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Management Strategies for Sugarcane Aphid, Melanaphis Sacchari (Zehntner), in Grain Sorghum

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By

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Grain sorghum is a drought tolerant crop used in the Mid-south region in rotation with corn, cotton, soybeans, and corn. In 2015 and 2016, research was conducted to determine the influence of insecticide treatment, planting date, planting population, hybrid, and environmental temperatures on sugarcane aphid, *Melanaphis sacchari* (Zehntner), populations and yield in grain sorghum, *Sorghum bicolor* (L.) Moench. In general, cooler temperatures had a negative effect on sugarcane aphid control with sulfoxaflor and flupyradifurone. Additionally, there was a negative relationship between grain sorghum plant population and sugarcane aphid densities per plant. These data suggest management of sugarcane aphid with insecticide seed treatments and foliar sprays is critical for maximizing grain sorghum yields. Additionally, growers should wait for warmer temperatures to ensure optimum control.

DEDICATION

William, thank you for your constant love and support. I would not want anyone else by my side during these last few years. I know that God has a plan for us and I cannot wait see what the future holds. To my mother, thank you for instilling in me, determination and that I can be whomever I want and to always fight for those things that I believe in. I thank you for teaching me that everything is not always within my control, but instead to believe in the perfect timing of Christ. To my dad, thank you for showing me the importance of hard work, even when it involves blood, sweat, and tears. You have shown me that no matter how hard things may be at times, hard work does truly pay off. Without the support and love each of you have provided all these years, I would not be the person I am today nor would I have the drive to better myself with each passing day.

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CHAPTER I

INFLUENCE OF TEMPERATURE ON THE EFFICACY OF FOLIAR INSECTICIDE SPRAYS AGAINST SUGARCANE APHID (HEMIPTERA: APHIDIDAE) POPULATIONS IN GRAIN SORGHUM

Abstract

The use of foliar insecticide sprays at low temperatures may result in decreased efficacy in grain sorghum, *Sorghum bicolor* L. Moench, when managing sugarcane aphid, *Melanaphis sacchari* (Zehntner). To test this hypothesis, two insecticides, sulfoxaflor and flupyradifurone, were evaluated to determine the impact of temperature on their efficacy against sugarcane aphid in grain sorghum. Sorghum was treated at the soft dough growth stage with sulfoxaflor and flupyradifurone, as well as an untreated check. Leaf discs were pulled at various intervals from 0 to 10 days after treatment, placed in water agar plates, infested with aphids, placed in growth chambers at 15.5°C or 29.4°C and evaluated 48 hours after each interval: 1, 2, 3, 5, 7, and 10 DAT. In 2015, both insecticides resulted in similar levels of sugarcane aphid mortality and efficacy decreased at a similar rate at 15.5°C. At 29.0°C, flupyradifurone resulted in greater mortality of sugarcane aphid than sulfoxaflor as length of time after treatment increased, suggesting that it provides longer residual control than sulfoxaflor. In 2016, both insecticides provided poor control of sugarcane aphid at 15.5°C for all time intervals. At 29.0°C, flupyradifurone provided overall better control than sulfoxaflor. These data

suggest that lower temperatures can reduce the efficacy of both sulfoxaflor and flupyradifurone. Additionally, flupyradifurone appeared to provide longer residual control and overall better control of sugarcane aphid than sulfoxaflor. If lower temperatures do occur when sugarcane aphid populations exceed current thresholds, growers should consider the weather forecast for the next several days in their pest management decision making process.

Introduction

Grain sorghum, *Sorghum bicolor* L. Moench, is one of the top five cereal grain crops and is important for livestock feed in many areas of the world (United Sorghum Checkoff 2008). Approximately 2.62 million hectares of grain sorghum were harvested in the United States during 2016, a drastic decrease from 3.42 million hectares harvested in 2015 (NASS 2016). Sorghum is inherently a heat and drought tolerant crop, requiring less water to produce grain yield at full potential (Rosenow et al.1983). It is also an important rotation partner for other crops to aid in weed and pest management (Cronholm et al. 1998).

Numerous insect species infest grain sorghum throughout the season, but only a few are economically important (Cronholm et al. 1998). The most consistent economic insect pests of grain sorghum in the southern U.S. prior to 2014 were sorghum midge, *Stenodiplosis sorghicola* (Coquillett); sorghum webworm, *Nola sorghiella* (Riley); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); and corn earworm, *Helicoverpa zea* (Boddie), (Cronholm et al. 1998). A new pest of grain sorghum, the sugarcane aphid, *Melanaphis sacchari* (Zehntner), was discovered in Texas, Louisiana, and Mississippi in 2013 (Elliott et al. 2015).

Sugarcane aphids are soft bodied insects that may vary from a yellow to gray color and can be alate or apteran depending on environmental conditions (Singh et al. 2004). Key morphological features distinguishing it from other aphid species found in grain sorghum include black cornicle tips and black tarsi (Bowling et al. 2016). They reproduce asexually and can produce 30-60 nymphs. (Singh et al. 2004). It can take as little as four days for an aphid to fully mature through four nymphal stages (Bowling et al. 2016). Adult aphids can live up to 28 days (van Rensburg 1973).

