Influence of cultivar maturity and leaf type on the agronomic water use efficiency of raingrown cotton

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ABSTRACT

A series of experiments compared cotton cultivars of differing maturity and leaf type across three seasons. Cultivar maturity explained about 70% of the variation in lint yield when data from the experiments were pooled. There was an increase in yield of 34.4 kg lint ha^{-1} for each day increase in maturity. Later maturing cultivars also had higher harvest index, were taller and had more nodes before the first fruiting branch. Compared with an early maturing normal leaf Texan cultivar, a full season okra leaf Australian cultivar extracted more water from deeper layers in the soil profile and had 20% greater agronomic water use efficiency (kg lint ha^{-1} mm^{-1} evapotranspiration). It was concluded that breeders should continue to utilise the okra leaf trait in full season cultivars for raingrown situations.

KEY WORDS

Cotton, water use efficiency, maturity, okra leaf.

INTRODUCTION

Water supply is a major determinant of cotton yield. Published agronomic water use efficiency (WUE) for cotton is 2.7 kg lint ha^{-1} mm^{-1} (5). Unreliable rainfall means that irrigation supplies can not be guaranteed. In addition, 20% of the industry is raingrown and depends on the same unreliable rainfall.

Breeding for increased water stress tolerance in cotton has become an important objective of the CSIRO cotton breeding program. Ray et al. (8) reviewed the research of WUE in cotton and concluded that variability existed for numerous traits that enhance WUE suggesting the potential for gains to be made through breeding. Roark and Quisenberry (9) proposed that plant growth habit affects yield and WUE in raingrown crops. Relatively indeterminate cultivars tended to have higher yields and higher WUE under conditions of water stress than more determinant cultivars. They also suggested that the traits associated with this WUE were heritable and could be accumulated in drought resistant strains.

This paper reports on experiments aimed at determining if variation in agronomic WUE existed among cotton cultivars, and the plant traits that contributed to this variation.

METHODS

Four field experiments containing 12 cultivars each were conducted at Narrabri NSW. Experiments in 1994/5 and 1995/6 were raingrown. In the 1996/7 season, both raingrown and irrigated experiments were conducted. Cultivars were arranged in randomised blocks with three replicates. Plots were 15 metres long ? 3 rows on a 1 metre row spacing. Neutron probe access tubes were located in the middle of the centre row of each plot to a depth of 180 cm. Total evapotranspiration (ET) was calculated using a water balance model corrected for individual neutron attenuation measurements. Four sequential hand harvests on 1 metre of each plot allowed crop maturity to be calculated using the method given by Christidis and Harrison (1955). This is presented as Mean Date of Maturity (days after sowing). Lint yield was measured by machine harvesting the centre row of each plot and ginning on an experimental gin. Data from three cultivars are presented in detail. Tamcot HQ95 is a short season, normal leaf cultivar bred by Texas A&M University reported to have high WUE under the Texas environment. Sicot 189 is a longer season, normal leaf cultivar bred by CSIRO. Siokra L23 is a longer season, okra leaf cultivar bred by CSIRO.

RESULTS AND DISCUSSION

Cultivar maturity

Across all experiments it was found that the longer season cultivars were highest yielding under raingrown conditions. In the one irrigated experiment, longer season cultivars were also higher yielding. The multiple linear regression of this association is shown in Figure 1. This association is highly significant and suggests that for every day increase in maturity there was a yield increase of 34.4 kg ha^{-1}. The variable rainfall patterns across the Australian cotton growing regions can cause water stress at any time throughout the growing cycle of a raingrown crop. In part, a longer season cultivar is able to perform better under this situation due to the tendency to start fruiting later, and hence staying vegetative longer. This allows roots to develop further and explore a larger volume of soil. Roots in the lower zone are also less susceptible to drought than those in the upper zone. This greater root system allows the plant to avoid stress by maintaining cell turgor and volume by maintaining water uptake. This is illustrated in Figure 2. In this particular experiment, Siokra L23 extracted an extra 20mm of water from the profile compared to the shorter season Tamcot HQ95. This water was extracted from deeper layers of the profile during the periods of 40-80 days after sowing (DAS) and particularly 130-155 DAS.

