Research's contribution to the evolution of the Australian cotton industry

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Abstract

This paper firstly illustrates the considerable changes which have occurred in the Australian cotton production system in the last 25 years. Changes in soil, water, insect, weed and disease management and cultivar development have been dramatic and together have produced a yield increase of 180% with better fibre quality. The change from a system heavily reliant on persistent pesticides and with exploitive soil and water practices to Integrated Crop Management (Pest, Weed, Disease and agronomy) has substantially improved sustainability. The use of crop rotation; development of disease resistant cultivars; and transgenic insect protection have been the three greatest single factors behind progress, although there is a genuine system package where no factor alone can explain the improvement. Research has played a role in all subject areas.

It has been estimated that breeding has contributed 45% to yield improvement, with soil and water management contributing 25%; insect management contributing 20%; and disease management contributing 10%. Performance indicators for improvements in fibre quality, disease resistance, water use efficiency; insecticide use and contamination are specified. Organisation is a feature of the cotton industry, with an overarching Australian Cotton Industry Council being comprised of research and extension bodies, an industry promotion body; seed and chemical retail representatives; and groups representing ginners, classers, shippers, merchants and spinners. Research organisation includes a Cooperative Research Centre which coordinates much of the research and extension activities.

There is not much in common between Australian cotton growers and smallholder farmers in developing countries, except that an organised industry structure helps research and extension of new technology. Farmers need to want to change and they have to be able to afford the change. With these criteria, farmers need help and advice from a familiar person to implement extension messages. All methods of information delivery from face-to-face, to written packages and electronic methods are available.

Media summary

This paper summarises changes in cotton cropping systems in the past 25 years in Australia and specifies which research disciplines have most contributed to those changes. Extension of research is an important component of progress.

Key words

Cotton, soil, water, weeds, insects, disease, yield, fibre quality

Introduction

Cotton seed was first brought to Australia in the first fleet in the late 16^{th} century and small trials were begun as settlement moved north from Sydney. Significant cotton was grown in Queensland during the American Civil War to fill a demand from cotton spinning mills in England at that time. The modern cotton industry started with irrigation development in the Namoi Valley in the early 1960s and was based on a Californian production system. At that time, cotton production was encouraged by the Federal Government to replace imported cotton used by Australian cotton spinning mills. Within 15 years, Australia was a significant cotton exporter and by the year 2000, 95% of production was exported, particularly to Asia (Indonesia, Japan and Korea). Growth in Australian cotton production is shown in Figure 1a illustrating rapid expansion during the 1980s. The improvement in crop yield is shown in Figure 1b.

Approximately 80% of the Australian cotton crop is irrigated from State-regulated irrigation schemes located from inland Central Queensland to Southern NSW. The remaining area is rainfed in production systems which involve rotations with wheat and other cereals or pulses, especially in a belt from inland Northern NSW to the Darling Downs in Qld.

Cotton production systems have gained a reputation for excessive use of pesticide and water and inaccurate reporting in our media reinforces this view. This paper will firstly illustrate changes in management practices in the past 25 years to specify what has been done by research. Exact performance indicators for research contribution to industry performance and industry organisation are detailed. Throughout this paper, where research is specified, it also includes extension, which is considered an essential component of research adoption.

The production system and its dynamics

Soil management

The major soil types used in cotton production systems are grey clays, with heavy grey and brown soils and black earths also being common (Ward 1999). These relatively fertile soils can have clay contents above 50%; have low organic matter and can be sodic at depth. Research and grower experience quickly showed the benefits of crop rotation (mostly with wheat) and minimum tillage (Hearn 1986; Constable et al 1992). By 1992, the average rotation was two years cotton followed by one year of wheat (Cooper 1999).

These changes in soil management have ameliorated compacted soils or maintained new soils in good physical, chemical and biological condition. Soil structure has benefited from rotation with wheat, due to drying with a good fibrous root system and also from the nine month fallow between harvest of a wheat crop and sowing of a following cotton crop (Chan and Hodgson 1981; Daniells 1989; McGarry 1990). Nitrogen fertility benefits have occurred with mineralization during the same fallow (Hearn 1986; Rochester et al 1991). A wheat fallow has also been shown to be a good verticillium wilt disease break (El-Zik 1985).

Fertilizer programs have kept up with depletion of nutrients from continued cropping of high-yielding crops (Constable and Rochester 1988; Constable et al 1992; Rochester et al 2000a; 2000b) from what had been a simple nitrogen fertilizer program in the 1960s. Current research and grower practice now include potassium and phosphorus fertilizer programs. Heavy soil types and irrigation licence conditions maintain runoff on farm that retain fertilizer in the profile and on farm respectively, rather than contamination of waterways or ground water.

