COTTON WATER-DEFICIT STRESS, AGE, AND CULTIVARS AS MODERATING FACTORS OF COTTON FLEAHOPPER ABUNDANCE AND YIELD LOSS

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Abstract

Field experiments were conducted in 2012 and 2013 during drought conditions in South Texas and the Texas High Plains to test whether cotton water-deficit stress, age, and cultivars are moderate factors that affect cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) (Hemiptera: Miridae), abundance and yield loss. Irrigation and sequential plantings of several cultivars were used to simulate a range of water-deficit stress, plant ages, and cultivar variability. Cotton grown under these experimental conditions were exposed to cotton fleahopper using natural and artificial infestation. Cotton cultivars had a strong influence on cotton fleahopper abundance, with higher densities on Stoneville cultivar 5458 B2RF, which is relatively pubescent, than densities on the Phytogen cultivar 367 WRF, which is relatively glabrous, in South Texas ($p < 0.04$). But the strong cultivar effects on cotton fleahopper abundance did not correspond to yield reduction. No water regime effects on cotton fleahopper densities were observed in 2012 ($p > 0.05$), whereas cotton fleahopper densities increased on older cotton grown under no water stress in 2013 in South Texas ($p < 0.05$). In contrast, yield response was primarily sensitive to soil moisture conditions (up to 50% yield reduction when grown in dryland mimic conditions below 75% crop ET replacement, $p < 0.0009$). Yield loss attributable to cotton fleahopper activity was relatively lower than that attributable to water-deficit stress. Modest water and cotton fleahopper stress synergies occurred, with enhanced yield loss attributable to cotton fleahopper seen in cotton grown in high water-deficit conditions in the High Plains ($p < 0.05$). These yield trends were consistent across cultivars (no interaction with cultivar), even though cotton fleahopper populations varied significantly across cultivars.

Introduction

Cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) (Hemiptera: Miridae), feeding on squares (i.e., pre-floral buds) of cotton, *Gossypium hirsutum* L. (Malvaceae), has reduced yield by up to 6% and also has delayed harvest in the southwest and mid-south (USA) cotton growing regions. But variability in the relationship of cotton fleahopper-induced square loss to subsequent yield loss under similar cotton fleahopper feeding pressure occurs and presents a challenge to cotton fleahopper management using traditional sampling and economic threshold methods. In practice, field history of cotton fleahopper damage, weather conditions, and IPM practitioner sensitivity to square loss have been used to adjust decision-making locally. In South Texas, one to four foliar sprays for cotton fleahopper control are common across cotton fields that have apparently similar pest risk based on similar cotton fleahopper density estimates generated from pest monitoring (Brewer, pers. obs).

In review of the literature, cotton yield loss variability to cotton fleahopper feeding has been partly associated with cultivar differences (Holtzer and Sterling, 1980), including heritable traits considered for plant resistance (Knutson et al., 2013). Ring et al. (1993) calculated visual-based cotton fleahopper economic injury levels (EIL) of between 0.015 and 0.45 insects per plant. The wide range was attributed to cultivar influences, based on comparison of yield—cotton fleahopper density relationships. Parajulee et al. (2006) partly attributed severity of cotton square loss to susceptibility differences across stages of cotton development and age of the reproductive tissues when cotton fleahopper migrated into fields from overwintering sites. Cotton may also compensate for early square loss (Anon, 2015). Cotton water deficit-induced stress (water stress) also has been associated with square retention rates (Stewart and Sterling, 1989), which may influence plant sensitivity to cotton fleahopper feeding. These factors may be the underpinning of why thresholds in outreach materials vary across cotton growing regions of the southwest (i.e., 0.10 to 0.30 insects per terminal visually inspected during the first three weeks of squaring) (Anon, 2015), and why this insect is a minor pest in other locations. But if management strategies (i.e., planting time and cultivar selection) and weather conditions (i.e., poor rainfall in dryland production areas) influence cotton sensitivity to cotton fleahopper feeding, direct density estimation of cotton fleahopper for decision-making may give false indication of damage potential and improperly trigger insecticide applications using economic thresholds based on insect population estimates.