The sugarcane aphid was first detected in Hawaii on sugarcane in 1896 (Zimmerman 1948). In 2013, the pest was first observed in the U.S. on grain sorghum (Bowling et al. 2016). Whether it was a host switch or a new introduction of an existing biotype from overseas is currently heavily debated (Bowling et al. 2016). This pest rapidly dispersed throughout the sorghum producing regions of the U. S. Twelve states confirmed sugarcane aphid infestations during 2014, followed by 17 states in 2015 including Arkansas, Kansas, Oklahoma, and Texas, the top four sorghum producing states (Brown et al. 2015, Bowling et al. 2016, NASS 2016). By the end of 2015, sugarcane aphid infestations had spread to 97% of the grain sorghum planted in the U. S. (Bowling et al. 2016). Because of rapid population growth, aggressive feeding nature, and honeydew production, this aphid caused substantial yield losses in grain sorghum (Bowling et al. 2016). Sugarcane aphid also causes physical damage to developing plants, disrupting vascular tissues and nutrient flow when present in high numbers (Bowling et al. 2016).

Sugarcane aphid feeds on the underside of leaves and stems, typically starting at the bottom of the plant and working upward as populations increase (Narayana 1975).

Because sugarcane aphid is a new pest of grain sorghum in the U.S., little is known about their damage potential to grain sorghum. Most of the literature on sugarcane aphid feeding on sorghum is from other areas of the world such as India. Initial symptoms of feeding are characterized by yellowing and purpling of leaf tissue that may eventually lead to necrosis (Singh et al. 2004). Large infestations prior to panicle emergence may cause uneven flowering or prevent panicle emergence, reduce grain size and quality, or completely kill the grain sorghum plant (Singh et al. 2004). Uneven flowering can make management of other insect pests in sorghum, such as the sorghum midge, more difficult (Cronholm et al. 1998). Sorghum midge adults oviposit in glumes of sorghum flowers, where the larva feeds on the developing seed (Cronholm et al. 1998). Because the sorghum flowering and pollination process can take 4-9 days to complete, insecticide applications targeting adult sorghum midge must be well timed to prevent oviposition. In fields with uniform panicle emergence and flowering, one well timed application is usually sufficient (Vanderlip 1993, Cronholm et al. 1998). In fields where panicle emergence is not uniform, multiple applications are often needed to provide adequate control of sorghum midge (Cronholm et al. 1998). Therefore, management of sugarcane aphid prior to panicle emergence is important not only to minimize direct damage, but also to facilitate management of other pests (Cronholm et al. 1998).

Sugarcane aphid feeds on the sap and nutrients from the plant phloem, but cannot digest all the sugars ingested (Singh et al. 2004). The sugars that are not digested are secreted as honeydew from the aphid which serves as a substrate for sooty mold growth (Singh et al. 2004). Accumulation of honeydew on the panicles during late season can cause up to a 50% loss of grain (Bowling et al. 2016). This loss occurs because the grain can stick to the mechanical parts of the harvest equipment which can result in mechanical failures and reduce harvesting efficiency (Bowling et al. 2016). Yield losses ranging from a 45 to 181 kg per hectare with economic losses ranging from $62 to $432 per hectare were observed in studies conducted during 2014 and 2015 (Bowling et al. 2016).

Cultural practices have been successful in reducing some pest populations in grain sorghum (Cronholm et al. 1998). Several cultural practices such as crop rotation, hybrid selection, seedbed preparation, adequate fertility, manipulation of planting date and harvest time can be used to reduce pest populations (Cronholm et al. 1998). Natural enemies such as Barber brown lacewing, *Sympherobius barberi* (Banks); common green lacewing; *Chrysoperla carnea* (Fitch); parasitoids, *Aphelinus* spp. and *Syrphophagus* spp.; hoverflies, *Syrphini* spp.; and multicolored Asian ladybeetle, *Harmonia axyridis* (Pallas), can play a role in regulation of sugarcane aphid populations (Singh et al. 2004). Although natural enemies can assist with regulating sugarcane aphid populations, this usually occurs well after damaging levels occur. As a result, foliar insecticide applications are often needed to manage this pest in the southern U.S. to minimize grain sorghum yield losses. Neonicotinoid seed treatments provide protection against early season insect pests, including sugarcane aphid, but foliar insecticide applications are the primary tool to effectively manage late season infestations in the Mid-South (North 2016).

Foliar insecticides commonly used in grain sorghum for control of other pests have little activity on sugarcane aphid (Bowling et al. 2016). Based on the widespread occurrence of sugarcane aphid in Louisiana in 2013, Mississippi successfully applied for a Section 18 emergency exemption for sulfoxaflor (Transform™ 50WG, Dow

AgroSciences, Indianapolis, IN) for the 2014 season. In 2014, sugarcane aphids infested every grain sorghum producing county in Mississippi (Catchot 2016). In 2015, Bayer CropScience was granted a Section 3 label for flupyradifurone (Sivanto™ 200 SL Bayer CropScience, Leverkusen, Germany) for use for controlling sugarcane aphid. Dow AgroScience applied for a Section 3 label for use of sulfoxaflor in grain sorghum but that label was never granted based on a ninth circuit court of appeals case *Pollinator Stewardship Council, et al. v. EPA* (No. 13-72346). As a result of the court ruling, the Environmental Protection Agency (EPA) revoked the registration of sulfoxaflor stating there was not substantial evidence that it was not a risk to managed pollinators (EPA 2015). In 2015, in the absence of a Section 3 label in grain sorghum, Mississippi and other states were again granted a Section 18 emergency exemption for sulfoxaflor so producers would have two modes of action available to manage sugarcane aphid. Currently, sulfoxaflor and flupyradifurone are the only two products recommended for control of sugarcane aphid, and are recommended in rotation to delay resistance (Catchot et al. 2016).

