Evolution and future research needs for progressing Australian cotton systems

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Abstract

This paper summarises the challenges and important lessons for management since inception of the modern Australian cotton industry (1960's onwards) and presents opportunities to progress yield and resource use efficiencies into the future. Early challenges faced in the industry included insects and weeds, genotypic adaptation, soil constraints, and water and nutritional challenges; with some of these challenges still important today. In facing these challenges yield improvement has been achieved through integrated management approaches that have included Genetic (G) x Environment (E) x Management (M) concepts. Integrated management will still be needed to face challenges associated with a variable and changing climate to maintain yield improvement, and meeting needs to improve water and nutrition efficiencies.

Keywords

yield improvement, Genetics, Environment, Integrated, Management

Introduction

The Australian cotton industry has evolved from low yielding rainfed systems to be Australia's fourth biggest exporter, achieving some of the highest yielding crops worldwide (Fig. 1a, typical Australian yields are 2200 kg/ha irrigated and 500 kg/ha dryland. Brazil has yields about 1700 kg/ha, USA 1000 kg/ha, with global average of 800 kg/ha). Success of the industry has resulted from significant investment in integrated cotton management addressing all aspects of the production across the whole value chain. The paper forms two parts: (1) A brief history of the modern Australian cotton industry challenges with examples of research efforts that demonstrate success through an integrated approach utilising Genetic (G) x Environment (E) x Management (M) considerations; and (2) future research needs.

Part 1. Brief history of research progress so far (1960-2021)

Agronomy

It became evident in the early years of modern irrigated cotton production in Australia that the heavy clay soils were prone to compaction from traffic unless soil was dry. Considerable research and extension efforts provided options for maintaining soil structure through crop rotation and careful assessment of soil moisture before cultivation. Today similar concerns remain as significant soil compaction is caused by heavy cotton pickers that have on-board module-building capabilities. These pickers have the potential to increase compaction in the sub-soil, limiting efficiencies in both water and nutrition. Growers using these pickers will need to consider strategies to: ameliorate compaction using crop rotations that dry the soil profile; further implement controlled traffic systems; and seek to reduce moisture in the profile at picking.

Irrigation scheduling of cotton in Australia has been revised over the last 50 years and improved water use efficiency (WUE) has been obtained (Constable and Bange 2005), although there are ongoing community concerns relating to water use / and growers' concerns on irrigation supplies. Reviews of cotton WUE have highlighted significant opportunities to further improve WUE at farm levels. These analyses have shown that irrigated cotton farms incurred significant losses through conveyance, storage and application of water, or improper scheduling. Due to cotton's indeterminate perennial nature, excess water and nutrients can also favour vegetative growth at the expense of fruit retention. This will delay maturity, and likely reduce yield and quality. Thus, the crop requires constant monitoring and management to ensure a balance between vegetative and reproductive growth.

Plant Breeding

From a breeding perspective progress in yield has come from addressing major biotic challenges associated with insect pests (particularly *Helicoverpa* spp.) and diseases such as Bacterial Blight (*Xanthomonas campestris* pv malvacearum), Verticillium Wilt (*Verticillium dahliae*) and Fusarium Wilt (*Fusarium oxysporum* f. sp. vasinfectum). An early success was the cultivar Siokra 1-4 in 1980, which has the okra leaf trait and is resistant to Bacterial Blight. It was particularly popular in dryland cotton systems, but the reduced leaf area with okra leaf restricted yield under ideal conditions. Subsequent cultivar releases with normal leaf shape and improved resistance to Verticillium and Fusarium have dominated planted area. Major concentration on yield components such as lint percentage (a component of harvest index) has continued yield improvement in recent times, although emphasis on these components has become challenging (e.g. small seed size has created some crop establishment issues in subsequent crops) (Conaty and Constable 2020). This has required an increased emphasis in recent years on more precise planting operation to avoid poor establishment. It is also worth noting that improvement in fibre quality became important for breeding to meet the properties required by spinners. All Australian raw cotton is now exported and for it to remain so, high quality is important.