Here, we hypothesize that cotton water stress, age, and cultivars affect cotton fleahopper abundance and yield loss. The practical goal of understanding these relationships is to improve our assessment of cotton risk from cotton fleahopper and begin generation of a data base to make objective economic threshold adjustments under variable weather and management practices.

Methods

Drought conditions in Texas, 2012 and 2013, provided opportunity to assess cotton fleahopper activity and cotton response in a high contrast of water stress conditions manipulated by using irrigation in a field setting. Cotton fleahopper abundance and cotton response including yield were evaluated in high to low water-deficit conditions in two widely separated cotton growing regions: the coastal region of South Texas and the Texas High Plains. Standard agronomic practices were used. Cultivars, planting dates, and natural and artificial infestations of cotton fleahopper were used to optimize contrast in cotton fleahoppper pressure and cotton response. Experimental manipulation varied between South Texas and the Texas High Plains per opportunities and constraints outlined below.

South Texas location

A natural cotton fleahopper population was followed across time at a Corpus Christi, TX, location. A split plot design was used to expose a natural population of cotton fleahopper to a soil moisture gradient of three (2012) and two (2013) water regimes (main plot), to two different plant ages by using two planting dates (sub-plot), and to two cotton cultivars (sub-sub-plot). An insecticide treatment was added as a final split plot in the design to directly test for cotton fleahopper-induced yield loss. Water regimes were established by using an above-ground drip irrigation system. Square injury from cotton fleahopper feeding was also confirmed by visual observation. The specific plot site was moved yearly so that the previous year crop was either sorghum or corn. There were five replications, and individual plot size was four 15.24 m rows on 96.5 cm centers.

In 2012, the water regimes used were a substantial water-deficit dryland mimic using minimal irrigation during drought (2.90 cm of irrigation), a moderate water-deficit dryland mimic using irrigation targeting 75% crop evapotranspiration replacement (crop ET) (6.245 cm of irrigation), and a non-water-deficit mimic using irrigation targeting 90% crop ET (10.85 cm of irrigation). Cumulative rainfall from planting to harvest was 15.5 cm for both plantings. The surface irrigation drip tubes were 17 mm (dia.) and emitted 3.4 liters per h. The two planting dates were April 12 and 30. The two cultivars were Phytogen 367 WRF (Dow AgroSciences) and Stoneville 5458 B2RF (Bayer CropScience). The Stoneville cultivar was relatively pubescent, a trait which has been associated with high cotton fleahopper populations (Knutson et al. 2013), while the Phytogen cultivar was more glabrous with a lower density of trichomes on the leaves. The last split was a foliar insecticide treatment: no insecticide and acephate applied four times at a rate of 560.4 g per ha weekly beginning at first week of squaring. In 2013, two water regimes were used: a substantial water-deficit dryland mimic which required irrigation due to the continuing drought (15.49 cm of irrigation for an earlier planting and 20.07 cm of irrigation for a later planting) and the non-water-deficit mimic using irrigation targeting 90% crop ET replacement (26.42 cm of irrigation for an earlier planting and 35.05 cm or irrigation for a later planting). Cumulative rainfall was 31.0 cm and 27.9 cm for the earlier and later planting, respectively, measured from planting to harvest. The two planting dates in 2013 were April 22 and May 6, moved later this year to further encourage cotton fleahopper movement into the crop during the ongoing drought. The same cultivars were used as in 2012. The insecticide treatment was changed to thiamethoxam (Centric 40 WG, Syngenta) applied three times at a rate of 87.6 g per ha weekly beginning at first week of squaring.