Earliness is a strategy that is employed by plant breeders to mediate the consequences of limiting factors (such as water stress) toward the end of the season. Cook and El-Zik (2) concluded though, that even in a short season environment, mechanisms other than escape are responsible for increased yield under water limiting conditions. This is partly due to the predictability of soil moisture. When the crop is forced to make its yield on stored soil moisture, earliness and yield are correlated (7), however under conditions such as the raingrown cotton areas of Australia, soil moisture is less predictable, and indeterminacy appears to have been more beneficial than earliness.

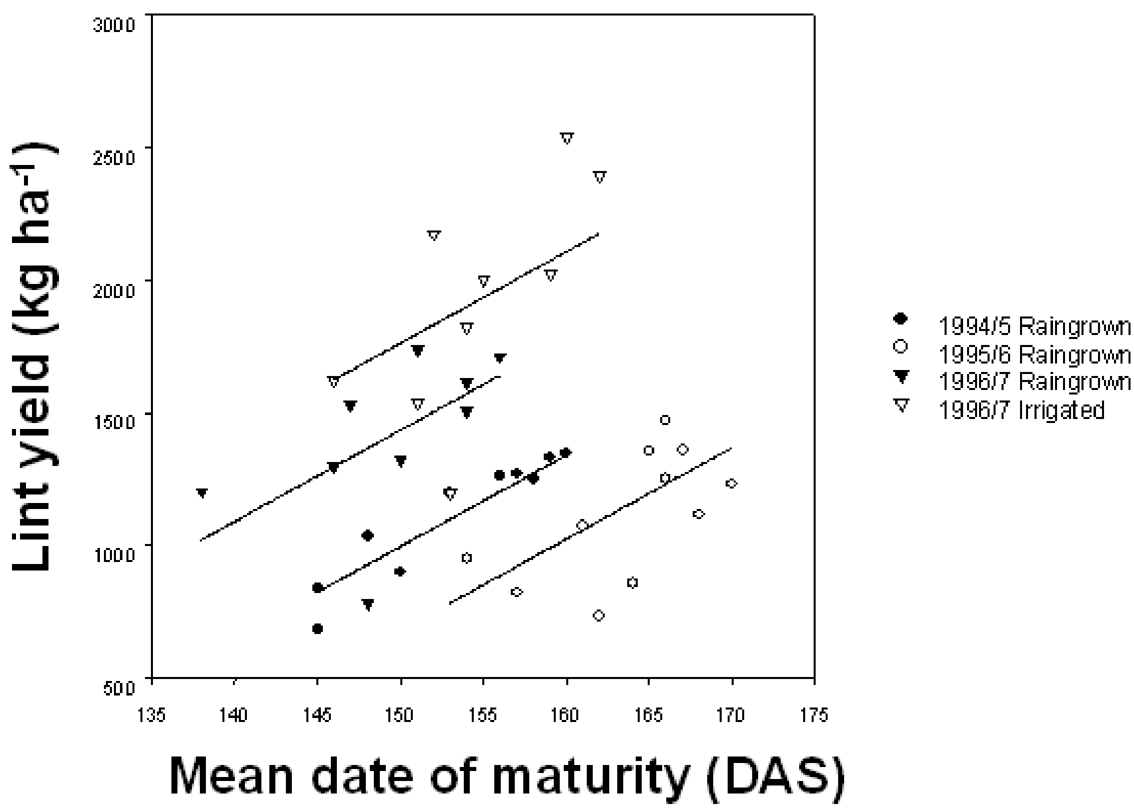
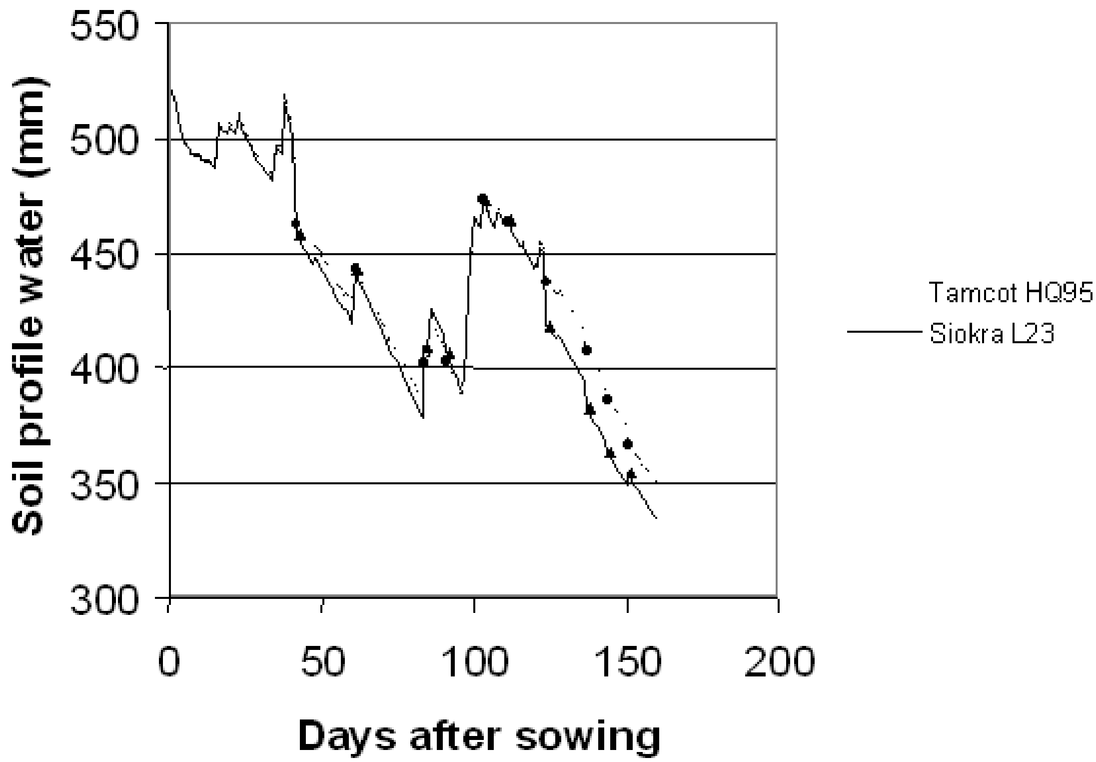