Under original agreements with Monsanto (USA), CSIRO began to introduce the Bacillus thuringiensis (Bt) trait into CSIRO cultivars by backcrossing. Commercial release began in 1996 with limited area as part of the important resistant management program. As additional Bt genes were included, the crop area increased (now three Bt genes and 99% adoption). There is now a substantial reduction (85%) in pesticide use (Wilson et al. 2018). The growth habit of Bt cotton cultivars is different to non-Bt cultivars because there is now little fruit loss from insect damage, resulting in higher and earlier carbohydrate and nitrogen demand by the fruit. Yields can be reduced if management does not meet internal assimilate demands. Despite cotton being an indeterminate species, high fruit retention can restrict vegetative growth, so Bt cultivars need to be a later maturing growth habit. The breeding program developed more indeterminate cultivars.

Pest management

Ineffective pest control of a range of insect (especially *Helicoverpa* spp.) and mite pests results in significant yield losses. During the 1970's to 1990's, pest management was the major focus for cotton research as Australian cropping systems which relied on intervention with chemical pesticides - a major component of the cost of production and also gave rise to significant pesticide resistance in key pests and environmental concerns about pesticide movement off-farm (Wilson et al. 2018). Emphasis was on integrated pest management where regular scouting, use of beneficial insects, rotation of chemicals, and appropriate agronomy (e.g. choice of cultivar, nutrition management) to suit the region and maintain plant health. The germplasm containing Bt genes reduced pesticide use for the control of major Lepidopteran pests (particularly *Helicoverpa* spp.). However, as the system was changing, pests formerly suppressed by pesticide were emerging as new challenges.

GxExM in Australian Cotton Systems

There are few studies in cotton that have demonstrated the value of GxExM to improve cotton productivity, although analyses by Liu et al. (2013), using advanced line trials containing cultivars grown over a 30-year period from 1982 to 2009, demonstrated that yield gain in the Australian cotton industry resulted from improvement in cultivars (G; 48% improvement), in crop management (M; 28% improvement), and from the interaction between improved cultivars and improved management (G x M; 24% improvement) (Fig. 1b). The magnitude of GxM interaction varied with region. Overall, best management is required to achieve performance benefits from new high-yielding cultivars in any region. Many of the successes in agronomy, pest management and breeding described above have contributed to yield improvement. Adopting directed successful research across the whole value chain was facilitated by the establishment of the Australian Cotton Research Institute in Narrabri NSW, involving both CSIRO and NSW DPI from 1972, and three Cotton Cooperative Research Centres from 1996 to 2008.

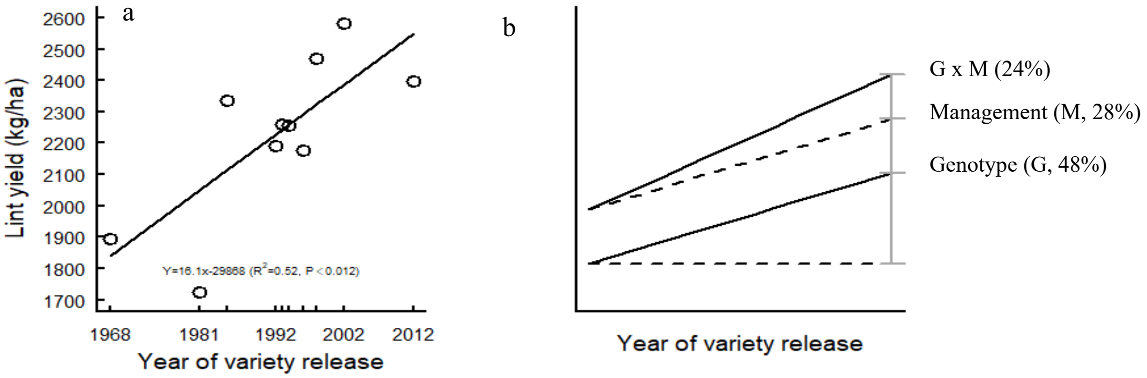

Figure 1: Lint yield gain due to the release of new genotypes, improved management and genotype × management interaction. a: estimated by new release from 1968 to 2012 (Adapted from Conaty & Constable 2020); b: estimated by new release from 1985 to 1998. The bottom and top solid lines represent the regression for the early and late 15-year periods, respectively (Adapted from Liu et al. 2013).