High Plains location

The Lamesa, TX, location experienced barely detectable cotton fleahopper populations in 2013 likely due to the extended drought; therefore we focused on boll retention and subsequent yield using an augmented population of cotton fleahopper. Water stress and cotton fleahopper pressure were each manipulated at two levels in a randomized complete block. A high water-deficit dryland mimic (11.43 cm of irrigation) and a moderate water-deficit dryland mimic (22.86 cm of irrigation) were delivered through a low-energy precision application via center pivot irrigation system. Only trace amounts of rainfall were detected. An augmentative release of cotton fleahopper was used to directly test for yield response to cotton fleahopper as compared with a no infestation control. Square injury from cotton fleahopper feeding was also confirmed by visual observation. The cultivar planted was Phytogen 367 WRF. The treatments were replicated three times, and plot size was 13.7 m by four rows on 101.6 cm row centers.

Plants were artificially infested during the third week of squaring at a rate of five cotton fleahopper nymphs per plant across a three meter uniform section of each plot. The source of nymphs was from the wild host plant woolly croton, *Croton capitatus* Michx. Woolly croton was collected in the fall near College Station, TX, and placed in laboratory cold storage (Lubbock, TX) until fleahoppers were needed the following year following the protocol of Hakeem and Parajulee (2015). In brief, conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment in order to induce hatching of overwintered eggs embedded in the woolly croton stems, and emerged cotton fleahoppers were placed on fresh green beans. At approximately ten days post-emergence, fleahopper nymphs were provided fresh cotton squares as a training substrate prior to field release. Releases were conducted by aspirating third to fourth instar cotton fleahopper nymphs from the laboratory colony, transferring them into 1.9 cm by 3.2 cm plastic vials, then depositing them onto the terminals of plants in each treatment plot.

Measurements and analyses

At the South Texas location, insect counts using a beat bucket technique (Brewer et al., 2012) were made on a weekly basis after cotton fleahopper numbers exceeded 0.10 bugs per plant through the sixth week of squaring. A total of 20 plants were sampled per plot. Plant data included lint yield and percent boll retention measured near harvest. Weekly data showing treatment differences were reported here. At the Texas High Plains location, the data included number of harvestable bolls and lint yield.

All measurements were analyzed with ANOVA, conforming to the plot designs for the South Texas and Texas High Plains locations. Count data were transformed by the square root of the count + 0.5. Percent boll retention data from South Texas were transformed by the arcsine of the square root of the proportion. Based on our hypotheses, we gave special attention to cotton fleahopper density and yield patterns discerned from significant interactions between water stress and plant age, and water stress and cultivar. Cotton fleahopper-influenced effects were experimentally verified by a significant insecticide spray (South Texas) or cotton fleahopper augmentation (Texas High Plains) effect. Using the split plot design and limiting each split to two treatments in the South Texas location, differences in means were directed tested with the ANOVA. In the Texas High Plains location, Tukey's Honest Significant Difference test was used to compare means across four treatments.

Results and Discussion

Cotton fleahopper density and plant response measures of boll retention and yield were sensitive to changes in cotton water-deficit stress, age, and cultivars. Plant response was partly attributable to cotton fleahopper activity. Typical square injury caused by cotton fleahopper was observed (Anon, 2015). In South Texas, yield reduction caused by cotton fleahopper injury was experimentally verified in 2012 (spray effect: $p = 0.005$) and to a more limited extent in 2013 especially for Phytogen 367 WRF (cultivar by spray interaction: $p = 0.028$) (Fig. 1). Water-deficit stress and cotton fleahopper stress influences on cotton yield appeared to function independently (no water stress by spray interaction, $p > 0.10$).

In the Texas High Plains, yield reduction attributable to water-deficit stress and cotton fleahoppers were observed, especially in the high water-deficit regime. Synergies in water and cotton fleahopper stress occurred, with enhanced yield loss attributable to cotton fleahopper stress seen in cotton grown in high water-deficit condition artificially infested with cotton fleahopper ($p < 0.05$) but were not seen in cotton grown in a moderate water-deficit regime (Fig. 2).

