YIELD AND PHYSIOLOGICAL RESPONSES OF MODERN VERSUS OBSOLETE CULTIVARS GROWN UNDER WATER-DEFICIT CONDITIONS

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RESEARCH PROBLEM

Year-to-year variability in yield is a major concern in U.S. cotton production. Recent literature and hypotheses indicate that this yield variability is mostly related to extreme environmental conditions, particularly high temperatures and drought, as well as a peak in genetic improvements in yield. It is speculated that modern and obsolete cultivars partition dry matter and energy pools differently within the boll and at the seed level, making the modern cultivars potentially more sensitive to environmental stresses. The goal of this current field study was to quantify the effect that water-deficit stress had on modern versus obsolete cultivars in terms of lint yield, components of yield, and physiological plant responses that might hinder the overall development of yield.

BACKGROUND INFORMATION

Cotton yields in Arkansas as well as in much of the U.S. increased steadily during the 1980’s, but in the 1990’s there has been a leveling off with a decrease in yields in the late 1990’s (Meredith, 1998; Lewis and Sasser, 1999). Of more concern, however, is the extreme year-to-year variability. According to Helms (2000), there is clearly a significant problem with the lack of uniformity in current yields. In Arkansas, three out of five seasons from 1995 to 1999 were extremely disappointing with unusually low yields (Oosterhuis, 1999), with the 1998 and 1999 crop yields being the poorest in recent history. Much of this disappointment in yields was related to extreme weather conditions and not to insect pressure. Generally, each year the cotton crop appears to have good potential at mid-season, but this potential is not always achieved at harvest due to combinations of moisture stress and high temperatures during the critical first three to five weeks of boll development. Besides environmental conditions, changes in breeding objectives over the past few decades may also be an underlying reason for yield variability. It is hypothesized that increased yield variability may be the result of differential partitioning of carbohydrate and energy pools between fiber and seed of modern and obsolete cultivars as a result of environmental stress during early boll development. To test this research hypothesis the following research objectives were initiated.

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The first objective was to evaluate lint yield and boll and yield components of modern versus obsolete cultivars under well-watered and water-deficit conditions. The second objective was to study physiological responses of modern and obsolete cultivars in order to better understand boll development and yield as affected by environmental stresses. An improved understanding of physiological differences between modern and obsolete cultivars under water-deficit stress should help to clarify yield development and potentially answer yield variability issues.

RESEARCH DESCRIPTION

Field studies were conducted in northeast and northwest Arkansas in 2003 to test the impact that contrasting environmental conditions coupled with genotypic differences had on partitioning in field grown cotton. The study contained two factors which were water and cultivar. Water was the whole plot factor and consisted of either well-watered or water-deficit conditions. The sub-plot factor was cultivar and consisted of eight cultivars (four modern and four obsolete). The modern cotton (\textit{Gossypium hirstum} L.) cultivars were ST 474, SG 747, DP 33B, and Acala Maxxa and the obsolete cultivars included ST 213, DP 16, REX, and Acala SJ2. Each of these eight cultivars was subjected to both water treatments and replicated six times. Numerous in-season physiological and end-of-season agronomic measurements were evaluated to help explain yield variability. Physiological measurements included leaf fluorescence measured with a fluorometer, canopy temperature measured with a hand held infrared thermometer, chlorophyll content taken with a Minolta SPAD meter, specific leaf weight (SLW) or leaf thickness, leaf adenosine triphosphate (ATP) measured with an ATP lumitran, leaf total soluble protein utilizing the Bradford method through colorimetric procedures, leaf membrane integrity measured with a conductivity meter, leaf wax concentrations and leaf antioxidant enzyme concentrations. End-of-season measurements included lint yields, yield and boll components, gin turnout, and fiber quality. Boll components consisted of average boll weight, seed weight fiber per seed, and seeds per boll. Yield components consisted of bolls per acre and seeds per acre.

