Weed Science, 54:651–657. 2006

Spurred anoda (*Anoda cristata*) interference in wide row and ultra narrow row cotton

William T. Molin
Corresponding author. Southern Weed Science Research Unit, U.S. Department of Agriculture–Agricultural Research Service, Stoneville, MS 38776; wmolin@ars.usda.gov

Debbie Boykin
Statistics, U.S. Department of Agriculture–Agricultural Research Service, Stoneville, MS 38776

Josie A. Hugie
Department of Crop Science, University of Illinois, Urbana, IL 61801

H. Harish Ratnayaka
Department of Biology, Xavier University of Louisiana, New Orleans, LA 70125

Tracy M. Sterling
Department of Entomology, Plant Pathology and Weed Science, New Mexico State University, Las Cruces, NM 88003

A field experiment was conducted in 2000, 2001, and 2002 at Stoneville, MS, to determine the effect of spurred anoda interference on yield loss of two cotton cultivars, 'Delta Pine 5415' and 'Pima S-6', grown under wide (1 m) (WR) and ultra narrow (0.25 m) row (UNR) spacings. The relationship between spurred anoda density and dry weight per plot was linear each year. At a spurred anoda density of 8 m^{-2}, spurred anoda dry weight per plot was 507, 322, and 777 g m^{-2} in 2000, 2001, and 2002, respectively. However, spurred anoda did not interfere with seed cotton yield in 2001, which was probably attributable to the low branch development in that year. Yield losses exceeded 55% at a spurred anoda density of 8 m^{-2} compared with controls in both WR and UNR. The effect of spurred anoda density on boll numbers was nearly identical in 2000 and 2002, regardless of cotton cultivar and row spacing. Boll weights decreased in response to spurred anoda interference. Spurred anoda interference resulted in a decrease in cotton branch dry weight in WR but not in UNR. The yield decrease as a result of spurred anoda interference in WR was due to reduction in boll retention or fruiting sites (predicated on a decrease in branch weight). However, in UNR, the yield decrease was due to plant mortality; the plant density of both cotton cultivars decreased by one plant for each additional spurred anoda, but the yield per plant for surviving plants remained constant. Neither WR nor UNR cotton had significant advantage in response to spurred anoda interference. The decreased boll weight observed in UNR, and the failure to increase boll numbers m^{-2} to compensate for decreased boll weight in UNR compared with WR, may limit its appeal to cotton producers.

Nomenclature: Spurred anoda, *Anoda cristata* (L.) Schlecht. ANVCR; cotton, *Gossypium hirsutum* L. 'DP 5415'; *Gossypium barbadense* L. 'Pima S-6'.

Key words: Ultra narrow row management system (UNR), wide row management system (WR).

Spurred anoda, an indigenous summer annual weed in cotton, has been characterized as one of the most troublesome weeds in North Carolina, Virginia, and Tennessee (Dowler 1992). However, in more recent surveys, spurred anoda was not included on the list of the 10 most troublesome weeds in cotton in Tennessee (Dowler 1998) or in Virginia (Webster 2001). Spurred anoda interferes with cotton growth because it has a large vegetative growth capacity that coincides with cotton flower and fruit development (Chandler 1977). For example, full-season spurred anoda interference in cotton at densities of eight plants per 12 m of crop row resulted in seed cotton yield losses of 30% (Chandler 1977). By 80 d after planting, the average height and width across year and location of four regionally separate accessions of spurred anoda were 61 and 139 cm, respectively (Van Gessel et al. 1998). In addition, the average primary branch number was 24 at 80 d after planting.

The effects of spurred anoda interference also varied with cotton variety. The yield reductions resulting from spurred anoda interference with 'Deltapine 16' (DP 16) were greater than with *Stoneville 213* or *DES 21326-04* (Chandler and Meredith 1983). Early season spurred anoda interference also reduced the yield of determinate varieties more than that of indeterminate varieties, indicating that early season weed control is more important in the early maturing cultivars (Chandler and Meredith 1983).

There has been renewed interest in growing cotton in UNRs in recent years, partially because of potential weed control benefits. UNR cotton production systems have row widths of 19 to 25 cm, and populations of 210,000 to 378,000 plants ha^{-1} compared with WR systems, which usually have row widths of 76 to 100 cm, and populations of 80,000 to 120,000 plants ha^{-1}. The weed control benefits of UNR cotton are likely to be derived from more complete and rapid canopy closure compared with WR cotton (Jost and Cothren 2000). Light penetration through a UNR cotton canopy was reduced by over 70% compared with WR systems (Molin et al. 2004). Growth of prickly sida (*Sida spinosa* L.) and hyssop spurge (*Euphorbia hyssopifolia* L.) was lower in the UNR system than in the WR system (Molin et al. 2004). Narrow row spacings also suppress weed growth and reduce weed resurgence (Teasdale and Frank 1983). These attributes correlate with the amount of light reaching the soil surface (Yelverton and Coble 1991). Weed growth under shaded conditions resulted in a decrease in dry weight and branch number and an increase in height and leaf biomass (Benvenuti et al. 1994).

