Breeding cotton for improved dryland performance

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A new project at Narrabri aims to develop methods of breeding cotton varieties that perform better under dryland and limited water situations.

Introduction

Cotton is recognised as being relatively drought tolerant. Though most of the cotton produced in Australia is grown under irrigated conditions, there is increasing interest in dryland production. Water supply is a major determinant of cotton crop performance. For irrigated cotton, lower than average rainfall in the catchment areas, and over allocation of irrigation licences have led to a situation where all major production regions have often been restricted in irrigation allocation. The declining water table in underground aquifers, and increased pumping costs all focus attention on the overall water supply problem. For the dryland cotton industry, cotton plantings are more variable, depending on fallow moisture and price, but there is a very significant area of raingrown cotton at present and that situation is likely to remain in future. Any potential expansion in Australian cotton production will involve raingrown areas.

The performance of cotton under dryland conditions is extremely variable. To improve its performance, or create consistency of production between years, we need to know the major physiological and morphological traits associated with drought tolerance in order to know which traits may be utilised in a breeding program. Some of the traits identified in Texas as having breeding potential include leaf conductance and osmotic adjustment, leaf water potential, root growth and soil water extraction, and heat and desiccation tolerance.

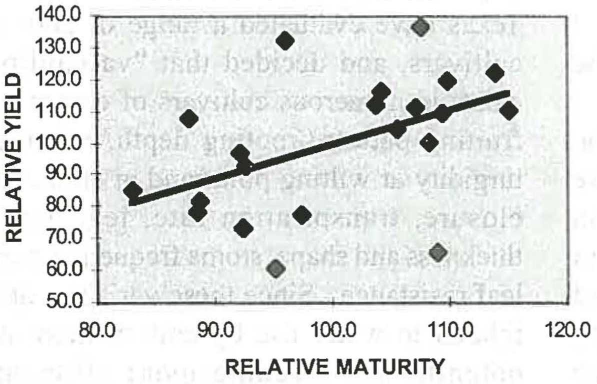
The whole issue of breeding assumes variability between plants, whether natural or induced. When this variability is present, the best individuals can be selected and hopefully an improvement in the population can be made. Scientists in Texas have evaluated a range of cotton cultivars, and decided that "variability exists in numerous cultivars of cotton in fruiting pattern, rooting depth, relative turgidity at wilting point and at stomatal closure, transpiration rate, leaf area, thickness and shape, stoma frequency, and leaf resistance. Since these variables are related to water use by cotton, there is potential for breeding more efficient varieties with respect to water requirement."

There is existing technology to evaluate these traits. Some methods are simple, rapid and can be used to screen large numbers of plants, whereas others are complex and time consuming. In the past, plant breeders have made little use of these techniques to improve the dryland performance of cotton.

Breeding strategy

To survive periods of water stress, plants use one of two main strategies. With the first, the plants *escape* water stress by completing their life cycle before serious water deficit occurs. In the semi-arid dryland cotton areas of the United States, particularly Texas, emphasis has been placed on early maturing cultivars. Dryland cotton in Texas is usually grown in a terminal drought situation, that is, the crop is planted on a full profile of moisture with little or no rain falling throughout the rest of the season. The problem with this however, is that a negative relationship generally exists between yield and earliness. We have demonstrated this in trials in Australia over a number of years, and with two trials in particular, where early maturing cultivars from Texas were included together with longer season CSIRO bred cultivars (figure 1).

Figure 1: Yield vs Maturity of 21 cultivars over 2 seasons



The second plant strategy is *drought resistance*. Longer season plants perform differently, and are said to have tolerance by maintaining water uptake while reducing water loss. In Australia, significant rainfall can occur throughout the growing season, with some years being nearly ideal for production. However, this rain often falls sporadically, and towards the middle or end of the season. To take advantage of this variability, cultivars that can survive dry times, then utilise rain when it falls, together with sufficiently high yield potential are needed. The medium to late maturing CSIRO cultivars appear to fulfil this criteria (figure 1).