Soil management, particularly the use of crop rotations, has been a key element of yield progress in the cotton industry. Future farming systems issues include weed resistance management for herbicide tolerant crops and a better understanding of management of sodic subsoils.

Water management

High-yielding cotton crops require sufficient water to maintain growth of the crop and its fibre. The main cotton production area, despite being supported with irrigation schemes, is regularly affected by drought. Large dips in national production in Figure 1a are associated with droughts when irrigation schemes have reduced allocation; even zero irrigation in many cases. Research on irrigation scheduling began in the 1970s to develop management strategies during drought and this work was able to define critical crop growth stages and especially address strategic management to maximise water use efficiency (Constable and Hearn 1981; Hearn and Constable 1984) and reduce waterlogging (Hodgson and Chan 1982). Water reform will most likely reduce irrigation allocations, so irrigation system design and irrigation scheduling will be challenges for the future.

The crop being valuable economically also encourages efficient water use and available data shows Australian cotton production systems are amongst the most water efficient in the world (Hearn 1994a). There are opportunities to improve irrigation design to prevent channel distribution losses in some instances (Cull 1981; Hodgson et al 1990; Constable and Hodgson 1990; Tennakoon and Milroy 2003).

The crop rotation and tillage advances mentioned earlier have benefits for farm water use efficiency: rotations allow more opportunity to store rainfall in the soil profile and better soil structure improves the ability of plant roots to explore the profile (Constable et al 1992).

Integrated Weed Management
The flood plains now used for cotton production have high incidence of weeds, especially where there is history of pastoral land use (Charles 1991). These weeds have direct effect on cotton production from competition, but some weeds are also disease and insect pest hosts, so growers have low weed control thresholds. Cotton in Australia has a genuine IWM system with a range of weed control practices including crop rotation, tillage, chemical and even hand weeding as components (Charles 1991). Since 2000, Monsanto's Roundup Ready cotton has been adopted enthusiastically because farmers appreciate the flexibility. Glyphosate has replaced some prophylactic residual herbicides under low weed incidence (Taylor et al, 2003). Possible benefits to soil structure and moisture retention have been obtained from the reduced tillage, but weed resistance management will play an increasing role in weed management.

Integrated Pest Management
Cotton is attractive to a number of insect pests and many of those pests are numerous and endemic to Australia (Evenson and Basinski 1973; Hearn and Fitt 1992). This is a potentially disastrous combination and pest management in Australian cotton has been the largest challenge – research on IPM has consumed up to 60% of the research budget in some years. Pesticide contamination of water and livestock and resistance by major pests to common insecticides has occurred (Forrester et al 1993). Adoption of IPM has been slow, but with the release of transgenic cotton in 1996, in combination with other advances in pest management and information transfer, the use of insecticides on Australian cotton continues to drop (Wilson et al 2004).

IPM research developed a better understanding of damage thresholds; plant compensation for damage; sampling procedures; encouragement of beneficials; and destruction of over wintering pupae. Conventional breeding introduced some host plant resistance with traits such as leaf shape (Thomson 1987; 1994), but Monsanto's single Bt gene (Ingard®) transgenic cotton has enabled a 50% reduction of insecticide since 1996 (results from industry surveys) and the new-generation two Bt gene Bollgard II ® is expected to further reduce insecticide by another 50% after 2003. Future research needs include better understanding and management of what were minor pests previously controlled in conventional systems and now remaining in Bollgard II crops.

The pre-emptive resistance management strategy driven by research (Fitt 2003) will ensure Bt technology is viable for many years. Sustainability is improved in comparison with 25 years ago as there is far less use of insecticides – and the ones used are more selective and less disruptive of IPM systems.

Integrated Disease management
As with weeds and insects, many cotton diseases are endemic to Australia (Evenson and Basinski 1973), with a broad host range on weed species. Disease such as Bacterial blight (*Xanthomonas axonopodis*) and Verticillium wilt (*Verticillium dahliae*) were major production constraints in the 1970s and 1980s. Conventional breeding has eliminated bacterial blight (Allen 1986) and dramatically reduced the severity of verticillium (Reid et al 1999; Nehl et al 2003). Other diseases such as Seedling Disease Complex, Boll Rots (Nehl et al 2003) and Cotton Bunchy Top (Reddall et al 2004) are important, but not major. As mentioned earlier, crop rotations assist with reduction of some diseases.