Growth of spurred anoda and cotton depends on the specific environmental conditions under which they are grown. Patterson et al. (1988) found that spurred anoda was more successful than cotton when grown alone at a day/night temperature regime of 26/17 C compared with 32/23 C day/night temperatures, indicating low temperatures affect cotton more adversely than spurred anoda. In addition, spurred anoda recovered from chilling conditions more completely than did cotton (Patterson and Flint 1979) and was more competitive than cotton under cooler conditions (Flint et al. 1983). In UNR cotton, the subcanopy microclimate with reduced light intensity and quality, and perhaps lower soil temperatures, may provide conditions that favor spurred anoda growth more than cotton growth.

Oxidative stress is considered to be a major limiting factor in plant productivity (Allen 1995). Oxidative stress may be caused by a multitude of unfavorable environmental factors, such as low temperature, drought, nutrient deficiency, heat, ozone, high light, and herbicides. However, each of these stresses cause oxidative damage to cells resulting in impaired cell function from the accumulation of reactive oxygen species (Inzé and Montagu 1995). Plants resistant to one oxidative stress, such as ozone or paraquat, were also cross-tolerant to other oxidative stresses, such as sulfur dioxide or triazine herbicides (Shaaltiel et al. 1988). Cotton cultivars, *DP 5415* and *Pima S-6*, differ markedly in tolerance to prometryn and may contain differences in endogenous protective mechanisms to the oxidative stress caused by prometryn (Molin and Khan 1996). The mechanisms that provide differences in sensitivity to oxidative stress caused by prometryn may confer advantages that translate into less stress arising from interference.

The objective of this research was to determine the effects of increasing spurred anoda densities on the growth and yield of cotton cultivars grown in WR and UNR cotton management systems. Our hypothesis was that these cultivars, and their management under different production practices, would respond differently to weed interference from spurred anoda in a manner consistent with their tolerance to other stress factors.

Materials and Methods

Research was conducted from 2000 to 2002 at the U.S. Department of Agriculture–Agricultural Research Station (USDA-ARS) Southern Weed Science Research Station, Stoneville, MS (33°N latitude), on a Dundee silt loam (fine-silty, mixed thermic Aeric Ochraqualf) soil. The field used in 2000 and 2002 had soil properties of pH 6.6, 1.4 % organic matter, a cation-exchange capacity (CEC) of 18 me 100 g^{-1}, and soil textural fractions of 26% sand, 56% silt, and 18% clay; and in 2001, pH 6.3, 0.9 % organic matter, a CEC of 12 me 100 g^{-1}, and soil textural fractions of 23% sand, 58% silt, and 19% clay. Field preparation consisted of fall disking and bedding. In the spring, beds were harrowed to a height of approximately 8 cm, which provided a suitable bed for planting UNR cotton that could still be furrow-irrigated. Potash, phosphorus, and sulfur (134 : 34 : 5.6 kg ha^{-1}) were applied with a granular applicator. Nitrogen (112 kg ha^{-1}) was applied as urea ammonium nitrate solution 3 to 4 wk before planting. Before planting, the experimental area was treated with paraquat at 1.1 kg ai ha^{-1} to kill existing vegetation. The experimental area was treated PRE with metolachlor at 1.1 kg ai ha^{-1} immediately after planting spurred anoda seed. Subsequent weed control was accomplished by hoeing at weekly intervals. Cotton was furrow-irrigated at the rate of 5 cm of water on August 8, 2000; July 8 and 24, 2001; and July 14, and August 4, 2002. Cotton plant height was managed by applying mepiquat chloride at first match-head square stage followed by a second application 2 wk later. Harvest preparation consisted of defoliation by tribufos at 1.5 kg ai ha^{-1}, followed by boll opening with ethephon at 1.1 kg ai ha^{-1}, and desiccation with paraquat at 1.1 kg ha^{-1}. Herbicide and growth-regulator treatments were applied with a tractor-mounted sprayer with flat fan nozzles[1] calibrated to deliver 187 L ha^{-1}.

The experimental design was a split-plot in a randomized complete block, with row spacing and cotton cultivar as main units in a factorial treatment structure. The subunit was spurred anoda density, with four levels, and density was treated as a log-linear trend. The experiment was combined over 2 yr, and year was considered a fixed effect. The experimental subplot consisted of 16 rows spaced 25-cm (UNR) apart and four rows spaced 100-cm apart (WR) and 3 m long. Cotton cultivars, Delta and Pine Land DP 5415 and Pima S-6, were planted on June 3, 2000; May 20, 2001; and May 1, 2002 at 312,000 seeds ha^{-1} using a precision planter[2] in 25-cm rows for UNR, and at 125,000 seeds ha^{-1} using a planter set at 100-cm rows for WR. Spurred anoda seeds were planted by hand, 1 d after seeding cotton, 12.5 cm from the crop row in both WR and UNR cotton. Ten to 20 seeds were sown 1 cm deep, covered with soil, and irrigated. Seedlings were hand thinned to densities of 0, 0.5, 2, and 8 spurred anoda per m^2 subplot. Spurred anoda and cotton emerged simultaneously. Spurred anoda, which died in the course of development, were replaced with plants from a nursery established on the day cotton was planted. Transplanting was performed weekly until 10 wk after planting, and plants equivalent in size to those in the plot were used as transplants. Fully expanded leaves were removed from transplants, and transplants were irrigated immediately after transplanting.