Objectives

With this project, we have two major objectives in mind:

1. To determine the range of genetic differences for WUE among Australian and Texan cultivars, and decide on reliable methods for identifying differences in the field.

2. To measure the heritability of traits important for WUE of field-grown cotton, and include the information and plant material into the existing CSIRO breeding program.

Research summary

Crop WUE is not difficult to measure, simply by calculating the amount of water applied to a field and the amount of lint harvested. However, the same technique can not be applied when attempting to select single plants, nor can it be applied to large numbers of progeny rows. So different techniques had to be developed.

We are measuring the WUE of field grown cotton in several ways. Gas exchange technology is being used to measure a range of physiological characters, such as leaf photosynthesis (*A*), stomatal conductance to water vapour loss (g), transpiration (T), and internal CO_2 concentration (C*i*). All of these characters give an indication of how well a plant is performing, and reflects such things as a deep, extensive root system for extracting water, and osmotic adaptation. We have discovered variability within a range of commercial cotton cultivars and breeding lines for most of these characters. One example of this is shown in figure 2, the photosynthesis/transpiration ratio (WUE).

Plant tissue has an outer layer which prevents water loss, but it also prevents the diffusion of carbon dioxide (CO_2) into the leaf, which the plant needs for photosynthesis. The plant allows CO_2 into its tissues by opening stomata, pores that regulate gas diffusion. However, these pores also allow water vapour to escape from the leaf (transpiration). If this water loss is excessive, dehydration of the plant can occur. The stomatal opening is regulated by the plant so that the rate of CO_2 fixation is fast enough for growth, but not so fast that transpiration exceeds the rate of water drawn from the soil. Obviously, the plants that have the greatest WUE are the ones that can balance the CO_2 intake with a low water loss.

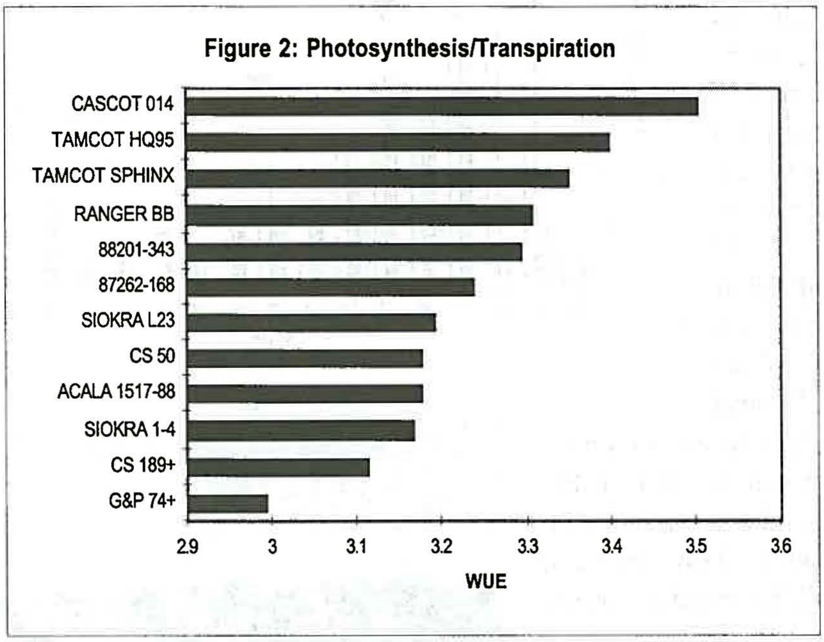


Figure 2: Photosynthesis/Transpiration

Another technique that is also being evaluated as an indirect estimate WUE is the ability of cotton to discriminateagainst the stabe isotope of carbon (^{13}C) Only about 1% of atmospheric CO_2 is composed of ^{13}C; the remainder is ^{12}C. Plant drymatter contains less ^{13}C than the air because the enzymes of photosynthesis discriminate against $^{13}CO_2$ in favour of $^{12}CO_2$. The level of ^{13}C discrimination (termed Delta) is dependant on how plants lose water in relation to photosynthesis, and can be accurately measured in only a few milligrams of dried tissue using an isotope ratioing mass spectrometer. We are interested in using Delta to estimate WUE because it is easy, it extends the time scale of our plant gas exchange measurements, and it alllows a large number of genotypes to be screened for WUE. While a trait like WUE may not relate directly to drought resistance in cotton, a large body of evidence suggests that Delta is possitively associated with productivity in a number of crops.