RESULTS AND DISCUSSION

The 2003 season was the third year for the project investigating the yield and physiology of modern versus obsolete cultivars under water-deficit conditions. Unfortunately, the 2001 and 2002 seasons resulted in above-average rainfall during the growing season. As a result we were unable to impose moderate water-stress conditions during boll development to properly evaluate physiological differences between modern and obsolete cultivars in response to water stress as a means of explaining yield differences and arising yield variability questions. Fortunately, in 2003 we were able to obtain an appreciable water-deficit stress at the Fayetteville, Arkansas, location. This report will include some of the physiological results from the Fayetteville location in 2003, and yield and yield component results from both
the Clarkedale and Fayetteville locations collected in 2003. Results will be presented as the average of the four obsolete and the average of the four modern cultivars and presented as modern versus obsolete cultivars under each water level.

**Lint Yields**

In 2003, modern cultivars had higher lint yields than the obsolete cultivars at both test locations under both well-watered and water-deficit conditions (Fig. 1). At the Fayetteville test site this increase in lint yield by the modern cultivars was significant at $P < 0.05$. Our hypothesis was that obsolete cultivars would yield higher than modern cultivars under a significant stress event, such as water-deficit stress, due to improved partitioning of carbohydrates between fiber and seed. However, the modern cultivars yielded higher than obsolete cultivars even under water-deficit conditions. An explanation for this might be that the stress did not last long enough during boll development and compensation occurred giving the modern cultivars the advantage to yield higher since modern cultivars contain more seeds per acre, which give rise to more fiber/acre, since modern cultivars have equal or more fiber/seed (Tables 1&2) than obsolete cultivars.

**Yield Components**

Boll and yield component data from Clarkedale (Table 1) and Fayetteville (Table 2) showed similar results when comparing modern cultivars to the obsolete. At Clarkedale, obsolete cultivars had significantly ($P < 0.05$) larger bolls and greater seed weight than the modern cultivars at both water levels (Table 1). However, the modern cultivars had significantly ($P < 0.05$) more bolls and seeds per acre than the obsolete cultivars (Table 1). There were no significant differences between modern and obsolete cultivars for producing fiber/seed. This indicates that the improved yields by the modern cultivars (Fig. 1) were the result of more bolls and more seeds per acre with fiber per seed being near equal between modern and obsolete cultivars. There were no significant trends in relation to seeds/boll between modern and obsolete cultivars (Table 1). However, the obsolete cultivars had numerically more seeds/boll than the modern cultivars, which was not expected and difficult to explain. Boll and yield component data from the Fayetteville test site (Table 2) showed the same trend as Clarkedale with increased boll weight and seed weight with obsolete cultivars and more bolls and seeds per acre with modern cultivars. However, the only significant differences were detected under the water-deficit conditions and not under well-watered environments.

**Leaf ATP Concentrations and Leaf Soluble Protein**

ATP concentrations and total soluble protein levels of cotton leaves were measured to determine any differences in plant energy dynamics. There were no significant differences ($P < 0.05$) in measured ATP or protein concentrations at the water or cultivar level (Fig. 2). However, modern cultivars had numerically higher
ATP and protein concentrations under each water level compared to the obsolete cultivars. It was also noticed that protein concentrations were higher under well-watered conditions, but ATP concentrations were lower under well-watered conditions. An explanation for this might be that under well-watered conditions the cotton plant is better suited for making protein than are water-stressed plants; however, this manufacturing of protein cost the plant more energy (ATP).

**Leaf Wax Concentrations and Leaf Membrane Integrity**

There were no significant differences between modern and obsolete cultivars at either water level for altering leaf wax concentrations or leaf membrane leakage (a measure of leaf integrity). However, membrane leakage was significantly greater ($p<0.05$) in water-stressed leaf samples compared to well-watered leaf samples and obsolete cultivars exhibited less leakage under water-deficit conditions (Fig. 3). Leaf membrane leakage appears to be an excellent technique for quantifying water stress. This measurement also supported our hypothesis of improved stress resistance of obsolete cultivars under stressed environments by showing a numerical decrease in membrane leakage of obsolete cultivars compared to modern cultivars. This difference was not observed under an adequate-moisture environment.