Similar to other insects, sugarcane aphid activity, metabolism, and reproduction are influenced by temperature (Mellanby 1939). Several ions including Na^+, K^+, and Mg^{2+}, are not distributed appropriately within the body at lower temperatures, causing complications with muscle action potentials (Koštál et al. 2007). During the 2014 season, unacceptable control of sugarcane aphid and cotton aphid, *Aphis gossypii* (Glover), with sulfoxaflor was experienced in grain sorghum and cotton aphid, respectively, across Mississippi and the surrounding states. The one common denominator among these control issues was lower than normal temperatures at the time of application. During observed failures in 2014, high temperatures averaged 27.3°C in June; 6 degrees Celsius lower than the 5 year average of 33.1. It was suggested that the cooler temperatures resulted in poor control, but the exact cause was never determined. To address the impact of temperature on the efficacy of both sulfoxaflor and flupyradifurone against sugarcane aphid, a series of laboratory experiments were conducted using field treated plant tissues.

Materials and Methods

To determine the impact of temperature on the efficacy of sulfoxaflor and flupyradifurone insecticides against sugarcane aphid, experiments were conducted during 2015 and 2016 at the R.R. Foil Research and Demonstration Center in Starkville, MS. DEKALB 'DKS54-00' (Monsanto Company, St. Louis, MO) grain sorghum seed were planted in a randomized complete block design with 4 replications. Plot size was 15.24 meters by 3.86 meters rows on 96.52 cm beds. Sorghum was planted on 28 May in 2015 and 27 May in 2016. Treatments consisted of sulfoxaflor applied at 35 g ai/ha, and flupyradifurone applied at 58.5 g ai/ha along with an untreated control. Insecticide foliar sprays were applied with a tractor mounted sprayer calibrated to deliver 93.5 L/ha at 448.16 kPa with TX-6 ConeJet VisiFlo® Hollow Cone nozzles (TeeJet Technologies, Springfield, Illinois). After treatments were applied, an individual 4.5 cm diameter leaf disc was cut from the uppermost leaf below the flag leaf of 10 plants at 0, 1, 3, 5, 7, and 10 days after treatment. Leaf discs were placed in 16.5 cm x 14.9 cm Ziploc® bags (S.C. Johnson & Johnson, Inc., Racine, WI). At the same time leaf discs were cut at each assay date, sugarcane aphid were collected from a separate block of untreated DEKALB 'DKS54-00' planted in an adjacent field. Sugarcane aphids were collected by removing whole leaves heavily infested with sugarcane aphids. Infested leaves were placed in 30.48

cm x 17.78 cm x 43.18 cm 1/6 barrel paper grocery bag until approximately 1000 aphids were collected. All aphids and leaf discs were returned to the Mississippi State University Clay Lyle Entomology Rearing Lab at Mississippi State, MS for assays to be performed. Petri dishes used for assays were 100mm x 15mm with two 3.81 mm holes in the lid for ventilation to allow for air movement and reduce condensation within the dishes. The holes were covered with a 5.1 cm diameter chiffon fabric attached to each hole in the lid with a hot glue gun. Each petri dish was filled with a 3mm layer of 10 g agar/ 500 ml water mixture to keep leaf discs turgid. All prepared petri dishes were labeled randomly with a plot number and temperature. Leaf discs were removed from the Ziploc® bags and placed in the corresponding petri dish according to plot number. Each leaf disc was then infested with five wingless adult aphids with a no. 3 round paint brush. Individual paint brushes labeled according to treatment were used to transfer aphids to petri dishes to ensure there was no contamination. Lids were placed on the petri dishes and 1.9 x 10.16 cm pieces of Parafilm M® All-Purpose Laboratory Film (Product No. 13-374-12, Fisher Scientific, Norcross, GA) were used to seal the dishes to prevent aphids from escaping. All petri dishes were then arranged in a completely randomized design according to temperature and insecticide treatment and placed in separate growth chambers with a 12:12 L:D photoperiod at 29.4°C, 84.3% relative humidity or 15.5°C, 85% relative humidity. Mortality was assessed at 48 hours after introduction into growth chambers. Mortality was defined as an aphid that failed to respond to a needle prick or showed no signs of life. Percent mortality was then calculated by dividing the number of dead aphids by the total number of aphids found in the 5 correlating petri dishes for each plot. Schneider-Orelli's formula was used to correct for control mortality (Püntener 1981).

Mortality data were analyzed with regression analysis (PROC GLM, SAS 9.4) to determine the relationship between percent mortality and time after treatment. Additionally, analysis of covariance was used to test for differences in the slopes and intercepts of regression equations between insecticides and between temperatures. After recording mortality, if check mortality was higher than 20%, replications were excluded in analysis.

Results

During 2015, there was a significant relationship between percent mortality and days after treatment at 15.5°C ($F=45.10$; $df=3, 47$; $P<0.01$). The slopes for sulfoxaflor and flupyradifurone were not significantly different ($F=0.18$; $df=1, 47$; $P=0.67$) suggesting that mortality for both compounds decreased at a similar rate over time (Figure 1.1). Sugarcane aphid mortality on leaves treated with flupyradifurone decreased by 7.32% per day and mortality on leaves treated with sulfoxaflor decreased by 7.88% per day. The intercepts were not significantly different between insecticides for percent mortality, suggesting that sulfoxaflor and flupyradifurone provided similar levels of mortality at 15.5° C ($F=1.68$; $df=1, 47$; $P=0.20$).