In recent years a new strain of fusarium wilt (*Fusarium oxysporum vasinfectum*) has emerged (Kochman 1995) and is a potential major problem. Some resistance has been found from conventional breeding, but not sufficient to enable production under situations of heavy disease incidence. Research continues on discovery of better sources of resistance. Pathology research has identified weed and rotation crop hosts to enable development of cropping systems to minimise spread of Fusarium.

Conventional breeding has played a major role in minimising damage from disease and some of the yield progress from breeding can be attributed to this factor.

Performance indicators for the contribution of R&D to industry performance

Yield

CSIRO have replicated experiments in all cotton producing regions every year (Reid et al 1989). These experiments include old control cultivars which had been grown in the 1970s. This data can be used to estimate progress with new cultivars and Constable et al (2001) calculated an annual yield increase of 1.8% in Australia due to conventional breeding. Similar calculations in the US with cotton have shown no increase for the past 20 years (Meredith and Bridge 1984; Meredith 1991) – a dramatic comparison.

Yield progress is a direct production performance indicator. A recent economic assessment of cotton breeding in Australia found the net present value of that program to be $4.9b and with a benefit: cost ratio of 86 (CIE 2002).

Fibre quality

Since Australia grows cotton primarily for export, the quality of that fibre is important to ensure demand from international spinners. Conventional breeding has addressed spinners requirements and long term data referred to above shows progress also in improving fibre length, fibre strength and fibre maturity (Constable et al 2001). Changes in spinning technology will require further improvements in fibre quality – from breeding, management and in processing.

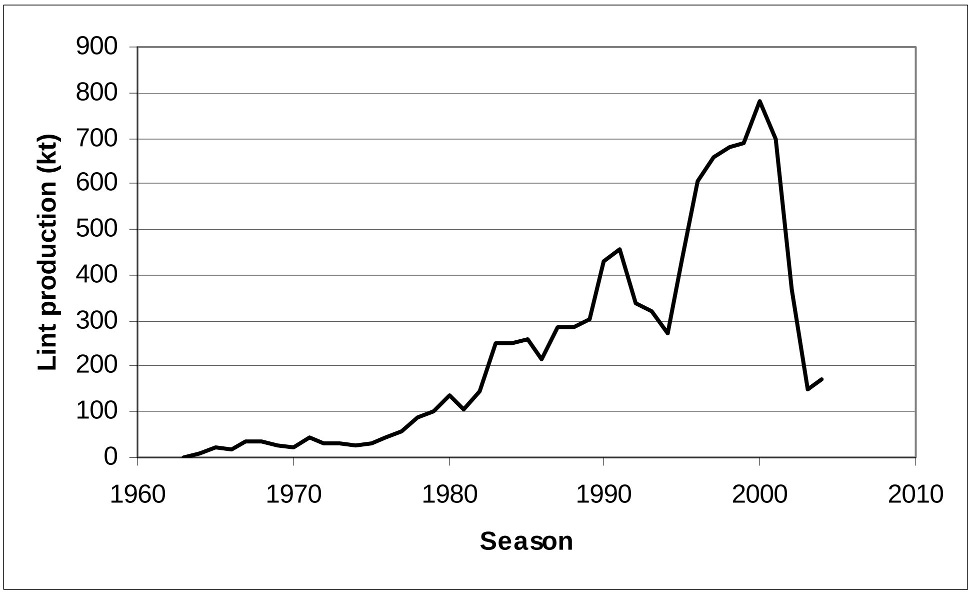
Other

- Verticillium wilt grew in importance through the 1970s and 1980s as a disease affecting yield and susceptible cultivars contributed to that increase. With release of resistant cultivars in the late 1980s, the incidence of verticillium wilt in cotton fields reduced from 16% in 1989 to 5% in 1995 (Nehl et al 2003). The resistant cultivar also yielded more (Reid, unpublished) and that increase is a component of industry yield trends shown in Figure 1b.
- Fusarium wilt was discovered in south Queensland in the early 1990s (Kochman 1995) and most cultivars available at that time were susceptible. With continued release and adoption of more resistant cultivars, the relative Fusarium resistance level of common cultivars doubled between 1994 and 2003 (Reid, unpublished).
- Water use efficiency. Two detailed water balance comparisons have been made which show that water use efficiency (yield per unit of evapotranspiration) has doubled between 1979 and 2002 (Cull 1981; Tennakoon and Milroy 2003). The major component of this change has been in yield (Figure 1b); in other words, the same amount of water is being used to achieve substantially higher yield.
- Insecticide use. Adoption of more sustainable insect management practices has been slow but gradual and total insecticide use on cotton has decreased from 11 kg ai/ha in conventional cotton and 7 kg ai/ha in transgenic in 1998 to 2 and 1 kg ai/ha respectively in 2002 (Wilson et al 2004). Research on IPM and legislation on changing registration of pesticides and on conditions for use of them have all been important steps.
- Contamination of rivers by insecticides. As a consequence of reduced input, measured contamination of the Namoi River with endosulfan by the Department of Land and Water Conservation for example has reduced from 0.07 ug/l in 1991 to 0.002 ug/l in 2000.