Figure 3 shows some of the Delta results that were obtained from the 1994-95 season. This data suggests that by selecting for a smaller Delta, yield can be significantly increased.

We have determined that there are differences in a range of physiological and yield traits and that we can reliably identify

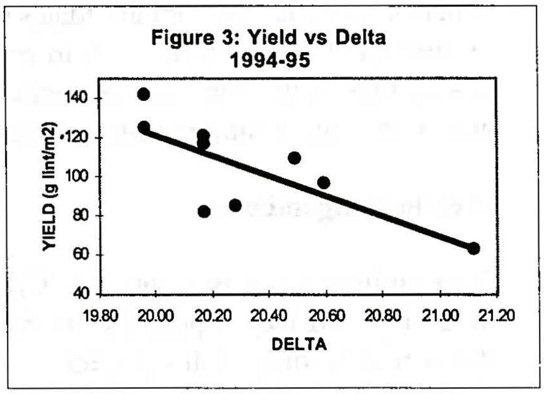
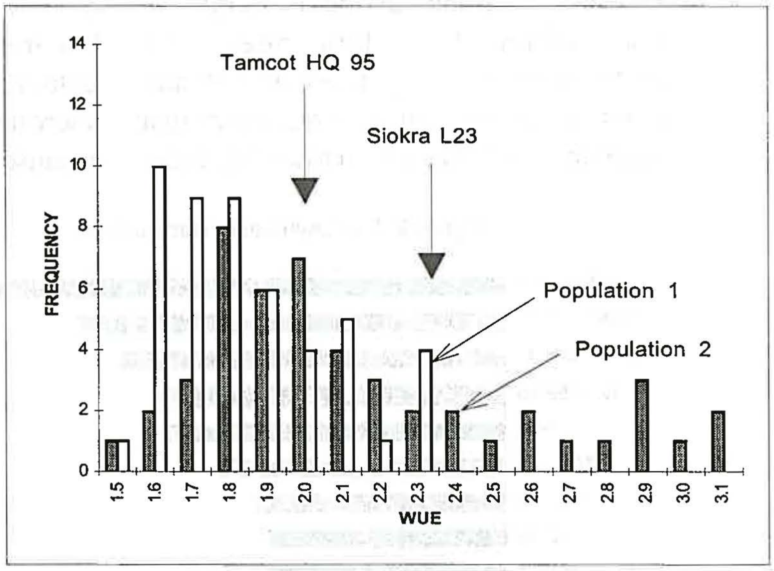


Figure 3: Yield vs Delta
1994-95

them in the field. Now we need to determine the heritability of these measures to see if we can *select* for them in the field. To do this, a series of crosses were done, and populations developed, between selected CSIRO and Texan cultivars having diverse growth characteristics. Within these populations individual plants were sampled for the same characteristics described previously . As expected, a range of WUE were observed (figure 4). The location of two of the parents (Siokra L23 and Tamcot HQ 95) are also shown to indicate where the current commercial cultivars fall on the scale. The individuals in population 2 that rank above Siokra L23 (WUE of 2.4) are the ones we will be targeting in the breeding programfor further field measurements in order to combine improved WUE with high yield and fibre quality.

Figure 4: Frequency distribution of WUE's of two early generation populations of cotton



Measuring gas exchange characteristics of cotton with the Licor 6400

Future direction

We now know that cotton can display quite large variations in WUE. From this, we need to determine what are the quickest and most reliable techniques for identifying WUE in the field. The immediate goal then, is to determine whether we can select for individuals with improved WUE, and from them create populations with improved performance under dryland or limited water situations.

Acknowledgements

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