During 2015, there was a significant relationship between percent mortality and days after treatment at 29.4°C ($F=33.17$; $df=3, 45$; $P<0.01$). The slopes for sulfoxaflor and flupyradifurone were significantly different ($F=15.97$; $df=1, 45$; $P<0.01$) suggesting that mortality decreased at different rates over time (Figure 1.2). Mortality of sugarcane aphid on leaves treated with flupyradifurone decreased by 3.09% per day compared to 8.34% per day on leaves treated with sulfoxaflor. The intercepts were significantly different between insecticides for percent mortality, suggesting flupyradifurone provided better control than sulfoxaflor (F=11.83; df=1, 47; $P<0.01$).

During 2016, there was a significant relationship between percent mortality and days after treatment at 15.5°C (F=6.38; df=3, 40; $P<0.01$). The slopes for sulfoxaflor and flupyradifurone were not significantly different (F=3.38; df=1, 40; $P=0.07$) suggesting that mortality decreased at a similar rate over time (Figure 1.3). The efficacy of flupyradifurone decreased by 1.80% per day and the efficacy of sulfoxaflor decreased by 5.54% per day. The intercepts were not significantly different between insecticides for percent mortality, suggesting that sulfoxaflor and flupyradifurone provided similar levels of mortality at 15.5° C (F=0.06; df=1, 47; $P=0.81$).

During 2016, there was a significant relationship between percent mortality and days after treatment at 29.4°C (F=12.76; df=3, 42; $P<0.01$). The slopes for sulfoxaflor and flupyradifurone were not significantly different (F=0.08; df=1, 42; $P=0.78$) suggesting that mortality decreased at a similar rate over time (Figure 1.4). The efficacy of flupyradifurone decreased by 6.58% per day and the efficacy of sulfoxaflor decreased by 5.97% per day. The intercepts were significantly different between insecticides for percent mortality, suggesting flupyradifurone provided better control than sulfoxaflor (F=5.93; df=1, 47; $P=0.02$).

Discussion

Sugarcane aphid can be an extremely damaging pest of grain sorghum production in the U. S. Insecticide experiments conducted for control of sugarcane aphid in both the U. S. and Thailand concluded that it is essential to treat infested grain sorghum to prevent yield losses. Researchers in Thailand sprayed plots infested with sugarcane aphid with high and low rates of triazophos, methamidophos, carbosulfan, cyhalothrin, pirimicarb, and methomyl (Chawanapong et al. 1990). They concluded that one spray of any insecticide at either rate was sufficient when compared to the untreated control (Chawanapong et al. 1990). Researchers in the U. S. tested lambda-cyhalothrin, gamma-cyhalothrin, flonicamid, thiamethoxam, imidacloprid and acetamiprid against sugarcane aphid in sugarcane, *Saccaharum officinarum* L. (Akbar et al. 2017). Similar to what was observed in Thailand, all of the insecticides performed equal to each other, but significantly better than the untreated control (Akbar et al. 2007). A similar experiment was performed in west Tennessee with multiple insecticides and insecticide mixtures at different rates in grain sorghum (Steckel and Stewart 2016). In those studies, flupyradifurone and sulfoxaflor provided better control of sugarcane aphid than chlorpyrifos, dimethoate, and a mixture of chlorpyrifos plus dimethoate (Steckel and Stewart 2016).

In an experiment designed to determine the effect of temperature on the efficacy of permethrin, cypermethrin, detamethrin, and fenvalerate against cabbage looper, fall armyworm, and tobacco budworm, fenvalerate and detamethrin exhibited a negative relationship between toxicity and temperature when controlling fall armyworm and tobacco budworm (Sparks et al.1982). Permethrin and cypermethrin exhibited a positive relationship between toxicity and temperature for tobacco budworm and fall armyworm (Sparks et al.1982). All insecticides exhibited a positive relationship between toxicity and temperature for cabbage looper (Sparks et al.1982). Musser and Shelton (2005) observed decreased efficacy of pyrethroids and spinosyns for *Ostrinia nubilalis* (Hübner) control at 35°C compared to 29°C.

In the current experiment, mortality of sugarcane aphid exposed to grain sorghum leaves treated with field use rates of sulfoxaflor and flupyradifurone was relatively low at the lower temperature. This could be attributed to the fact that sugarcane aphid biological processes are influenced by temperature; with lower activity in cooler temperatures causing feeding to slow. Previous research by Ma and Ma (2012) compared the behavioral feeding response of aphids avoiding heat stress from higher temperatures by using the heat-escape temperature measurement. This method measures at what temperature, ranging from 10° C to 36°C (10, 15, 20, 25, 30, 35, and 36 degrees Celsius), aphids become uncomfortable and show avoidance behavior (Ma and Ma. 2012). It was found that stimulating temperatures were between 20° C and 30° C before the aphids potentially became heat stressed. Similarly colder temperatures spur a reversible chill coma where there is less movement and feeding resulting from the complications with the muscle action potential (MacMillan and Sinclair 2011).