Five spurred anoda were selected at random and characterized with regard to shoot length, number of nodes, shoot dry weight, number of branches, and branch dry weight. The length of shoots was determined, rather than height, because shoots were not erect and intertwined in the cotton canopy. Shoot weight-to-length ratio was calculated from these data. Data are presented on a per-plant basis. Seed cotton yields, boll counts, and cotton plant densities were determined on the 2 m^2 center portion of the 3 m by 4 m subplot. Harvesting was performed by hand. In addition, five cotton plants were selected at random and characterized with regard to main stem height, nodes, dry weight, and branch dry weight.

The data were subjected to analysis of variance using PROC MIXED to determine the significance of main effects and any interactions among main effects (SAS 2005). Fixed effects were year, row spacing, and cultivar as classification effects and spurred anoda densities as continuous log-linear effect. Analyses were initiated with the four main effects and all two- and three-way interactions. The model was reduced by sequential elimination of nonsignificant interactions with the log-linear effect of spurred anoda density and year. Random effects for main units were replication within year and replication by row spacing and cultivar within year. Random effects for subunits were lack of fit and residual error. Lack of fit is defined as the failure of the log-linear trend to ex-

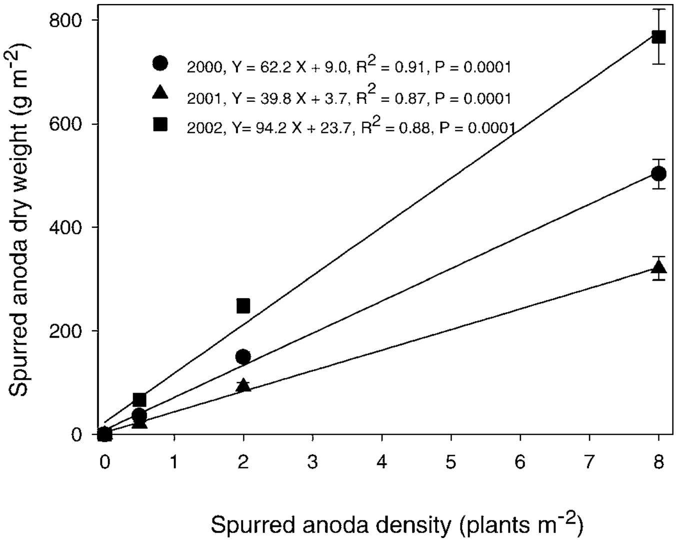

Figure 1. Relationship between spurred anoda density and spurred anoda dry weight in 2000, 2001, and 2002. Data points represent the averages over row spacing and cotton cultivars. Vertical bars represent standard errors.

plain the spurred anoda density treatment effect. Fitting a log-linear trend to the data to explain y as a function of x is the same as fitting an exponential model of the form $e^{(y)} = ax^b$.

The rectangular hyperbola model of Cousens (1985) was used to describe the relationship between spurred anoda density and percentage of seed cotton yield loss and to estimate the yield loss parameter, I, which is the percentage yield loss per weed as the weed density approaches zero (Askew and Wilcutt 2002). The rectangular hyperbola model did not fit the data as well as an exponential model, y = intercept + slope exp (log x + 1, where y = yield and x = spurred anoda density. The exponential model was used to describe the relationship between spurred anoda density and seed cotton yield, boll number per plant, cotton density, seed cotton yield per plant, boll weight, and cotton branch dry weight for each cultivar and row spacing.

Results and Discussion

Precipitation patterns in 2000 and 2002 were similar and were close to seasonal averages (Boykin et al. 1995). However, in 2001, August precipitation exceeded 20 cm, an amount several times the 30-year average of 5.8 cm (Boykin et al. 1995). The high August 2001 precipitation followed two field irrigations in July 2001. No similar August precipitation events occurred in 2000 and 2002. These differences in precipitation parallel spurred anoda and cotton response, which was similar in 2000 and 2002 as compared with 2001.

Spurred Anoda

A linear relationship between spurred anoda dry weight m^{-2} and spurred anoda density m^{-2} was observed, although the rates of dry weight accumulation per plant were different each year (Figure 1). There was an increase in dry weight of 62, 40, and 92 g for each additional spurred anoda plant in 2000, 2001, and 2002, respectively. Main effects of cotton row spacing or cultivar, and interactions between cotton row spacing or cultivar and spurred anoda density, were not significant for spurred anoda dry weight.

The lower spurred anoda dry weight per plant in 2001 was due to less branch development. The average number of spurred anoda branches, branch dry weight, and branch dry weight to total dry weight ratio were less in 2001 compared with 2000 and 2002, respectively (Table 1). Shoot length and dry weight in 2001 exceeded that in 2000 and 2002, and node numbers were not different between years (Table 1). However, shoot weight-to-length ratios were 0.106 g cm^{-1} in 2001 compared with 0.136 and 0.219 g cm^{-1} in 2000 and 2002, respectively (Table 1). These results indicate that shoots were less dense or more slender in 2001 and, perhaps, were less capable of supporting branching than in 2000 and 2002. Main effects of cotton row spacing or cultivar within year were not significant for spurred anoda shoot and branch parameters (Table 1), although year effects were significant with the exception of node number ($P = 0.0561$).