**PRACTICAL APPLICATION**

In recent years increasing year-to-year variability in U.S. cotton yields has become a major problem. It is speculated that this decline and lack of uniformity in cotton yields is the result of adverse environmental conditions during boll development coupled with changing germplasm lines being developed and grown commercially. Current and ongoing research is investigating the effect of drought and high temperatures on plant physiological functioning and yield development. Results are currently being analyzed across years and locations, but it appears that modern cultivars are more sensitive to adverse environmental conditions causing lower cotton yields in seasons with drought and above-normal temperatures. An investigation of physiological responses and yield development of modern versus obsolete cultivars exposed to environmental stresses could ultimately help in the establishment of counteractive management strategies before cotton yields are adversely affected.
LITERATURE CITED


### Table 1. Boll and yield components of modern versus obsolete cultivars under well-watered and water-deficit conditions at Clarkedale, Ark., in 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Boll weight</th>
<th>Bolls/acre</th>
<th>Seeds/acre</th>
<th>Fiber/seed</th>
<th>Seed/weight</th>
<th>Seeds/boll</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/boll</td>
<td>#/acre</td>
<td>#/acre</td>
<td>mg</td>
<td>g/100 seed</td>
<td>#/boll</td>
</tr>
<tr>
<td>Modern-water</td>
<td>4.00</td>
<td>79,000</td>
<td>2,162,000x</td>
<td>57.7</td>
<td>9.22</td>
<td>27.1</td>
</tr>
<tr>
<td>Obsolete-water</td>
<td>4.59x</td>
<td>57,000</td>
<td>1,649,000</td>
<td>57.8</td>
<td>10.40x</td>
<td>28.9x</td>
</tr>
<tr>
<td>Modern-dryland</td>
<td>4.24</td>
<td>96,000x</td>
<td>2,721,000x</td>
<td>62.5</td>
<td>9.28</td>
<td>28.1</td>
</tr>
<tr>
<td>Obsolete-dryland</td>
<td>4.68x</td>
<td>78,000</td>
<td>2,235,000</td>
<td>61.3</td>
<td>10.37x</td>
<td>28.9</td>
</tr>
</tbody>
</table>

x Significant at P≤0.05 for the paired treatments.

### Table 2. Boll and yield components of modern versus obsolete cultivars under well-watered and water-deficit conditions at Fayetteville, Ark., in 2003.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Boll weight</th>
<th>Bolls/acre</th>
<th>Seeds/acre</th>
<th>Fiber/seed</th>
<th>Seed/weight</th>
<th>Seeds/boll</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/boll</td>
<td>#/acre</td>
<td>#/acre</td>
<td>mg</td>
<td>g/100 seed</td>
<td>#/boll</td>
</tr>
<tr>
<td>Modern-water</td>
<td>3.72</td>
<td>312,000</td>
<td>8,373,000</td>
<td>55.1</td>
<td>8.55</td>
<td>27.1</td>
</tr>
<tr>
<td>Obsolete-water</td>
<td>3.72</td>
<td>281,000</td>
<td>7,584,000</td>
<td>51.0</td>
<td>8.88</td>
<td>27.0</td>
</tr>
<tr>
<td>Modern-dryland</td>
<td>4.16x</td>
<td>285,000x</td>
<td>7,718,000x</td>
<td>56.0</td>
<td>8.57</td>
<td>27.0</td>
</tr>
<tr>
<td>Obsolete-dryland</td>
<td>3.77</td>
<td>235,000</td>
<td>6,527,000</td>
<td>57.0</td>
<td>9.46x</td>
<td>27.7</td>
</tr>
</tbody>
</table>

x Significant at P≤0.05 for the paired treatments.
Fig. 1. Lint yields of modern versus obsolete cultivars under well-watered and water-deficit conditions at Clarkedale and Fayetteville, Ark., in 2003. The level of significance is presented above each set of columns.

Fig. 2. Leaf ATP and leaf total soluble protein of modern versus obsolete cultivars under well-watered and water-deficit conditions at Fayetteville, Ark., in 2003. No significant differences existed between treatments at $P \leq 0.05$. 
Fig. 3. Leaf membrane leakage and leaf wax concentration of modern versus obsolete cultivars under well-watered and water-deficit conditions at Fayetteville, Ark., in 2003. * Indicates a significant (P<0.05) difference under water-deficit conditions averaged over cultivars.