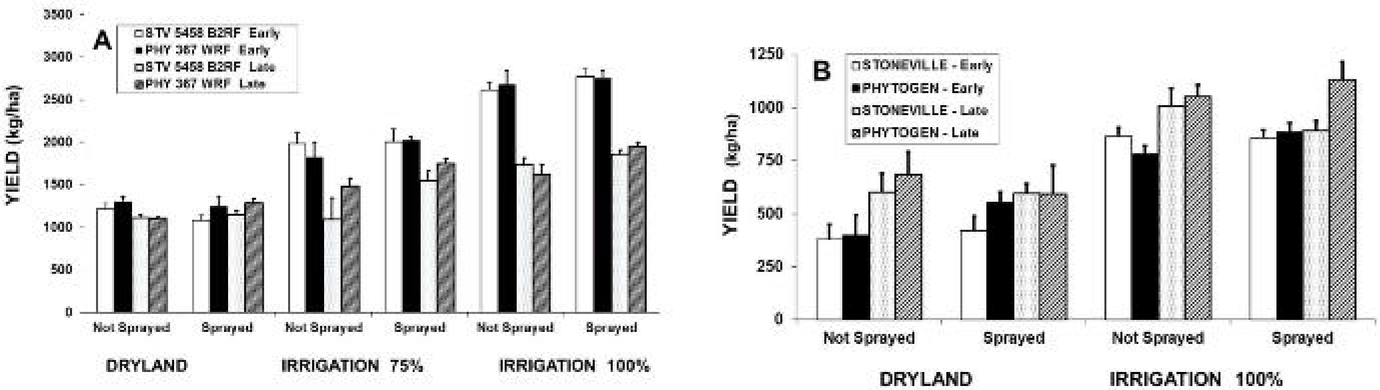
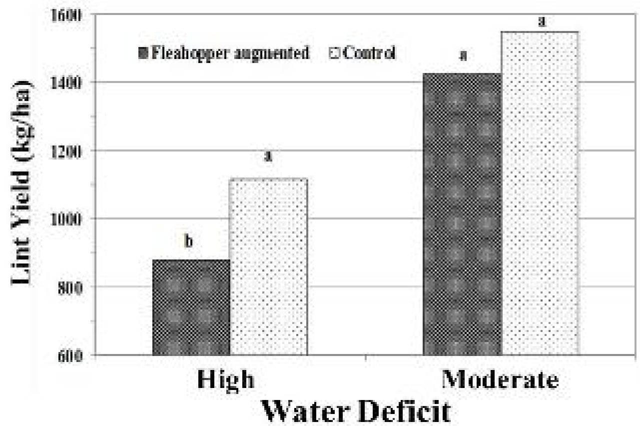


Fig. 1. Lint yield (kg/ha) across water regimes (a dryland mimic [dryland], targeting 75% crop ET replacement in 2012 only [irrigation75%], and targeting 90% crop ET replacement [irrigation 100%]), planting dates (early and late),



cultivars (Phytogen 367 WRF and Stoneville 5458 B2RF), and insecticide protection (sprayed and not sprayed) exposed to a natural population of cotton fleahopper in 2012 (A), and 2013 (B), Corpus Christi, TX.

Fig. 2. Lint yield (kg/ha) across high water-deficit (High) and moderate water-deficit (Moderate) regimes exposed to augmented populations of cotton fleahopper (fleahopper augmentation and control), Lamesa, TX, 2013. Different letters above bars indicated signficant differences based on Tukey's Honest Significant Difference test (p = 0.05).

South Texas location

Cotton fleahopper densities in the early planting exceeded an economic threshold of 0.30 cotton fleahoppers per plant using beat bucket sampling, which is about equal to 0.15 cotton fleahopper per terminal visually inspected (Brewer et al., 2012). Cotton fleahopper was most abundant during the fourth through sixth week of squaring (the early planting) in 2012 (planting date effect on June 1 and June 14: $p < 0.0006$) (Fig. 3), with more cotton fleahoppers occurring in the unsprayed plots (spray effect: $p < 0.0001$).

Cotton fleahopper densities were higher in the Stoneville cultivar ($p < 0.04$). They were also higher in the earlier planted cotton when grown in poorer soil moisture conditions during the fourth week of squaring (June 1 water regime by planting date interaction: $p < 0.011$) (Fig. 3).