Cotton Responses to Spurred Anoda

Cotton yield response to spurred anoda density was presented both as seed cotton yield loss and as seed cotton yield. Seed cotton yield loss allowed comparisons to data from other researchers (Askew and Wilcutt 2002), whereas seed cotton yield allowed presentation of main effects and yield data without competition.

Interactions between spurred anoda and cotton varied each year. In 2001, there was no effect of spurred anoda density on the percentage of seed cotton yield loss; therefore, 2001 data are not presented. The interactions between year,

Table 1. Mean values across cultivars and row spacings for spurred anoda parameters in 2000, 2001, and 2002.

Parameters	Year 2000	Year 2001	Year 2002	F[a] value, P
Shoot length (cm)	122	181	144	102.9, < 0.0001
Node number	44.4	39.5	41.5	4.0, 0.0561
Length to node ratio (cm g^{-1})	4.48	4.67	3.54	28.3, 0.0001
Shoot dry weight (g)	16.7	19.1	31.6	96.6, < 0.0001
Shoot dry weight-to-length ratio (g cm^{-1})	0.136	0.106	0.219	13.9, < 0.0001
Total dry weight (g)	70.2	42.5	117.9	106.3, < 0.0001
Number of branches	27.7	22.6	31.9	102.9, < 0.0001
Branch dry weight (g)	53.5	23.3	86.3	98.6, < 0.0001
Branch dry weight to total dry weight ratio	0.76	0.55	0.73	482.5, < 0.0001

[a] F value and P are the probability of F being significant between years.

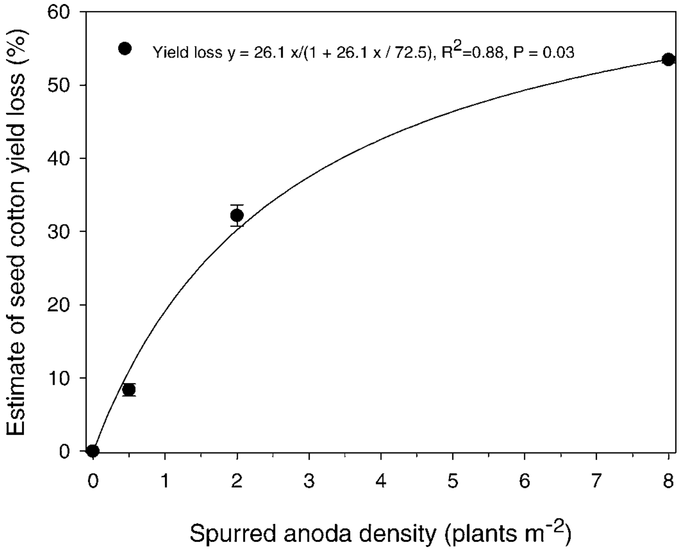

FIGURE 2. Estimate for the relationship between spurred anoda density and seed cotton yield loss averaged over years 2000 and 2002 and row spacing and cotton cultivars. Vertical bars represent standard errors.

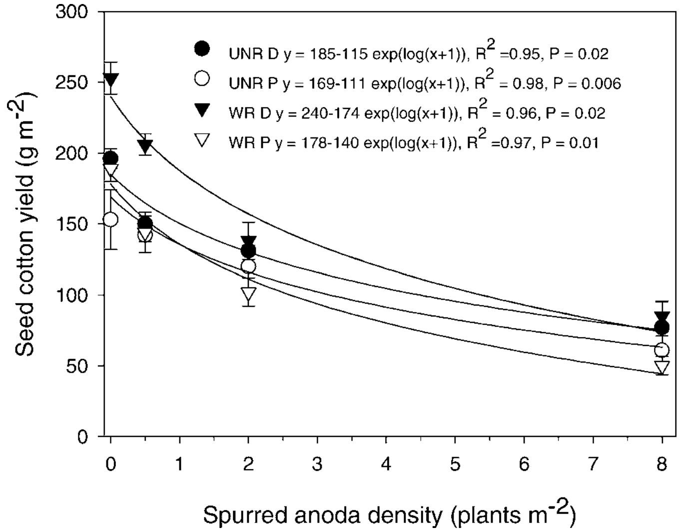

FIGURE 3. Effect of spurred anoda density on seed cotton yield. Data were combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

cotton cultivar, row spacing, and spurred anoda density were not significant for seed cotton yield loss in 2000 and 2002; therefore, data were combined for these years. There was no difference in seed cotton yield loss between 2000 and 2002, despite the spurred anoda dry weight in 2002 being 50% greater than in 2000, which in turn was 56% greater than in 2001 (Table 1). Considering that the spurred anoda branch dry weight was significantly less in 2001 compared with 2000 and 2002, spurred anoda branch development was likely a major contributor to cotton yield loss (Table 1).

