High insect protection of GM Bt cotton changes crop morphology and response to water compared to non Bt cotton.

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Abstract

Cotton is the broad acre crop with the longest history of production of GM cultivars in Australia (14 years). Bt cotton with two genes to control lepidopteran pests (Bollgard II?) has accounted for > 85% of cotton grown in Australia since its release in 2005 and can give superior insect control to sprayed non-Bt cotton. We measured the effect of this increased insect protection on morphology, growth and response to water using Bollgard II and non-Bt cultivars with the same genetic background. Where insect damage to the non-Bt cultivar was moderate to high, plants had multiple branching, increased leaf area and low fruit retention compared with Bollgard II plants, which for the Bollgard II cultivar, translated into earlier maturity, 10% lower seasonal water use and at least equivalent yield. Where insect damage to both cultivars was low, varietal differences in WUE were minimal, or favoured the non-Bt cultivar where terminal damage occurred. However, due to a higher, earlier boll load, Bollgard II was more sensitive to water stress late in flowering, extraction of ~60% of plant available water reduced yields 36%, compared with 17% in the non-Bt cultivar. Scheduling experiments showed that irrigating at smaller deficits than commonly used for cotton increased Bollgard II yield by 17% and WUE by 8% when conditions were hot and dry during flowering. Irrigating in response to plant/climate measures of water stress should improve the efficiency of irrigation water use. This research demonstrated the benefits of research to evaluate production issues beyond that intended by the GM itself.

Key Words

Water Use Efficiency, Bt-Cotton,

Introduction

Two gene Bt cotton cultivars (Bollgard II) were released in 2003 primarily to control *Helicoverpa* spp., which are the major cotton pest in Australia. This technology has provided season long control of *Helicoverpa* spp. and has reduced pesticide use by > 80% and the environmental impact quotient of the insecticides applied by > 64% (Pyke 2008; Knox et al. 2006). Previously insects were managed using insecticides with thresholds used to trigger insecticide treatment (Dillon and Fitt 1995). Because pests need to be present prior to spraying and weather conditions can prevent timely insecticide treatment, some damage to bolls was tolerated so yield compensation on later flowering bolls was incorporated into damage thresholds (Lei and Gaff 2003, Wilson et al. 2003).

Due to the high efficacy of Bollgard II cultivars, fruit retention was observed to be far higher than for non-Bt cultivars exposed to similar insect numbers (i.e. adjacent fields). Such high levels of retention and the subsequent early development of the fruit load may restrict plant development and yield potential. In particular, there was concern that high retention and resultant priority of assimilate to these bolls may make the plant more susceptible to moisture stress and limit maximum potential yield through early termination of flowering (cut-out) or reduced root growth.

The growth response of lower fruit retention conventional cotton is well documented (Hearn 1995). Abundant water combined with high rates of nitrogen fertiliser will stimulate vegetative growth, particularly leaves, at the expense of fruit, which is often shed. Therefore, at intermediate water and nutrient availability, vegetative and fruit growth is balanced. Below this optimum, nutrient and or moisture stress may reduce fruit production. Hence, in south-eastern Australia scheduling furrow irrigation after 40 to 60 % of plant available moisture is removed from the soil has been shown to be optimal for non-Bt cultivars on grey vertosols (Constable and Hearn 1981; Cull et al. 1981). However Australian yields have doubled since this research was conducted and the higher boll retention of Bollgard II would mean that to achieve similar yields to non-Bt cotton, a greater rate of yield accumulation was required. It is not known to what extent the higher yield potential and fruit retention will change the response of cotton to soil water deficit and evaporative demand.

Summarised here are experiments that aimed to: i) quantify the changes to morphology of Bollgard II compared with non-Bt cotton due to increased insect protection, ii) measure the sensitivity to water stress of Bollgard II cotton due to higher early boll load, iii) evaluate alternative irrigation scheduling strategies for high yielding Bollgard II cotton.