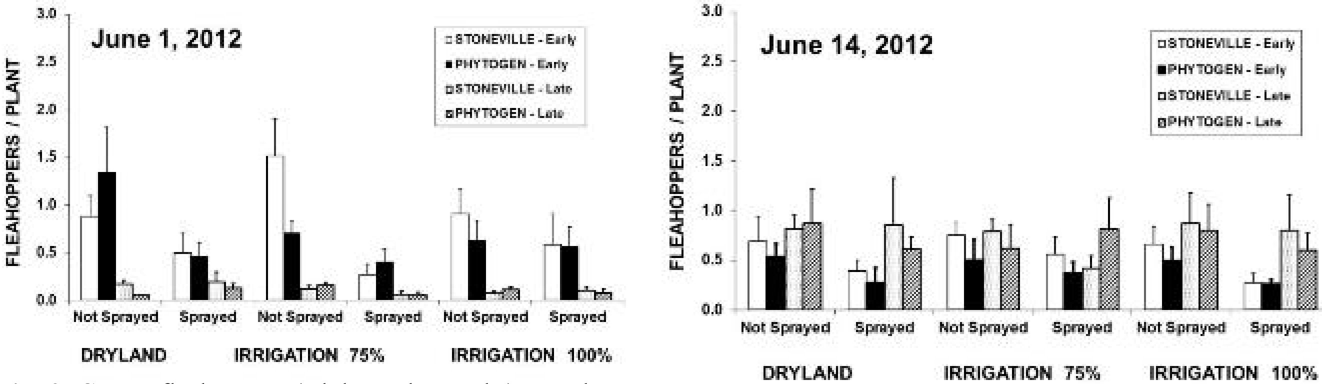


Fig. 3. Cotton fleahoppers (adults and nymphs) per plant during two sampling dates (June 1 and June 14) taken during the first six weeks of squaring. Data taken were across water regimes (a dryland mimic [dryland], targeting 75% crop ET replacement [irrigation 75%], and targeting 90% crop ET replacement [irrigation 100%]), planting dates (early and late), cultivars (Phytogen 367 WRF and Stoneville 5458 B2RF), and insecticide protection (sprayed and not sprayed) exposed to a natural population of cotton fleahopper, Corpus Christi, TX, 2012.

For earlier planted cotton, cotton fleahopper densities were highest under irrigation targeting 90% crop ET replacement in 2013 (July 3 and July 11 water regime by planting date interaction: $p < 0.05$) (Fig. 4). Insecticide treatment significantly reduced the populations where they were found in high density under good soil moisture, on the Stoneville cultivar, and on early planted cotton (various interactions with the spray treatment were significant, $p < 0.05$) (Fig. 4).