Figure 1. Association between crop maturity (days after sowing) and lint yield across three raingrown experiments and one irrigated experiment. Slope = 34.4 kg lint ha^{-1} day^{-1} ($p > 0.01$) Adjusted $R^2 = 0.70$ ($p > 0.001$).

Figure 2: Soil profile water in two cultivars in the 1994/5 season based on water balance and corrected for actual probe values, which are shown as symbols on the graph.



Leaf type

Okra leaf, an old and common mutant present in cotton, is characterised by deeply cleft and narrowly lobed leaves. In these experiments okra leaf cultivars were the highest yielding under raingrown conditions (data not presented). Across all experiments the CSIRO okra leaf types averaged 1406 kg lint ha^{-1} under raingrown conditions compared to 1296 kg lint ha^{-1} for the CSIRO normal leaf types. It has been reported that okra leaf types have a greater production of flowers but no apparent yield advantage over normal leaf types (10). It has also been reported by Landivar et al. (4) that okra leaf cultivars performed inconsistently under adverse conditions, such as water stress, because they had a lower LAI to intercept radiation than comparable normal leaf cultivars and suffered a yield reduction as a result. In these experiments LAI did differ significantly between cultivars, but this was generally related to the maturity of the cultivars, with the shorter season cultivars tending to have lower LAI, regardless of leaf shape.