Methods

The irrigation water requirement and sensitivity to moisture stress of Bollard II compared with non-Bt cotton

Three replicated experiments were conducted, using furrow irrigation at ACRI, Myall Vale, NSW, in 2004/5, 2005/6 and 2006/7. The Bollgard II and non-Bt were compared using the same Sicot 71 background. Irrigation was scheduled at extraction of 40% of plant available water content (PAWC) of the soil or an 80mm deficit for a soil with 200mm of available water. Plots were length of field (650m) and 24 m (rows) wide, with all data and yields collected from the centre 4 rows. Water stress was applied by at first flower, cut-out (last effective flower) by skipping irrigation at each growth stage. Soil water was measured using a neutron probe. The volume of irrigation applied and tail water run off was measured in each plot using odyssey probes in the channel and rotorbuck and in flumes in two furrows 20m from the tail drain.

The response of Bollgard II to irrigation at different deficits

Bollgard II cotton was grown in a replicated experiment in each of 3 seasons from 2006/7 to 2008/9 at ACRI, using furrow irrigation. Compared were four irrigation deficits 40, 60, 80 and 120 mm which equates to 20, 30, 40 and 60% of PAWC (plant available water content) for a soil with approximately 200mm of plant available water. Plot size was length of the field by 20 rows.

Results

The irrigation water requirement and sensitivity to moisture stress of Bollard II compared with non-Bt cotton

Table 1 shows the morphological differences between the Bollgard II and non-Bt cotton. Prior to flowering caterpillar pests tipped the main stem on the non-Bt cultivar 6 to 20 times more frequently than in Bollgard II. Fruit retention was also significantly reduced by these pests in the non-Bt cultivar. The effect of this damage was to delay time to maturity and increase leaf area of the non-Bt cultivar, which, in turn, increased crop water use (Table 2). An additional irrigation was required on the non-Bt cultivar in 2004/5. The lint yields varied between seasons and the average lint yield was similar for Bollgard II and non-Bt cultivar respectively.

Table 1. Changes in plant morphology and insecticide usage due to the greater protection from *Helicoverpa* spp. of Bt cotton. Where * = significantly different (p<0.05). NB insecticide applications are for the whole treatment and were not replicated.

	2004/5	2005/6	2006/7

	Bollgard II	Non-Bt	Bollgard II	Non-Bt	Bollgard II	Non-Bt
Insecticide applications	3	7	3	11	2	8
Main-stem tipping (%)	9	59*	3	62*	6	45*
Maximum LAI	2.1	3.1*	2.5	3.7*	2.2	2.9*
Fruit retention (%)	86*	70	86*	60	89*	80
Maturity (das)	173	196*	176	179*	171	177*

Table 3 summarises the percentage yield reductions due to water stress commencing at first flower and at cut-out (last effective flower) and continuing for 13 days, after which water was applied. Bollgard II was more sensitive to stress than conventional at cut-out. The lint yield reduction at cut-out equates to a loss of 2.7% per day of stress compared to 1.2% per day for the non-Bt cultivar. Interestingly, the percent yield reduction per day of stress for the non-Bt cultivar has not changed since the 1970's (Constable and Hearn 1981). The greater sensitivity to stress late in flowering was due higher fruit retention early in flowering creating to a much higher boll demand for assimilate at the time of stress in the Bollgard II cultivar. The non-Bt cultivar could compensate because it had a greater proportion of smaller bolls that were filled after the water stress was removed. This was an important finding at a time when growers were still adapting irrigation strategies for high retention Bollgard II cultivars and when drought necessitated stretching of irrigation intervals. Hence the message to avoid stress of Bollgard II cultivars during flowering or grow non-Bt cultivars instead was widely extended to industry.

Table 2: Total irrigation water applied (ML/ha).