In the above study in GxExM it is important to note that this did not include genotypes that included the Bt traits mentioned previously. One of the consequences of the release of these traits is that there is now less emphasis and time needed to manage insect pests leaving more scope to invest in research to exploit GxExM. Research showed that crops with higher fruit retention can maintain yield for delayed planting dates in warmer and longer seasons. In these studies, yield was maintained for plantings up to 20 days later than the normal planting date as early growth was more rapid when crops were planted into warmer temperatures (Bange et al. 2008). In addition, improvements in fibre length and optimisation in micronaire, contributed to improved fibre quality. From a resource use perspective, Braunack et al. (2012) was also able to show WUE could be improved with later planting with Bt cultivars.

Part 2. Future research needs

We contend that strategies to improve Australian cotton production and sustainability will continue to require integrated systems research over a wide range of environments (including future climates) and stresses, to assess impacts and adaptation options for yield and quality improvements. One of the most significant challenge for irrigated cotton is climate change as it is multifaceted and complex, and it will affect the sustainability of farms, ecosystems and the wider community. Because elevated CO_2 can mitigate many of the negative impacts of environmental stresses on plants, one promising course of action would be to breed cotton cultivars that are highly responsive to elevated CO_2. Broughton et al. (2017) suggested that breeding efforts have not yet exploited that variation. Future climate, however, may also present challenges associated with increasing canopy photosynthesis, especially for high input crops in elevated CO_2 with warmer temperatures. It may encourage excessive vegetative growth causing fruit shedding and increasing transpiration therefore lowering WUE, despite the improvements in leaf photosynthesis. Furthermore, molecular biology should target photosynthetic capacity to increase canopy radiation use efficiency especially in stressed situations. Conaty and Constable (2020) recently documented that lint yield improvement over the past few decades in Australia was associated with increases in harvest index and biomass; however, there was some evidence that yield was negatively associated with canopy radiation interception adding to the complication in improving yield improvement. Frameworks that scale from leaf to canopy photosynthesis are needed to address this complexity and considerations on how to resolve these issues are necessary for breeding and management combined (Bange et al. 2016).

For Australian cotton breeders, delivering high yielding cultivars to cotton growers is still essential to maintain economic viability. Along with traditional approaches to breeding, future breeding efforts will need to rely on both high-throughput genotyping and phenotyping approaches for trait selection. Specific tolerances for heat and water stress in rain-fed environments have been recorded despite no specific selection pressure on these stresses. Recently, genetic variability of transpiration rates to vapour pressure deficits (VPD) and sodicity tolerance have been identified.

Access to water through reductions in sources of irrigation, less rainfall or increases in evapotranspiration remains a significant challenge. Increased yields so far have been largely obtained by more rapid fruit setting. Well-managed, insect resistant crops have near optimal retention and fruit set, so further increases in yield will require a longer crop duration but maintaining a functioning canopy for longer would require more water. Considerable research has been undertaken in well-watered conditions, and less research has considered the implications of cotton growth, yield and fibre quality with less water availability. Australian systems will require closer examination of the response to various water deficits and drought recovery cycles.

Constable and Bange (2015) identified nutrition as a major limitation for yield improvement going forward. There is a wide diversity of nutritional management approaches used in cotton systems, a large diversity in soil types and regions, and proven diversity between cultivars in nutrient use efficiency (Rochester and Constable 2015). Consequently, we believe that improving yield through enhanced nutritional management, and better matching genotypes to different cropping environments, represent a key opportunity in GxExM research. A greater understanding of nutrient uptake and its timing, distribution, and redistribution in relation to cotton fruiting dynamics is required to develop strategies which would result in consistently high yields.

Given the importance of high fibre quality to Australian industry's share in international markets it is also imperative that it retains focus on further improving fibre quality. The task for the industry is to optimise fibre quality in all steps from strategic farm plans, cultivar choice, crop management, harvesting and ginning. Bange et al. (2018) have termed this 'Integrated Fibre Management' to emphasise the importance of a balanced approach across the whole value chain.

Conclusion

This paper has highlighted success in the Australian cotton industry resulting from integrated crop management which have resulted in yield improvements. Future challenges continue to need these approaches, and research approaches will need challenged to exploit GxExM rather than let it happen serendipitously.

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