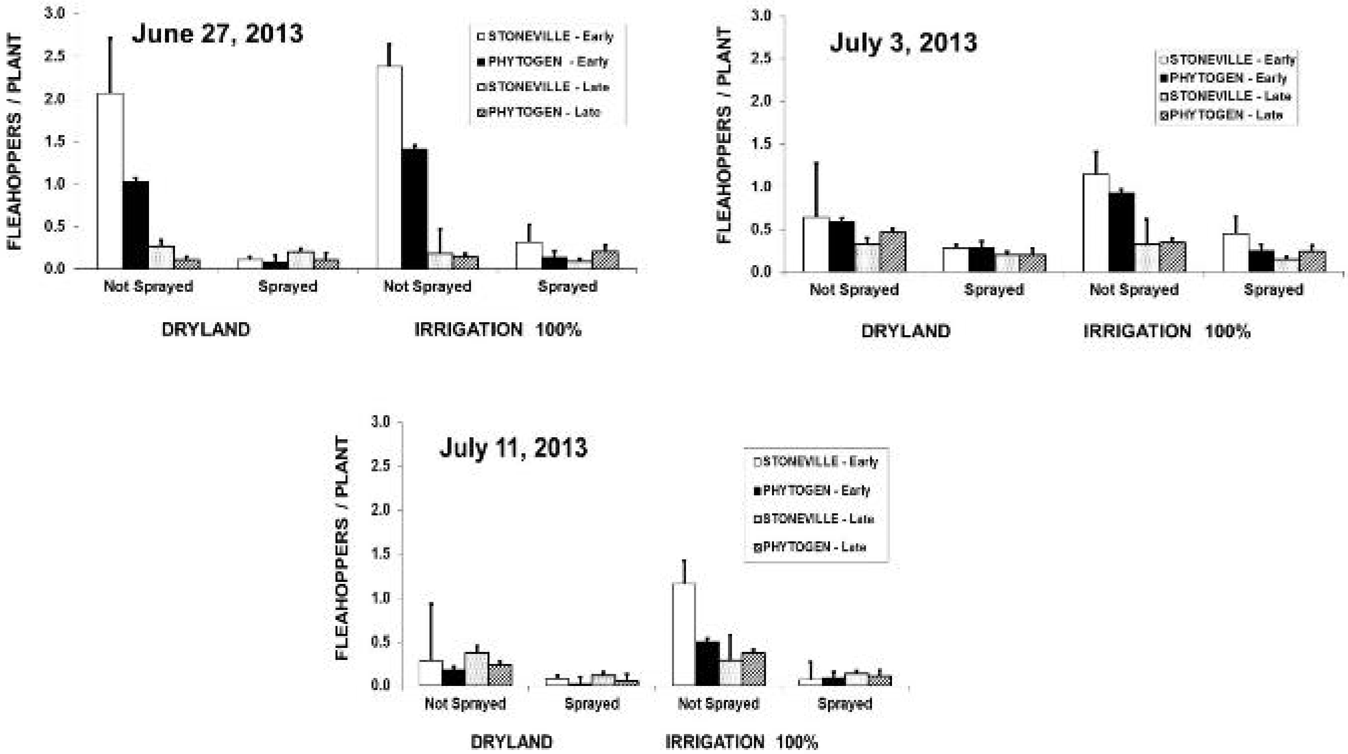


Fig. 4. Cotton fleahoppers (adults & nymphs) per plant during three sampling dates (June 27, July 3, and July 11) taken during the first six weeks of squaring. Data were taken were across water regimes (a dryland mimic [dryland] and targeting 90% crop ET replacement [irrigation 100%]), planting dates (early and late), cultivars (Phytogen 367 WRF and Stoneville 5458 B2RF), and insecticide protection (sprayed and not sprayed) exposed to a natural population of cotton fleahopper, Corpus Christi, TX, 2013.

Cotton cultivars had a strong influence on cotton fleahopper abundance. In 2012, higher densities were found on Stoneville 5458 B2RF than on Phytogen 367 WRF on June 14 ($f = 4.91$, d.f. = 1,24; $p = 0.036$) (Fig. 3). In 2013, the Stoneville cultivar planted early tended to build the highest cotton fleahopper populations (July 3 planting date by cultivar interaction: $p = 0.025$) (Fig. 4). Water stress had no to modest effects on cotton fleahopper densities. No water regime effects on cotton fleahopper densities nor two-way water regime interactions with other factors were observed in 2012 ($p > 0.05$). In 2013, cotton fleahopper densities continued to build on older cotton (the early planted cotton) grown under no water stress (July 3 and July 11 planting date by water regime interaction: $p = 0.05$) (Fig. 4).

In contrast, water stress had considerable influence on plant response, while cultivar influences on plant response were much reduced compared to its influence on cotton fleahopper density. Boll retention tended to be marginally higher in the early planted cotton growing under no water stress for both cultivars in 2012 (planting date by water regime interaction: $p = 0.06$) (Fig. 5). In 2013, boll retention was greater in non-water stress conditions (water regime effect: $p = 0.0037$). Boll retention did not significantly vary across cultivars ($p > 0.05$) (Fig. 5). We note that boll retention data were not taken in sprayed plots; therefore yield data was used to directly test for cotton fleahopper-induced plant response.