Season	Bollgard II	Non-Bt
2004 / 2005	6.9	7.8
2005 / 2006	5.7	6.1
2006 / 2007	6.3	6.5
Average	6.3	6.8

Table 3: Yield loss due to water stress (extraction of > 60% plant available water)

Growth Stage of Bollgard II	Average % yield loss compared to full irrigation 2005 to 2007

	Bollgard II	Non-Bt
1st Flower	23%	23%
Cutout	36%	17%

The response of Bollgard II to irrigation at different deficits

As expected the crop response to irrigation deficit was affected by seasonal conditions. The 2006/7 season was hotter and drier than average, particularly during flowering and boll filling (December to March), which was reflected in the highest ETo during this period. 2007/8 was the most favourable for cotton growth, receiving above average rainfall for November to March and maximum temperature near the 30^{o}C optimal for the flowering period. The 2008/9 season was hot and dry in the flowering period of January and early February but wetter up to early flowering. Seasonal ETo was 955mm, 799mm and 860mm for 2006/7, 2007/8 and 2008/9 respectively.

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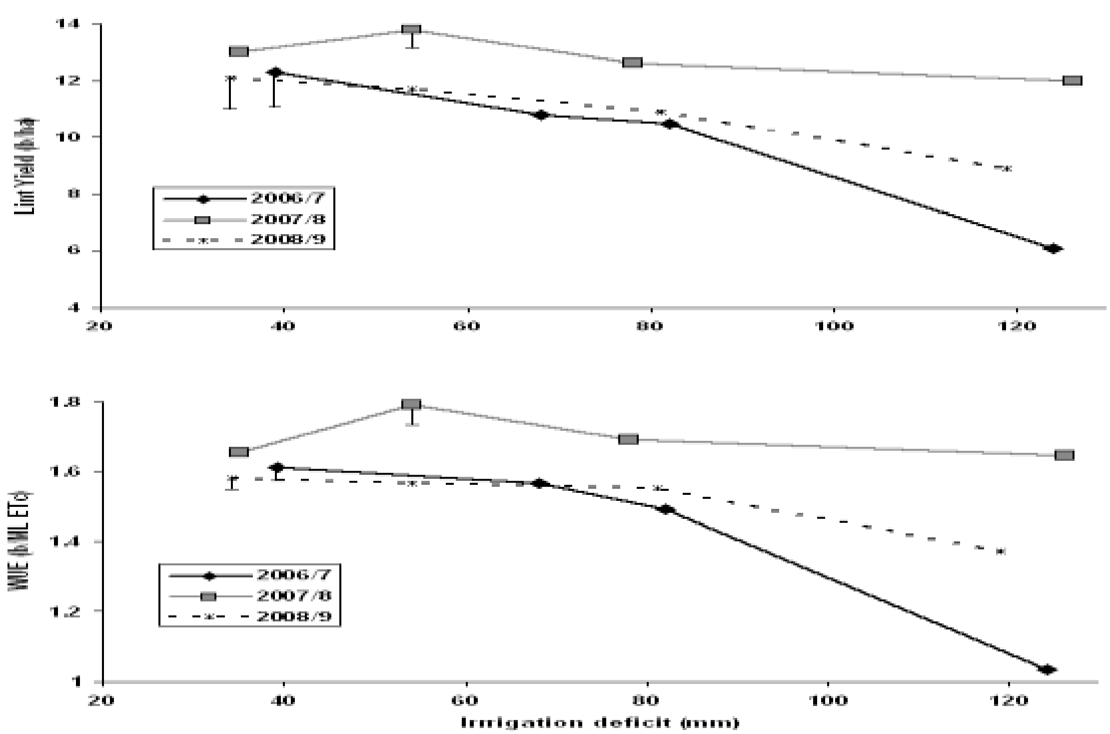