Estimates of seed cotton yield losses indicate that low spurred anoda densities, such as 0.5 plants m^{-2}, could significantly impact yields (Figure 2). These estimates of the yield loss parameters from the yield loss equation (Cousens 1985) were used to determine estimates of I, the yield loss per weed as the density approaches zero, and a, the asymptotic yield loss. The estimates of I and a were 26.13 ± 1.56 (mean ± SE) and 72.54 ± 2.50, respectively (Figure 2). The yield loss parameter for spurred anoda determined by Askew and Wilcutt (2002) using the data of Chandler (1977) was 65.38 ± 17.0. Although our estimate was less than half of that determined by Askew and Wilcutt (2002), these estimates can vary widely. For example, the estimate for the yield loss per weed for sicklepod (*Cassia obtusifolia* L.) ranged from 25.94 ± 2.1 to 61.57 ± 4.6 (Askew and Wilcutt 2002). The weed biomass at 3.5 plants m^{-1} of row was 833 g (Chandler 1977). Estimated spurred anoda dry weights at 3.5 plants m^{-1} of row were determined for 2000, 2001, and 2002 to be 217, 139, and 329 g, respectively, based on the equations from Figure 2. A higher yield loss per weed may have been observed had our weed dry weights been of the same magnitude as that of Chandler (1977).

In 2001, there was no effect of spurred anoda density on the seed cotton yield, boll number, g $boll^{-1}$, density, and bolls per plant; therefore, 2001 data were not presented. The interaction between year and spurred anoda density was not significant for seed cotton yield, boll number, cotton density, weight per boll, or boll per plant in 2000 and 2002; therefore data were combined for those years. The decrease in seed cotton yield and boll number as spurred anoda density increased followed similar trends regardless of row spacing or cultivar (Figures 3 and 4). In the absence of spurred anoda interference, seed cotton yields of WR cotton were greater than UNR. However, when the spurred anoda density was compared with a regression using cotton density (plant m^{-2}), the slope was −11.5 ± 1.0 ($P < 0.0001$) for UNR cotton and −1.1 ± 1.0 ($P = 0.2954$) for WR cotton (Figure 5). On the other hand, when the spurred anoda density was compared with a regression using seed cotton weight (g $plant^{-1}$), the slope was −1.3 ± 1.4 ($P = 0.3992$) for UNR cotton and −16.9 ± 1.4 ($P < 0.0001$) for WR cotton (Figure 6). The overall decrease in seed cotton yield was due to a decrease in bolls per plant in WR and a de-

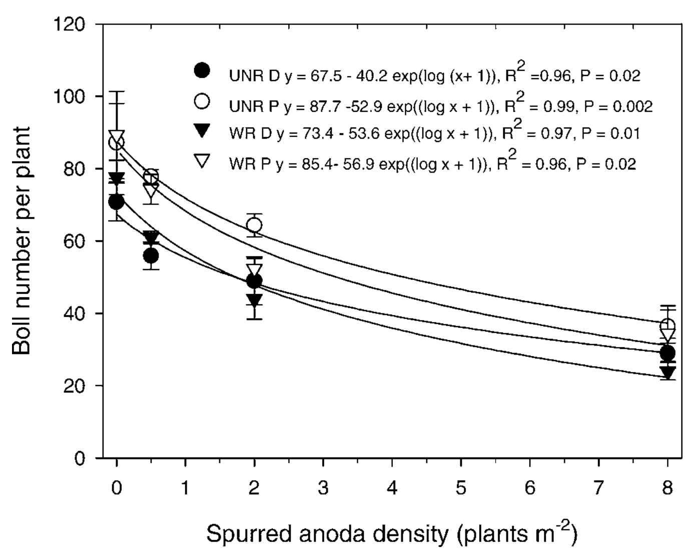

FIGURE 4. Effect of spurred anoda density on boll number per plant. Data were combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

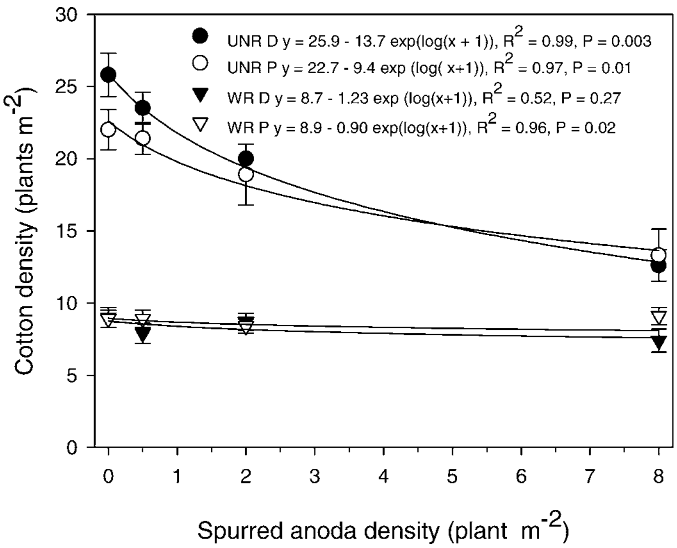

FIGURE 5. Effect of spurred anoda density on cotton density. Data were combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