Another possible explanation for the decreased efficacy could be that systemic insecticides may not be absorbed and translocated as efficiently at lower temperatures. Similar to insects, plant development and metabolism is also temperature dependent. The insecticides used in these experiments are systemic, and cooler temperatures may negatively affect translocation within the plant. Reduced translocation of sulfoxaflor or flupyradifurone combined with reduced feeding by the aphids could result in a reduced amount of active ingredient being ingested by the sugarcane aphid. Ultimately, both of these factors combined may contribute to poor performance in the field. However, field plots in the current study were sprayed under optimum growing conditions and the aphids were exposed to lower temperatures only in the growth chamber. Therefore, the results from the current study cannot be due to plant factors but must be the result of reduced feeding and activity by the aphids, but the impact of cooler temperatures on translocation of systemic insecticides in plants needs to be studied in the future.

These results suggest that temperature can influence sugarcane aphid control with both sulfoxaflor and flupyradifurone. Although initial mortality was similar, flupyradifurone resulted in longer residual mortality than sulfoxaflor at the higher temperature in 2015 and overall better control at the higher temperature in 2016. No differences in the performance of sulfoxaflor and flupyradifurone were observed in 2015 at lower temperatures. In 2016, results were highly variable with high control mortality due to crashing populations, but overall poor control was observed with both insecticides at lower temperatures. In 2015, there was little difference in the efficacy provided by either insecticide at 15.5°C. Flupyradifurone provided longer residual mortality than sulfoxaflor at 29.5°C based on greater mortality later during testing. In 2016, both compounds performed poorly at 15.5°C, but flupyradifurone provided overall better control than sulfoxaflor. Lower temperatures can reduce the performance of sulfoxaflor and flupyradifurone according to these data. These data suggest that temperature should be taken into consideration before making an application with these insecticides targeting sugarcane aphid populations in grain sorghum.

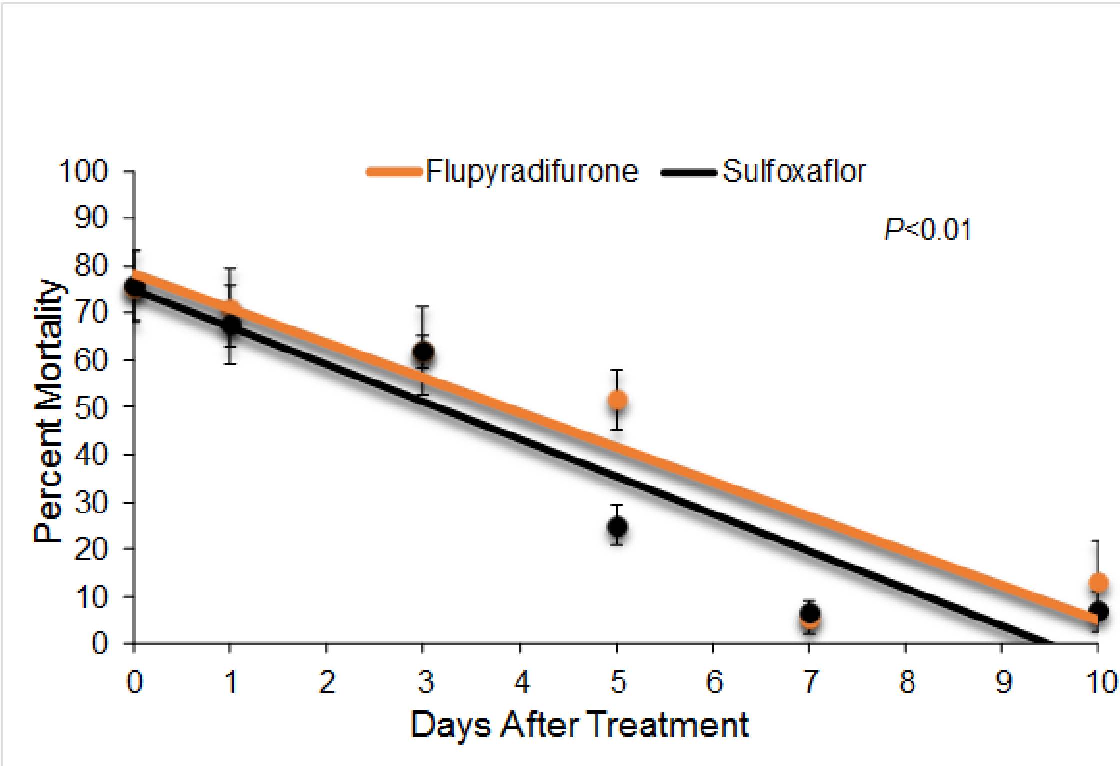


Figure 1.1 2015 Efficacy of sulfoxaflor and flupyradifurone over time at 15.5°C

Data corrected for check mortality. Points represent means ± (SE). Lines represent linear regression for both chemicals. (Flupyradifurone: Intercept 78.20, Slope -7.32) (Sulfoxaflor: Intercept 74.76 Slope -7.88)