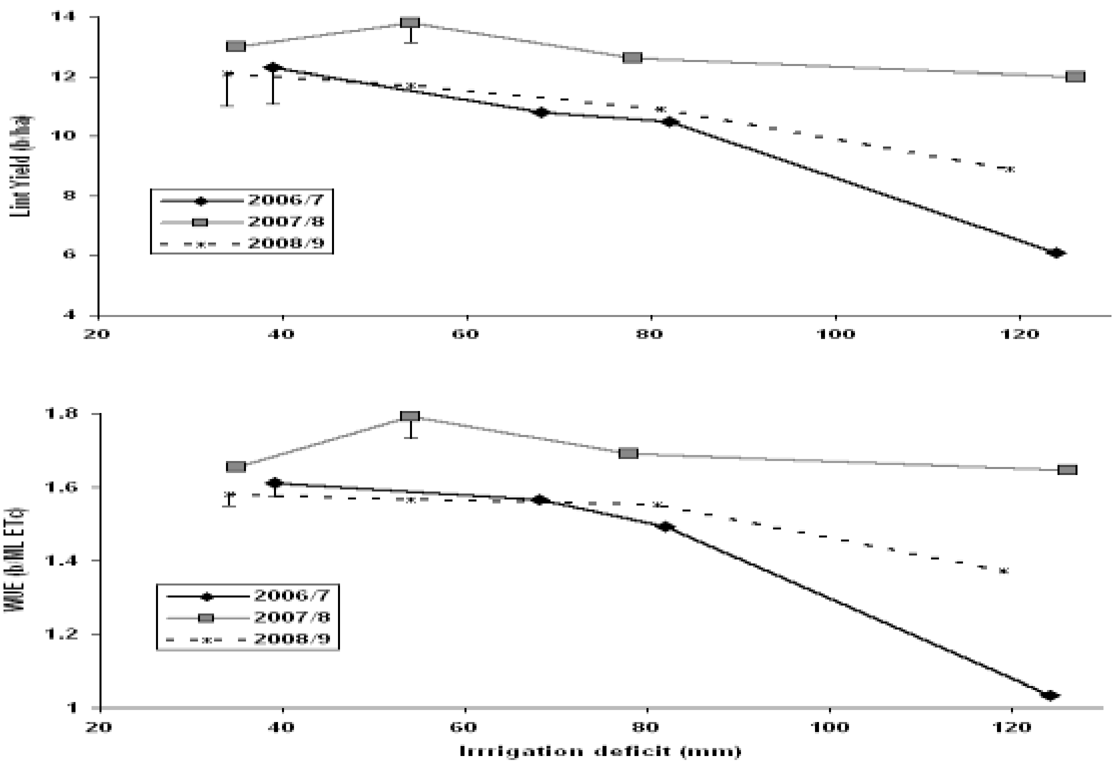

Figure 1. The lint yield and WUE (bales/mm ETc) response of high fruit retention Bollgard II cotton to irrigation deficit. Bars are Lsd$_{0.05}$. The 2006/7 season had high evaporative demand and low in crop rainfall, whereas in 2007/8 evaporative demand was below average and in-crop rainfall above average. In 2008/9 evaporative demand was high during flowering.

Fig. 1 shows that significant increases in yield and WUE were measured where Bollgard II was irrigated at smaller deficits than the 80 mm deficit (40% of PAWC) previously established for non-Bt cotton (Constable and Hearn 1981). These increases were greatest in hot and drier seasons. In 2006/7 this equated to 17% yield and 8% WUE gains over the 80mm deficit. Greater availability of soil water permitted vegetative growth to continue while the plant met the demand of a large number of early bolls. Consequently, more frequently irrigated plants produced more yield on later flowering nodes. In contrast, a crop with a lower proportion of early bolls would produce excessive vegetative growth when irrigated at smaller deficits (Hearn 1995). However, in the milder, wetter 2007/8 season there was less difference between irrigating at larger and smaller deficits, suggesting that deficits could be varied in response to seasonal evaporative impacts on plant water uptake

Conclusion

This research demonstrates the importance of evaluating the secondary impacts of GM traits on production. Due to the improved pest protection of Bt cultivars the need for compensation from pest damage has lessened, and changed plant morphology has reduced the water requirement of Bt cotton under typical pest numbers. In addition, this changed morphology has required different irrigation scheduling to improve yield and WUE.

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