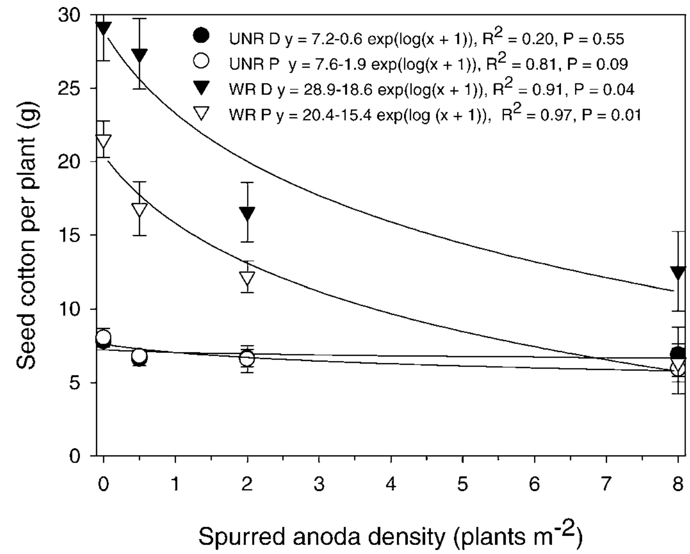

FIGURE 6. Effect of spurred anoda density on seed cotton yield per plant. Data were combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

crease in plant density, with bolls per plant remaining constant, in UNR. Thus, the decreases in seed cotton loss due to increasing spurred anoda density in the two cropping systems were caused by different mechanisms.

Addition of spurred anoda in UNR cotton may have sufficiently reduced light penetration to the extent that cotton death occurred. The UNR management systems alone have reduced light penetration through the cotton canopy (Jost and Cothren 2000; Molin et al. 2004) and altered morphology characterized by reduced branch length (Kerby et al. 1990; Munro 1987). In comparison, in WR systems, spurred anoda can cause height and yield reductions (Chandler 1977) and biomass and photosynthesis reductions as reported in greenhouse interference studies (Ratnayaka et al. 2003). Cotton subjected to low light intensities, which may mimic shading from neighboring plants, increases abscission of bolls and squares (Guinn 1974; Mauney 1979).

For DP 5415, boll weight decreased as spurred anoda density increased, regardless of row spacing, which indicated that reduced boll weight contributed to the yield loss (Figure 7). Boll weight was 1.0 g greater for DP 5415 than Pima S-6 for both row spacings, as has been reported previously for these cultivars (Unruh et al. 1994). For DP 5415, boll weight from WR was 0.4 g greater than UNR, which could indicate a potential limitation of UNR cotton. The boll weights of UNR and WR Pima S-6 were similar, regardless of spurred anoda density.

Although UNR and WR responded similarly to spurred anoda density, UNR cotton yielded less than WR cotton, and boll weight was reduced with UNR in DP 5415 in this study (Figures 3, 6, and 7). However, Jost and Cothren (2000 and 2001) reported that UNR cotton yield exceeded WR in 1 of 2 yr. Several other reports have shown little differences between yields of UNR and WR production systems (Gwathmey 1998; Kerby 1998), whereas others have shown UNR production systems to exceed WR (Atwell 1996; Atwell et al. 1996; Gwathmey 1996). Hence, our results do not support cotton management decisions such as reduced row spacing. The yield reductions observed with increasing spurred anoda densities indicate that UNR cotton may not be the system of choice where high weed pressure was expected or the crop could not be adequately protected from weeds. Of particular importance is that cotton populations in UNR may be diminished at high weed pressures. If successful weed control measures are brought to bear in heavy infested UNR cotton, there may be too few plants to recover yield. Guidelines for UNR cotton stress the importance of season-long weed control (Atwell et al. 1996; Brandon et al. 2004).

Spurred anoda density did not affect main stem length and weight, or number of nodes of cotton (data not shown).

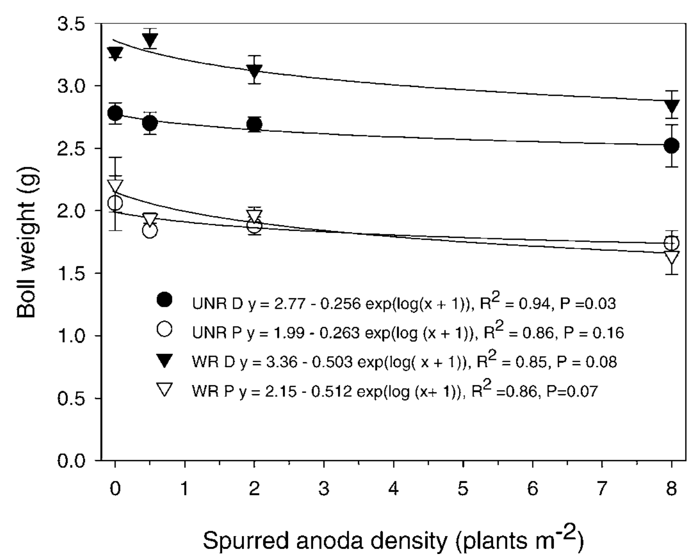

FIGURE 7. Effect of spurred anoda density on boll weight. Data were combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