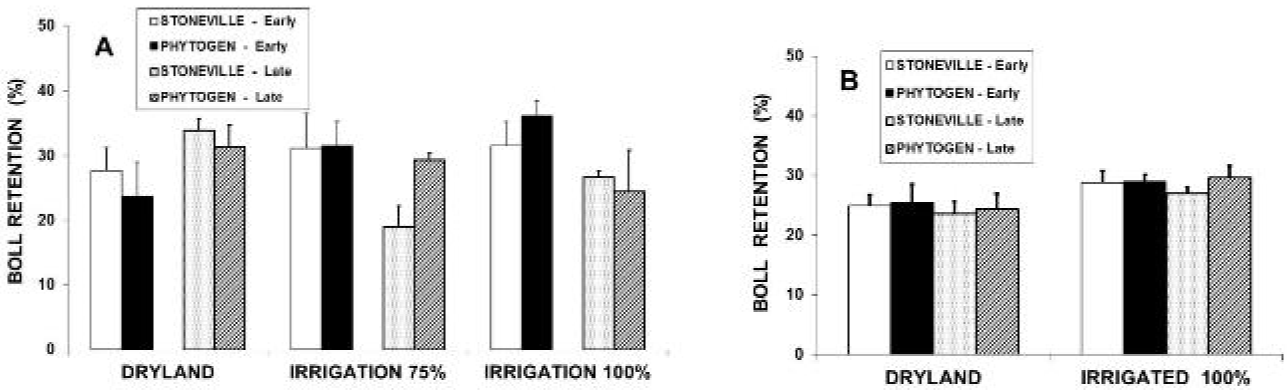


Fig 5. Percent boll retention averaged from all plant bolls taken across water regimes (a dryland mimic [dryland], targeting 75% crop ET replacement in 2012 only [irrigation 75%], and targeting 90% crop ET replacement [irrigation 100%]), planting dates (early and late), and cultivars (Phytogen 367 WRF and Stoneville 5458 B2RF) exposed to a natural population of cotton fleahopper in 2012 (A), and 2013 (B), Corpus Christi, TX.

Yield reduction was less severe in cotton grown under improved soil moisture (where boll retention was also higher), and there was comparably modest yield loss attributable to cotton fleahopper activity. The highest yields were in plots with improved soil moisture (2012 water regime effect: $p < 0.0001$, and 2013 water regime effect, *fp* = 0.0008) (Fig. 1). In 2012, the maximum yield occurred in early planted cotton grown under no water stress (water regime by planting date interaction: *p*- < 0.0001) (Fig. 1), even though cotton fleahoppers were more abundant on the early planted cotton (Fig. 3). The strong influence of soil moisture on yield was consistent across cultivars (no interaction with cultivar), even though cotton fleahopper populations varied significantly across cultivars (Figs. 3 and 4). Controlling fleahoppers modestly benefitted yield in 2012 as indicated by the significant spray factor noted above ($p = 0.005$), and modest yield benefits from controlling cotton fleahopper was also seen in 2013 for the Phytogen cultivar as noted above ($p = 0.028$). Although yield loss attributed to cotton fleahopper was greater on the Phytogen cultivar than on the Stoneville cultivar (Fig. 1), it commonly had fewer cotton fleahoppers (Fig. 3). As noted by Knutson et al. (2013), cotton resistance to cotton fleahopper includes tolerance in which cotton fleahopper presence does not induce yield loss.

High Plains location

In 2013, lint yield was lower in the fleahopper augmented treatment under the high water-deficit regime, while cotton fleahopper augmentation did not significantly lower yield under the moderate water-deficit regime ($p < 0.05$, Fig. 2). The plant may be able to compensate for fleahopper-induced fruit loss under no to modest water-deficit growing conditions. Although not significantly different ($p > 0.05$), the difference in total number of harvestable bolls attributable to the cotton fleahopper augmentation under the high water-deficit water regime (1.4 bolls per plant) was numerically greater than that for moderate water-deficit regime (0.4 bolls per plant) (Fig. 6).