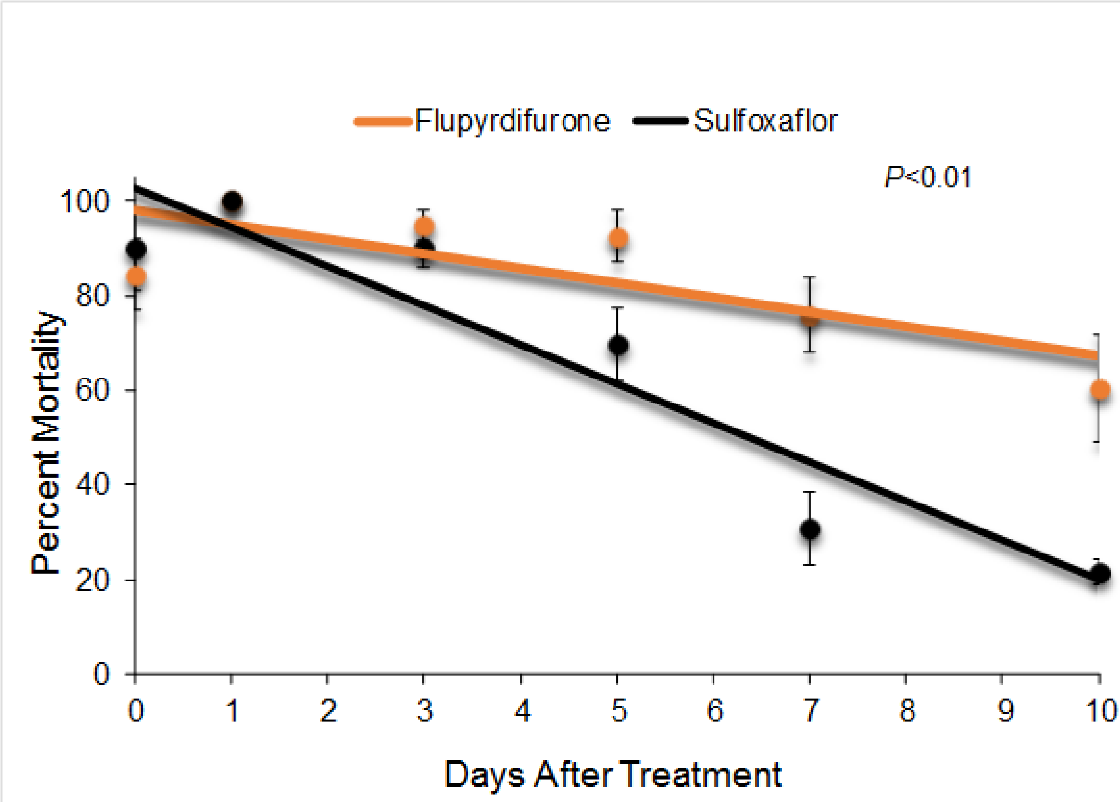
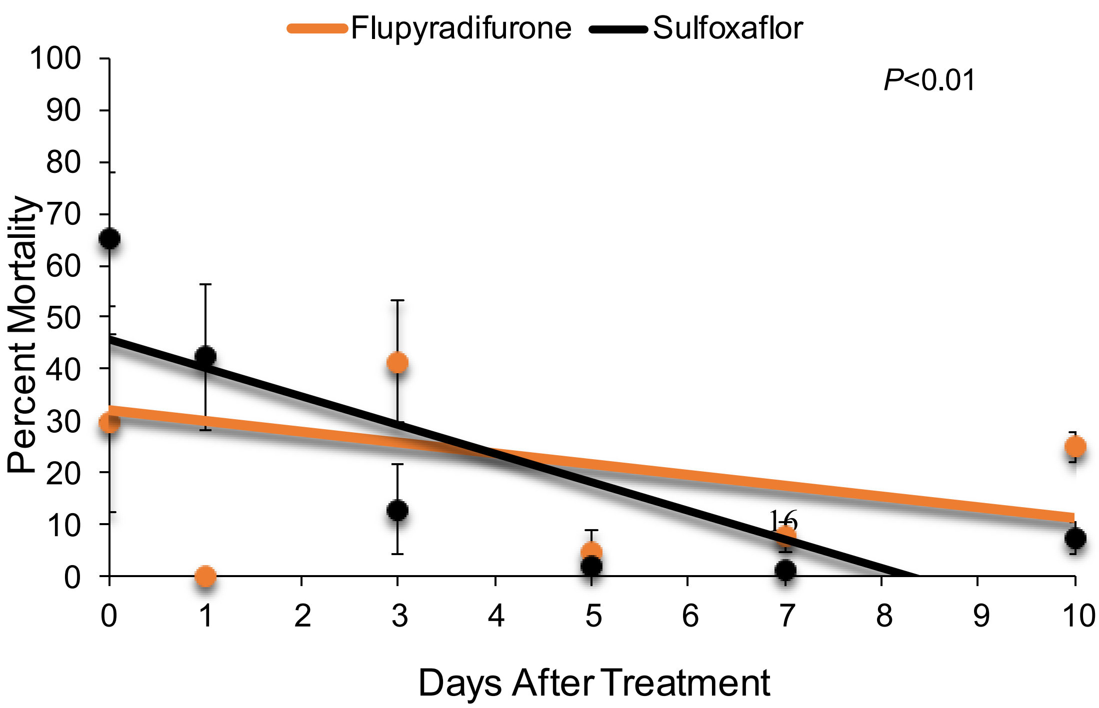


Figure 1.2 2015 Efficacy of sulfoxaflor and flupyradifurone over time at 29.4°C

Data corrected for check mortality. Points represent means ± (SE). Lines represent linear regression for both chemicals. (Flupyradifurone: Intercept 97.70, Slope -3.09) (Sulfoxaflor: Intercept 103.08 Slope -8.34)