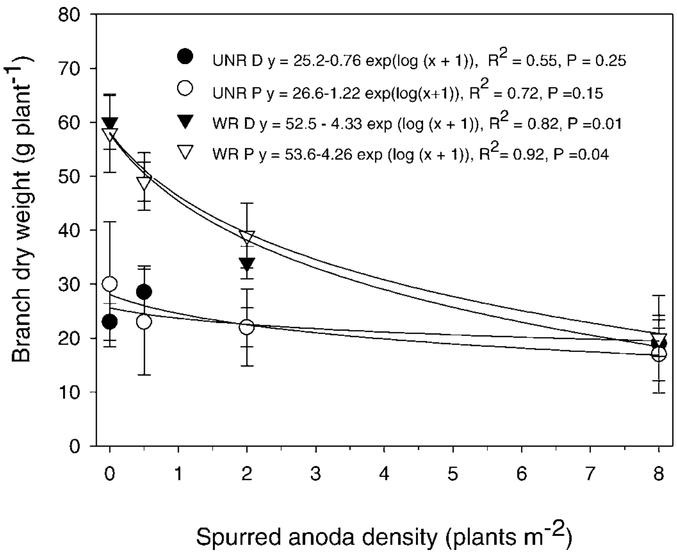

FIGURE 8. Effect of spurred anoda density on cotton branch dry weight. Data combined in 2000 and 2002. ● = ultra-narrow row [UNR], D is 'DP 5415' in UNR; ○ = UNR, P is 'Pima S-6' in UNR; ▼ = wide row [WR], D is DP 5415 in WR, △ = WR, P is Pima S-6 in WR. Vertical bars represent standard errors.

Branch weight of WR-DP 5415 and WR-Pima S-6 decreased with increasing spurred anoda density (Figure 8). Branch weight of UNR cotton was less affected than WR cotton by increasing spurred anoda density, possibly because branches were already shortened by the UNR spacing. Although branch length was not determined in this study, the decrease in branch dry weight could reflect decreased branch length, which in turn, could result in fewer fruiting sites. Branch length has been shown in cotton to decrease as plant density increased (Kerby et al. 1990). Closely spaced cotton was reported to have shorter fruiting branches than wide-row cotton (Munro 1987). The cotton yield losses (Figure 3), reduced boll weights (Figure 7), and branch dry weight reduction (Figure 8) could also be a consequence of increased soil water deficits created by high spurred anoda populations particularly late in the season in addition to shading effects from spurred anoda. Cotton dry matter accumulation (Jordan 1970) and number of fruiting positions (Guinn et al. 1981) were reduced by soil water deficits.

This study was based on the hypothesis that cotton cultivars that differ in tolerance to oxidative stress will respond to the stresses imposed by reduced row spacing and weed interference from spurred anoda in a manner consist with tolerance to oxidative stress. DP 5415 and Pima S-6 cultivars were selected based on the higher tolerance of Pima S-6 to prometryn compared with DP5415 (Molin and Khan 1996). The results did not support the hypothesis. Yields in WR were greater than in UNR in the absence of interference, indicating that reduced row spacing imposed a stress on both cotton cultivars and resulted in yield loss (Figure 3). The yields and boll weights of DP 5415 and Pima S-6 cultivars decreased similarly in response to increasing spurred anoda densities, regardless of row spacing. In DP 5415, UNR boll weight was less than in WR. The interference from spurred anoda was of sufficient magnitude to cause density-dependent thinning (Harper 1977) in UNR cotton, whereas boll load per plant remained constant, regardless of cultivar. In comparison, in WR, cotton densities remained constant, and boll load and branch weight decreased with increasing spurred anoda density, regardless of cultivar.

Sources of Materials

[1] Teejet Spray Systems Co., P.O. Box 7900, Wheaton, IL 60188.

[2] Monosem NG Plus ultra narrow row precision planter, Monosem ATI, Inc., 17135 West 116th Street, Lenexa, KS 66219.

Acknowledgments

The authors wish to thank Willie Reese for technical assistance. This research was supported by the New Mexico State Agricultural Experiment Station, New Mexico State University, and by the USDA/CSREES National Research Initiative Competitive Grants Program to T. M. S. and W. T. M. (Grant No. 99-35315-7727).

Disclaimer: Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Literature Cited

Allen, R. D. 1995. Dissection of oxidative stress tolerance using transgenic plants. Plant Physiol. 107:1049–1054.

Askew, S. D. and J. W. Wilcutt. 2002. Ladysthumb interference and seed production in cotton. Weed Sci. 50:326–332.

Atwell, S. D. 1996. Influence of ultra narrow row on cotton growth and development. Proc. Beltwide Cotton Conf. 2:1187–1188.

Atwell, S. D., R. Perkins, B. Guice, W. Stewart, J. Harden, and T. Odeneal. 1996. Essential steps to successful ultra narrow row on cotton production. Proc. Beltwide Cotton Conf. 2:1210–1211.

Benvenuti, M. Macchia, and A. Stefani. 1994. Effects of shade on reproduction and some morphological characteristics of *Abutilon theophrasti* Medicus, *Datura stramonium* L. and *Sorghum halepense* L. Pers. S. Weed Res. 34:283–288.

Boykin, D. L., R. R. Carle, C. D. Ranney, and R. Shanklin. 1995. Weather Date Summary for 1964–1993 Stoneville Mississippi. msa.ars.usda.gov/ms/Stoneville/jwdsrc/wbook/wbook.htm.

Brandon, H., F. Laws, and D. Muzzi, eds. 2004. Delta Agricultural Digest. Clarksdale, MS: Farm. p. 18.

Chandler, J. M. 1977. Interference of spurred anoda, velvetleaf, prickly sida, and Venice mallow in cotton. Weed Sci. 25:151–158.

