Identification of Characters for Selecting Increased Water Use Efficiency in Cotton

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ABSTRACT

Water supply is a major determinant of cotton yield. In Australia, unreliable rainfall means that irrigation supplies cannot be guaranteed. In addition, 20% of the industry is rain grown and depends on the same unreliable rainfall. The aim to determine if it is possible to identify and select characters that enhance the leaf and crop water use efficiency (WUE) of cotton. The occurrence of differences in WUE between genotypes was identified. Crosses were made between relatively diverse germplasm and F2's produced. 160 single F2 plants were measured for a range of gas exchange characters including photosynthesis, stomatal conductance, intercellular CO2 concentration and transpiration. Physiological WUE was calculated from these measurements. Each F2 plant was grown in an F3 row the following year. For the purpose of more intensive measurements, selection were based on the F2 data, and 24 F3's were measured for the same characters as the F3's. Estimates of narrow sense heritability (h2) were also calculated. Relatively low estimates of h2 were obtained (0-0.5) for gas exchange characters compared with the high h2 for characters such as lint percentage (0.9). However, some h2's were significant, indicating that it will be possible to select lines with improved physiological WUE. These lines can then be screened for other agronomic characters. We believe this procedure will produce improved raingrown types than has been possible with our previous procedure in testing successful irrigated types for dryland adaptation.

Introduction

In 1972, the CSIRO Cotton Research Unit commenced a cotton breeding program at Narrabri NSW Australia, which has produced high yielding, locally adapted varieties, with particular emphasis on producing varieties suited to irrigated conditions. Given the increased frequency of irrigation restrictions and the expansion of raingrown cotton production (now 80,000 ha), there is now greater need for varieties adapted to raingrown conditions.

Breeding for increased water stress tolerance in cotton, as well as many other crops, has occupied a large number of research projects. Ray et al. (1974) reviewed research in water use efficiency (WUE) in cotton and concluded that variability existed for numerous traits that enhance WUE. This gives rise to the potential gains to be made through breeding. Roark and Quisenberry (1977) proposed that plant growth habit affects yield and WUE in rain grown cotton crops. Relatively indeterminate varieties tended to have higher yields and higher water use efficiency under conditions of water stress than more determinant varieties. They also suggested that the traits associated with this water use efficiency were heritable and could be accumulated in drought resistant strains. Recently, physiological measures such as carbon isotope discrimination (Condon et al., 1987; Craufurd et al., 1991; Donovan and Ehleringer, 1994; Hall et al., 1994) have been used to select for greater water use efficiency in a range of crop species. The idea of selecting for WUE on physiological characters has also be put forward by Johnson and Tieszen (1994) in alfalfa, Johnson et al. (1995) in lentil, and Singh (1995) in common bean.

This paper reports on an experiment using F3 progeny rows to examine if selection pressure could be placed on physiological WUE characters in the early stages of a breeding program, with the aim of producing cultivars with improved water stress tolerance.

Materials and methods

The experiment was done in the field at the Australian Cotton Research Institute (149°47' E, 30°13'S) in the 1997-8 cotton season. The 24 F3 genotypes previously chosen from a population of 160 F2 plants on the basis of gas exchange measurements were arranged in randomized blocks with three replicates. Plot size was one row × 15 metres.

Nitrogen fertilizer was applied as anhydrous ammonia, at the rate of 120 kg ha−1 N. Trifluralin herbicide was incorporated in September before sowing in October. The crop was sown on the 14th October into a full soil moisture profile with a cone seeder on rows one metre apart to achieve a plant population of 80 000 ha−1. Fluometuron herbicide was applied after sowing before crop emergence. Hand hoeing and inter-row cultivation were used for all subsequent weed control. The crop was sprayed by aircraft to control insect pests as required. The crop was grown utilizing only rainfall. Effective rainfall for the growing season was 335 mm.
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differences were significant (Table 1). Heritability of these traits is presented in Figure 3, which presents the significant negative relationship between stomatal conductance and fall above the line shown in Figure 3, may be a more reliable growth stage to evaluate gas exchange traits.

Figure 3 presents the significant negative relationship between stomatal conductance and lint yield. In this particular season, where water was limited during flowering and there was a high evaporative demand, high conductance was an impediment to yield, presumably because the crop used all its available water before the time of yield determination (Singh et al., 1992). However, it is not expected that this would occur every season. In a favourable season, when rains are timely, the crop behaves like an irrigated crop, and genotypes with high rates of conductance and net photosynthesis can take advantage of the unlimited water. This variation between seasons is a problem when deciding on a selection strategy for rain-grown genotypes. Genotypes suited to highly stressed conditions may not have the yield potential to perform in a more favourable season. It may be possible however, to select those genotypes that have high conductance and fall above the line shown in Figure 3, and hence select for types that should perform well in a favourable season.

Conclusions

Because variation within a day makes it difficult to obtain reliable measures of gas exchange traits, robust statistical procedures are required to adjust the data. Heritability of several gas exchange traits indicates that significant genetic progress should be realized from selection. Care must be taken not to adopt a selection strategy using gas exchange traits based on conserving water, and thus reducing yield potential.

Acknowledgments

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References

photosynthesis for cotton in connection with breeding for increased yield. S.-Kh. Biol. 5:76-81.


Table 1. Range, narrow sense heritability and correlation with F3 generation associated with five gas exchange traits of F4 plots measured during early flowering, December 1997. * and ** indicate significance at the 0.05 and 0.01 levels respectively.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Units</th>
<th>Range</th>
<th>( h^2 )</th>
<th>( F_{3}:F_{4} ) (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Photosynthesis (A)</td>
<td>( \mu \text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1} )</td>
<td>27.1-28.6</td>
<td>0.38*</td>
<td>0.160*</td>
</tr>
<tr>
<td>Stomatal Conductance (g)</td>
<td>( \text{mol H}_2\text{O m}^{-2} \text{ s}^{-1} )</td>
<td>0.677-0.735</td>
<td>0.13</td>
<td>0.483**</td>
</tr>
<tr>
<td>Leaf WUE (A/g)</td>
<td>( \mu \text{mol mol}^{-1} )</td>
<td>40.3-42.5</td>
<td>0.18</td>
<td>0.117</td>
</tr>
<tr>
<td>Ratio of intercellular CO(_2) to ambient (C(_i)/C(_a))</td>
<td>-</td>
<td>0.724-0.736</td>
<td>0.19</td>
<td>0.113</td>
</tr>
<tr>
<td>Transpiration efficiency (TE)</td>
<td>( \mu \text{mol mmol}^{-1} )</td>
<td>-</td>
<td>0.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 1. Diurnal variation in stomatal conductance measured on the 24 F4 genotypes, December 17, 1997.
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Figure 2. Parent-progeny regression for stomatal conductance measured at early flowering for the 24 F$_4$ genotypes grown in 1997/8.

\[ y = 0.2968x + 0.5438 \]

\[ R^2 = 0.483^{**} \]

Figure 3. Relationship between yield and stomatal conductance measured at early flowering for the 24 F$_4$ genotypes grown in 1997/8.

\[ y = -1923.7x + 1627 \]

\[ R^2 = 0.245^{*} \]