It has been reasonably well documented that the okra leaf trait has greater canopy photosynthesis per unit leaf area (6). However, when considering integrated canopy photosynthesis it was shown that okra was significantly lower than its normal leaf counterpart (10). If indeed the okra leaf trait does confer greater photosynthesis per unit leaf area, and okra leaf cultivars do not differ from normal leaf cultivars in LAI, then the potential for yield increase becomes apparent. There is also evidence to suggest that okra leaf types have better assimilate distribution (3) and greater leaf WUE (6) compared with their normal leaf counterpart.

Agronomic WUE

Three cultivars were measured across all experiments, to demonstrate the extremes in water use and WUE. The results are summarised in Table 1. Agronomic WUE differed between cultivars. The main effects were related to maturity, as discussed above. The increased root exploration of the later maturing cultivars (Figure 2), together with turgor maintenance during vegetative growth, all add to improved WUE.

No statistics were able to be done on the water use and WUE estimates as means of leaf area and neutron attenuation were used for each cultivar. However, analysis of variance was done on the neutron attenuation readings themselves. In all experiments there were significant differences between cultivars for soil profile water. In addition, the coefficient of variation for cultivar differences in these analyses of water extraction was between 2 and 5%, indicating that the calculated differences in agronomic WUE are reliable.

Across experiments, WUE was greatest in the 1994/5 season (average 2.85 kg lint ha^{-1} mm^{-1}). This season had the lowest total rainfall of all the experiments, but was perhaps more timely. In this experiment total water use by the cultivars measured averaged around 400mm, compared with 588mm and 544mm in the following two raingrown experiments and 670mm in the irrigated experiment. However yield of the cultivars measured in the 1994/5 experiment averaged 1145 kg ha^{-1} which was greater than the 1995/6 raingrown experiment which averaged 1091 kg ha^{-1} even though it used considerably more water. Cultivar yields in the 1996/7 raingrown experiment average 1326 kg ha^{-1} for 544mm of total water use. The 1996/7 irrigated experiment produced quite high WUE (2.69 kg lint ha^{-1} mm^{-1}) due to the higher yields achieved with the higher water use.

Within an experiment cultivars varied for agronomic WUE. In all experiments Sicot 189 and Siokra L23 extracted more water from the soil profile, and from a greater depth than Tamcot HQ95, averaging 55 mm and 12 mm respectively. Just considering the extra 55 mm extracted by Sicot 189, with a WUE of 2.52 kg lint ha^{-1} mm^{-1}, the 55 mm would constitute an extra 139 kg lint ha^{-1}. Across all experiments Siokra L23 had 2.3% greater total water use than Tamcot HQ95, and an agronomic WUE 19.7% greater. Siokra L23 extracted less water than Sicot 189, but used the water more efficiently to make lint, averaging the greatest yield. Therefore, increased extraction partly explained the increased yield of Siokra L23 and Sicot 189 over Tamcot HQ95, but other factors must account for the increase in yield of Siokra L23 over Sicot 189. Some of these have been suggested above in relation to increased photosynthesis per unit area, better assimilate distribution and greater leaf WUE of the okra leaf.

Table 1. Mean Seasonal water use (evapotranspiration), lint yield and agronomic water use efficiency of cultivars grown in 1994/5 and 1995/6 under raingrown conditions, and in 1996/7 under both raingrown and irrigated conditions. WUE = ET/Yield.

Cultivar	Seasonal water use (mm ET)	Yield (kg lint ha^{-1})	Agronomic WUE (kg lint ha^{-1} mm^{-1})
Tamcot HQ95	537	1214	2.26
Sicot 189	592	1491	2.52
Siokra L23	549	1549	2.82

CONCLUSIONS

These results suggest that crop maturity and the okra leaf trait are important characteristics for a successful raingrown cultivar in Australia. Breeders should continue to exploit these traits in the development of raingrown cultivars.

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