Research disciplines contributing to progress

For yield progress shown in Figure 1b, it is difficult to accurately attribute all factors improving yield. The contribution of cultivar development can be estimated from data comparing the yield of 1970s cultivars when grown in modern systems. That analysis shows that new cultivars have contributed 45% of the yield increase (Constable et al 2001). The other 55% has come from management and Constable (2000) has proportioned this remainder into 25% for soil and irrigation management; 20% from insect management; and 10% for disease management.

However, progress has obviously come through the <u>combination</u> of a number of components, none of which on their own would necessarily contribute a large amount to improve yield or gross margin. For example, there would be little point in having a new cultivar with 10% potential yield increase if it was susceptible to disease.



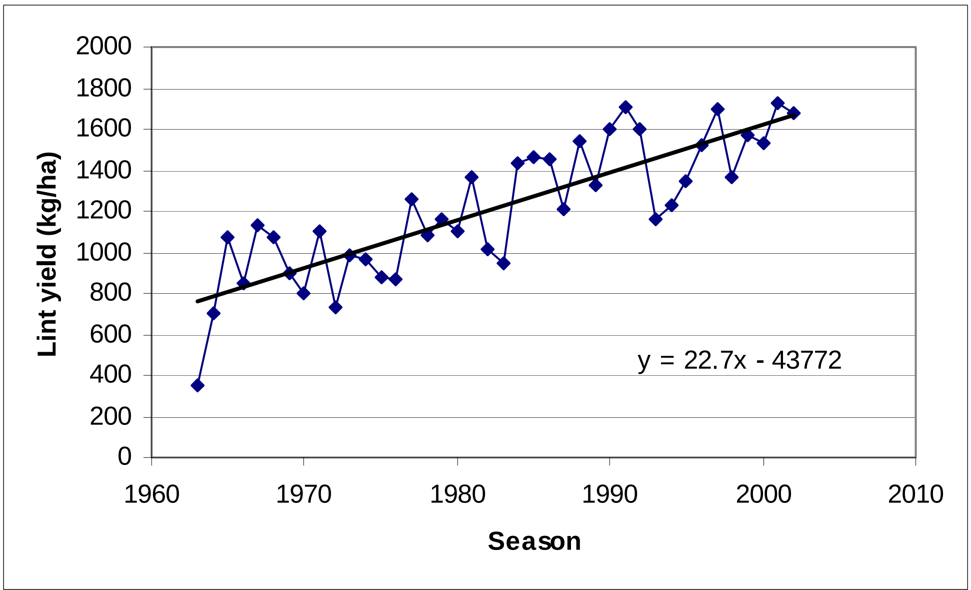


Figure 1. Production of cotton in Australia since 1960 (a) and lint yields (b) over the same time.

How R&D addresses industry crises

Organisation in the industry has facilitated discussion and action to address challenges. Where those challenges involve research, the main bodies involved are the Australian Cotton Growers Research Association (ACGRA), Cotton Research and Development Corporation (CRDC) and Australian Cotton Cooperative Research Centre (CRC – a coordinating body for much of the cotton research and extension of Government agencies and Universities). For longer term project areas, research organisations undertake the research with funding from CRDC and with consultation to ACGRA in working parties to plan and assess progress. Some issues require promotion and that is done by CRDC and Cotton Australia.

Mechanisms of new technology delivery

Delivery of research information and cotton grower adoption of new practices have been important components of progress in Australian cotton industry. The location of CRDC in a regional area central to cotton production is evidence of commitment to close involvement with industry.

Australian cotton growers continually seek new ideas and solutions to production challenges. Grower “suck” is an important component of extension: growers are proactive in seeking advice and on suggesting new ideas and approaches to research and extension.

Research and extension is a continuum in Australian cotton, with research scientists being actively involved in extension, while regional extension staff are also active in local research issues. This overlap assists with research extension coordination. Through time State extension staff in each region have become specialised as cotton Industry Development Officers (IDO), with coordinated extension activities and extension focus teams under the Cotton CRC.

Private industry also plays a significant role in extension through involvement of professional consultants or corporate agronomists on large cotton farms. Commercial bodies are also involved in research and extension, especially retail chemical suppliers in evaluating and promoting new products.

