the Namoi Catchment from 1991–1992 to 2006–2007

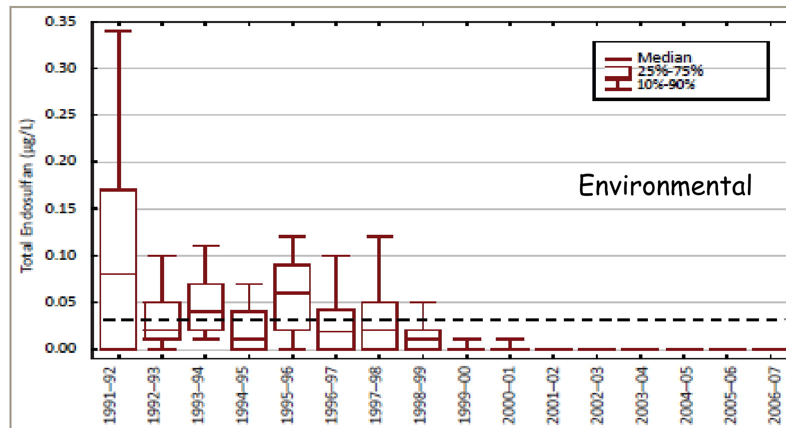
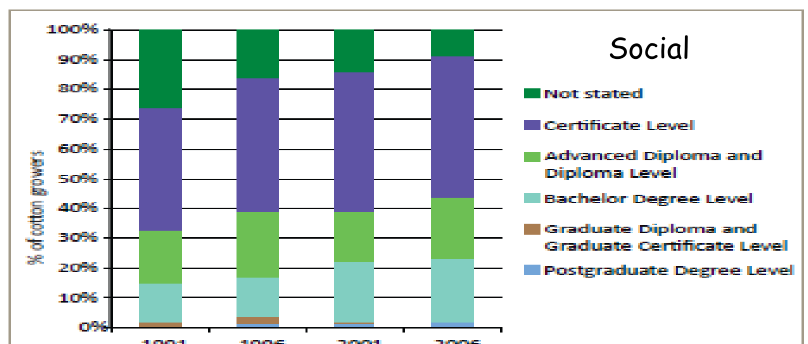


Figure 52 Highest post school qualification for ABS cotton growing classification (0162) 1991–2006



Source: data compiled from cotton growing ABS Classification (0162) from the 1991, 1996, 2001 and 2006 ABS Census

Acknowledgement: Funding
Australian Government
Cotton Research and Development Corporation