Figure 1.3 2016 Efficacy of sulfoxaflor and flupyradifurone over time at 15.5°C

Data corrected for check mortality. Points represent means ± (SE). Lines represent linear regression for both chemicals. (Flupyradifurone: Intercept 31.89, Slope -1.80) (Sulfoxaflor: Intercept 45.74 Slope -5.54)



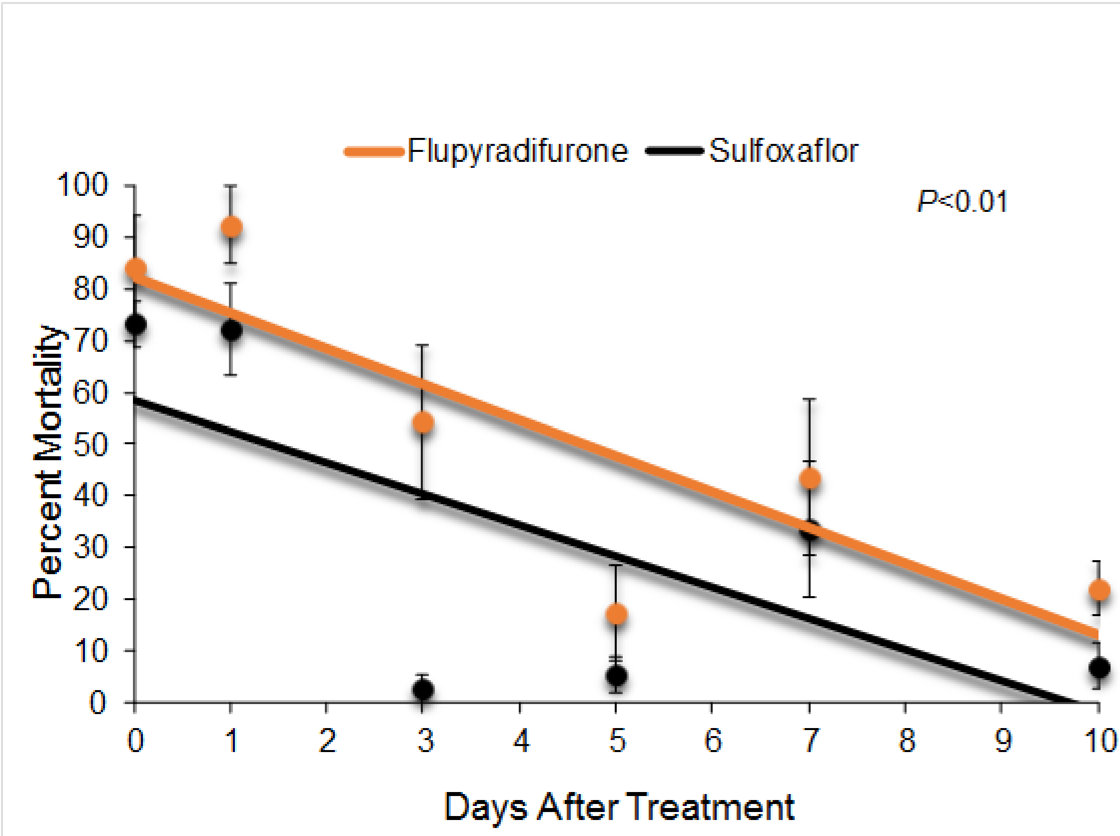


Figure 1.4 2016 Efficacy of sulfoxaflor and flupyradifurone over time at 29.4°C

Data corrected for check mortality. Points represent means ± (SE). Lines represent linear regression for both chemicals. (Flupyradifurone: Intercept 81.30, Slope -6.58) (Sulfoxaflor: Intercept 58.98 Slope -5.97)

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CHAPTER II

EVALUATION OF PLANT POPULATION AND INSECTICIDE TREATMENT ON SUGARCANE APHID (HEMIPTERA: APHIDIDAE) POPULATIONS IN GRAIN SORGHUM

Abstract

Grain sorghum requires less irrigation than many crops grown in Mississippi and provides good rotational benefits for other commodities grown in Mississippi due to high levels of nematode resistance. In 2013, the sugarcane aphid was discovered of grain sorghum in several states. When the sugarcane aphid was first discovered on grain sorghum, no control options were available. Although there are currently two insecticides available for foliar options, cultural practices remain important for reducing pest densities and minimizing the chance of resistance. Experiments were conducted at two locations in Mississippi during 2015 and 2016 to evaluate the influence of plant population and insecticide treatment on sugarcane aphid densities. Plant populations from 99,000-395,000 plants per hectare of Pioneer™ 84P80 were evaluated with and without foliar and insecticide seed treatment for sugarcane aphid. Treated plots were treated with a thiamethoxam seed treatment and sulfoxaflor as a foliar insecticide when populations reached current threshold. Control plots were untreated. In general, aphid densities decreased as plant population increased. There was also a significant difference in yield due to treatment. Untreated plots yielded significantly lower than treated plots. These

data suggest that manipulating plant populations may reduce sugarcane aphid densities, but management with insecticides will remain an important component of current IPM strategies.