Chandler, J. M. and W. R. Meredith, Jr. 1983. Yields of three cotton (*Gossypium hirsutum*) cultivars as influenced by spurred anoda (*Anoda cristata*). Weed Sci. 31:303–307.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107:239–252.

Dowler, C. C. 1992. Weed survey—southern states. Proc. South. Weed Sci. Soc. 45:392–407.

Dowler, C. C. 1998. Weed survey—southern states. Proc. South. Weed Sci. Soc. 51:299–313.

Flint, E. P., D. T. Patterson, and J. L. Beyers. 1983. Interference and temperature effects on growth of cotton (*Gossypium hirsutum*), spurred anoda (*Anoda cristata*), and velvetleaf (*Abutilon theophrasti*). Weed Sci. 31:892–898.

Guinn, G. 1974. Abscission of cotton floral buds and bolls as influenced by factors affecting photosynthesis and respiration. Crop Sci. 14:291–293.

Guinn, G., J. R. Mauney, and K. E. Fry. 1981. Irrigation scheduling and plant population effects on growth, bloom rates, boll abscission, and yield of cotton. Agron. J. 73:529–534.

Gwathmey, C. O. 1996. Ultra narrow cotton research in Tennessee. Proc. Beltwide Cotton Conf. 1:68.

Gwathmey, C. O. 1998. Reaching the objectives of the ultra narrow row cotton. Proc. Beltwide Cotton Conf. 1:91–92.

Harper, J. L. 1977. Population Biology of Plants. London: Academic. 892 p.

Inzé, D. and M. Van Montagu. 1995. Oxidative stress in plants. Curr. Opin. Biotechnol. 6:153–158.

Jordan, W. R. 1970. Growth of cotton seedlings in relation to maximum daily plant water potential. Agron. J. 62:699–701.

Jost, P. H. and J. T. Cothren. 2000. Growth and yield comparisons of

cotton planted in conventional and ultra-narrow row spacings. Crop Sci. 40:430–435.
Jost, P. H. and J. T. Cothren. 2001. Phenotypic alterations and crop maturity differences in ultra-narrow and conventionally spaced cotton. Crop Sci. 41:1150–1159.
Kerby, T. 1998. UNR cotton production system trial in the mid south. Proc. Beltwide Cotton Conf. 1:87–89.
Kerby, T., K. G. Cassman, and M. Keeley. 1990. Genotypes and plant densities for narrow row cotton systems, 1: height, nodes, earliness, and location of yield. Crop Sci. 30:644–649.
Mauney, J. R. 1979. Production of fruiting points. Proc. Beltwide Cotton Conf. 1:256–260.
Molin, W. T., J. A. Hugie, and K. Hirase. 2004. Prickly sida (*Sida spinosa* L.) and spurge (*Euphorbia hyssopifolia* L.) response to wide row and ultra narrow row cotton (*Gossypium hirsutum* L.) management systems. Weed Biol. Manag. 4:222–229.
Molin, W. T. and R. A. Khán. 1996. Differential tolerance of cotton (*Gossypium* sp.) cultivars to the herbicide prometryn. Pest. Biochem. Physiol. 56:1–11.
Munro, J. M. 1987. Cotton. New York: J. Wiley. 78 p.
Patterson, D. T. and E. P. Flint. 1979. Effect of chilling on cotton (*Gossypium hirsutum*), velvetleaf (*Abutilon theophrasti*), and spurred anoda (*Anoda cristata*). Weed Sci. 27:473–479.
Patterson, D. T., M. T. Highsmith, and E. P. Flint. 1988. Effects of temperature and CO_2 concentration on the growth of cotton (*Gossypium hirsutum*), spurred anoda (*Anoda cristata*), and velvetleaf (*Abutilon theophrasti*). Weed Sci. 36:751–757.
Ratnayaka, H. H., W. T. Molin, and T. M. Sterling. 2003. Physiological and antioxidant responses of cotton and spurred anoda under interference and mild drought. J. Exp. Bot. 54:2293–2305.
[SAS] Statistical Analysis Systems. 2005. SAS User's Guide. Cary, NC: SAS Institute.
Shaaltiel, Y., A. Glazer, P. F. Bocion, and J. Gressel. 1988. Cross tolerance to herbicidal and environmental oxidants of plant biotypes tolerant to paraquat, sulfur dioxide, and ozone. Pestic. Biochem. Physiol. 31:13–23.
Teasdale, J. R. and J. R. Frank. 1983. Effect of row spacing on weed interference with snap beans (*Phaseolus vulgaris*). Weed Sci. 31:81–85.
Unruh, B. L., E. R. Norton, and J. C. Silvertooth. 1994. Boll Sampling to Predict Lint Yield in Upland and Pima Cotton. Cotton, A University of Arizona Report. Tucson, AZ: University of Arizona Series P-96:44–48.
Van Gessel, M. J., J. Schroeder, and P. Westra. 1998. Comparative growth and development of four spurred anoda (*Anoda cristata*) accessions. Weed Sci. 46:91–98.
Webster, T. M. 2001. Weed survey—southern states. Proc. South. Weed Sci. Soc. 54:244–259.
Yelverton, F. H. and H. D. Coble. 1991. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (*Glycine max*). Weed Technol. 5:169–174.

Received June 8, 2005, and approved March 27, 2006.