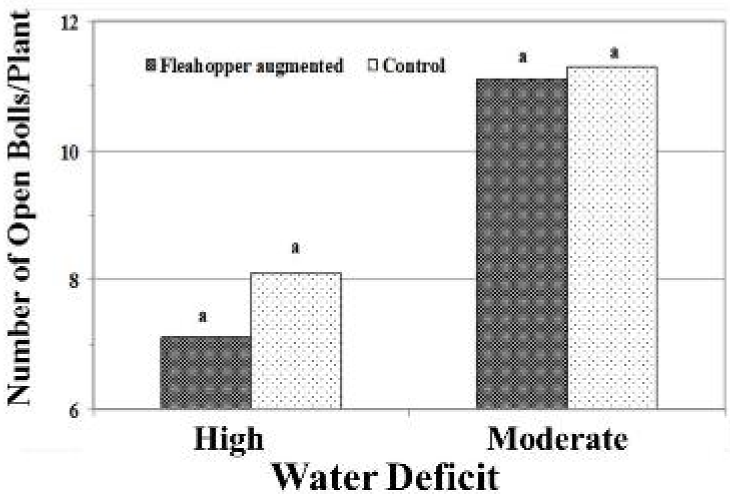


Fig. 6. Total number of harvestable bolls across high water-deficit (High) and moderate water-deficit (Moderate) regimes exposed to augmented populations of cotton fleahopper (fleahopper augmentation and control), Lamesa, TX, 2013. Different letters above bars indicated signficant differences based on Tukey's Honest Significant Difference test (p = 0.05).

Final Remarks

In our study, plant age and cultivar selection were main moderators of cotton fleahopper populations (Figs. 3 and 4), although strong cultivar effects on cotton fleahopper dynamics did not correspond to yield reduction (Fig. 1). We saw few planting date by cultivar interactions, suggesting the influence of these strategies on cotton fleahopper pest management can be considered independently. Water-deficit stress had much more modest influence on cotton fleahopper abundance (Figs. 3 and 4).

In regard to plant response, cotton fleahopper-associated yield loss was lower than water stress-associated yield loss, and the combined effects of water and cotton fleahopper stress on yield were variable. In South Texas, water stress directly affected yield with modest influence from cotton fleahopper (Figs. 1, 2, and 3). In the Texas High Plains, high water stress resulted in reduced yield and a trend toward reduced boll loads, and the effect was enhanced when cotton fleahopper was present (Figs. 2 and 6). The augmented release rate of five nymphs per plant at week three of squaring may have represented higher acute cotton fleahopper pressure than the natural populations experienced in South Texas. These results reflect the field variability seen in plant response to cotton fleahopper feeding, and the paradox of observations of different frequencies of insecticide sprays used to control cotton fleahoppers under apparently equal cotton fleahopper pressure.

We live in a climate that produces highly variable weather, as seen in drought conditions in Texas from 2011 to 2013. For the case of cotton fleahopper feeding on cotton, water-deficit stress affects yield substantially and directly, while our data supported a more modest water stress influence on cotton fleahopper dynamics. Cottton fleahopper-associated yield loss was lower than water stress-associated yield loss. Elevated yield loss attributable to the combined effects of cotton fleahopper and water-deficit stress was was more variable, seen under manipulated (artificial infestations) high cotton fleahopper densities. Cotton fleahopper decision-making may be more cultivar specific than as implied when reviewing regionally-based thresholds that do not mention cultivars (Anon, 2015). Cultivar sensitivity to cotton fleahopper injury leading to yield differences has been previously demonstrated for past cotton cultivars (Ring et al., 1993). For future work, use of more agriculturally representative cultivars should be emphasized, grown under a number of cotton fleahopper exposure scenarios. Including water regime scenarios remains relevant, but enhanced combined effects of water deficit-stress and cotton fleahopper stress appear to be less common than originally hypothesized.

Acknowledgements

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