Growers prefer a range of extension delivery methods, so all methods of delivery are used, including face-to-face contact between extension personnel and growers, but written material (either as hard copy or on the web) and computer packages have been developed.

- Written packages as comprehensive detail of all information as reference material for cotton growers include SOILpak (McKenzie 1998), ENTOpak, NUTRIpak and WATERpak for soil, insect pest, crop nutrition and irrigation management respectively.
- Computer decision support programs are provided to assist with complex decisions. The CottonLOGIC (Hearn and Bange 2002) suite of EntomoLOGIC, NutriLOGIC and HydroLOGIC are aimed at assisting management of insect pests, fertilizer programs and irrigation scheduling respectively. CSIRO's cotton crop simulation model, OZCOT (Hearn 1994b), is an integral component of some decision support packages, especially for examining long term rainfall data for irrigation strategies research. Some of these programs are available on hand-held devices to enable rapid data entry and recording.

The regulatory process has contributed to change in attitudes and practices by cotton growers. Water reform has reduced irrigation allocation in some areas, reducing production in all cases, but also stimulating careful attention to irrigation strategies aimed at maximising water use efficiency. Pesticide registration changes have modified application conditions on some chemicals and removed use of other chemicals altogether. Fines by State regulatory bodies for non-compliance on conditions such as pesticide drift have also ensured awareness of reduced off-site impact of chemicals.

Development of new cotton cultivars is also a method of delivery of new science. Obvious examples would be transgenic traits for insect and herbicide resistance where dramatic changes in pesticide use have occurred. Cultivars with disease resistance, improved fibre properties or yield potential also deliver the results of research.

Adoption rates are not consistent across issues. For example, grower adoption of IPM has been slow because of a lack of confidence in aspects of predator effectiveness and plant compensation for insect damage. Many factors have being involved in changed attitudes and practices, including new products and regulatory restrictions. At the other extreme, adoption of new cultivars is almost instantaneous. The cotton grower needs to integrate all information with the incentive of both sustainability and profit for their agribusiness.

How research community has influence in the industry

Research and extension personnel are participants in a number of bodies such as the Cotton CRC and in some grower committees such as those deliberating insect and weed resistance management strategies. Tradition has been to ensure good resources to a central research institute, so that an appropriate proportion of research is field based and focussed on industry challenges.

Industry organisation is a feature of Australian cotton. The original two organisations were the ACGRA, initiated to liaise with research organisations and to lobby for research and Australian Cotton Foundation (now Cotton Australia), which is responsible for cotton industry promotion and public relations. Cotton growers through ACGRA were levying themselves for research in the 1970s, even before the Federal Government Cotton Research Council was established and which has evolved to the CRDC.

In more recent times, a peak body, the Australian Cotton Industry Council (ACIC) has been established to draw together all segments of the industry. Members of ACIC are: ACGRA, CRDC and Cotton CRC as research and extension bodies; Cotton Australia; seed and chemical retail representatives; and groups representing ginners, classers, shippers, merchants and spinners.

Lessons for other industries worldwide
Agriculture in Australia has a relatively unique combination of economic, technical, sociological and climatic factors as well as scale. That is especially so for our cotton production system (Anon 1992) and our circumstances and constraints do not allow for exact extrapolation to any other country. However there are principles to apply as lessons for other situations: for example, people learn from one-another and learn by mistakes. Research - extension organisation and focus are also possible in any society. Continuity of staff is important, as experience is essential for understanding and communicating complex systems.

Cotton farming in Australia is a professional agribusiness and is relatively young in comparison with our traditional rural industries. Although not all growers like the intensity, cotton farming is advanced, intensive (Hearn and Fitt 1992), interesting and profitable (Anon 1992). The industry structure has grown to meet challenges with appropriate action. Innovation has been rewarded with improved gross margins and that incentive continually attracts new farmers and agribusinesses with new ideas.

There may not be much in common in that list with smallholder farmers in developing countries, except that an organised industry structure helps everyone learn. Successful farmers inspire others to follow. Farmers in any country need to want to change and they have to be able to afford the change. With these criteria, farmers need help and advice from a familiar person to implement extension messages.

Conclusions
Crop rotation and disease resistance have been key elements to yield progress and an IPM package containing transgenic cultivars is the major factor reducing reliance on insecticides. The changes illustrated in this paper have demonstrated the Australian cotton industry is more sustainable than it was. Research has played a significant role in these changes. Water reform will bring more changes to the industry, mainly from reduced water supplies, as water use efficiency is already high by world standards. Industry organisation is complete and enables good discussion of challenges and opportunities as well as timely action.

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