Introduction

Grain sorghum, *Sorghum bicolor* L. Moench, is naturally a drought tolerant (Cronholm et al. 1998). It is grown extensively in the semi-arid Great Plains and southern region of the United States (Rosenow et al. 1983). Approximately 2.62 million hectares of grain sorghum were harvested in the United States in 2016, down from 3.42 million hectares in 2015 (NASS 2016). The decrease was partially attributed to lower commodity prices, but outbreak populations of the sugarcane aphid, *Melanaphis sacchari* (Zehntner), and limited of control options also contributed (Larson 2016). Prior to the introduction of sugarcane aphid in 2013, the primary pests of grain sorghum included sorghum midge, *Stenodiplosis sorghicola* (Coquillett); sorghum webworm, *Nola sorghiella* (Riley); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); and corn earworm, *Helicoverpa zea* (Boddie), (Cronholm et al. 1998, Elliot et al 2015) .

Currently, the sugarcane aphid is distributed throughout all grain sorghum producing regions of the United States (Bowling et al. 2016). Key morphological features distinguishing the sugarcane aphid from other aphid species in sorghum are the presence of black cornicle tips, black tarsi, and their yellow-gray color (Bowling et al. 2016). Aphids mature through four nymphal stages within four days and can live as an adult for 28 days (van Rensburg 1973a, Bowling et al. 2016). Adults can be apteran or alate and are parthenogenic, giving birth to 30-60 viviparous nymphs (Singh et al. 2004).

Damage from sugarcane aphid is attributed to loss of sap and nutrients from the plant phloem (Singh et al. 2004). When aphids feed on the underside of leaves, they excrete excess sugars known as honeydew (Singh et al. 2004). Sugarcane aphid infestations generally start at the bottom of plants and expand to the top of plants as densities increase (Narayana 1975). Necrosis of the plant from sugarcane aphid feeding can occur due to the loss of needed nutrients (Singh et al. 2004). Uneven flowering, delayed head emergence, and reduced grain size or quality can result from sugarcane aphid feeding at moderate to high densities (Singh et al. 2004). These inconsistencies caused by the sugarcane aphid can cause difficulties managing other important pests such as the sorghum midge (Cronholm et al. 1998).

When the sugarcane aphid was first discovered on grain sorghum, no effective control options were available. Through Section 18 emergency exemptions and a Section 3 registration, sulfoxaflor (Transform WG™, Dow AgroSciences, Indianapolis, IN) and flupyradifurone (Sivanto 200SL™, Bayer CropScience, Raleigh, NC), respectively, have become commercially available since 2014 (EPA Website 2016). This gave Mississippi and other states two insecticide options that provide acceptable control of sugarcane aphid (Catchot et al. 2016). The use of neonicotinoid seed treatments also provides some early season protection from sugarcane aphid infestations (North 2015).

Natural enemies such as Barber brown lacewing, *Sympherobius barberi* (Banks), green lacewing, *Chrysoperla plorabunda* (Fitch); parasitoids, *Aphelinus* spp. and *Syrphophagus* spp.; hoverflies, *Syrphini* spp.; and multicolored Asian ladybeetle, *Harmonia axyridis* (Pallas), will help regulate low populations in combination with the neonicotinoid seed treatments (Bowling et al. 2016). With the limited number of foliar control options, cultural practices will be an important component of integrated pest management strategies for sugarcane aphid (Bowling et al. 2016). Cultural practices generally aim to avoid pest populations and make the environment less attractive to reduce pest pressure (Hill 1989). Cultural practices are used as a preventative management strategy and require long-term planning (Hill 1989). Cultural practices such as tillage can be used to reduce overwintering survival of some pests by manipulating or destroying crop residue (Cronholm et al. 1998). Leaving vegetation diversity such as weeds provides an alternate feeding source for pests and a better habitat for natural enemies (Schellhorn et al. 2000). Other cultural practices include crop rotation, hybrid selection, seedbed preparation, adequate fertility, water management, manipulation of planting date, plant population, and harvest time (Cronholm et al. 1998, Schellhorn et al. 2000).

Since sugarcane aphid is a new pest of grain sorghum in the U.S., little information exists about how these practices influence their populations and management. Grain sorghum is grown at a wide range of plant populations depending on region, row spacing, and irrigation practices (Shroyer et al. 1998). The primary objective in plant population experiments was to reduce the number of pests per plant and maintain pest numbers below threshold (Hill 1989). Depending of the pest being managed, a high or low plant population may be recommended (Hill 1989). Low plant populations are known to attract certain pests such as aphids (Hill 1989). Additionally, higher sorghum populations can attract more natural enemies and disperse the pest on a per plant basis without compromising yield (Hill 1989). Anecdotal reports from several consultants and growers throughout the southern U.S. suggested that sugarcane aphid densities were lower and fewer sprays were recommended in grain sorghum fields with higher plant populations or in twin-row planted grain sorghum fields. Currently, no information exists about the impact of grain sorghum plant population on sugarcane aphid population dynamics and crop productivity. In response to those reports, the objective of this study was to evaluate the impact of plant population on sugarcane aphid management in grain sorghum.

Materials and Methods

Experiments were conducted in 2015 and 2016 at the R. R. Foil Research and Demonstration Center in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS to determine the effects of planting population, foliar insecticides and neonicotinoid seed treatment on sugarcane aphid management in grain sorghum. Pioneer™ '84P80' grain sorghum seed were planted in a randomized complete block design with a 7 by 2 factorial treatment arrangement with 4 replications. Plot size was 15.24 meters by 3.86 meters on 96.52 cm beds in Starkville, MS and 15.24 meters by 4.06 meters on 101.6 cm beds in Stoneville, MS. In 2015, seed were planted on 3 June in Starkville, MS and in Stoneville, MS. In 2016, plots were planted on 23 June in Starkville, MS and 25 June in Stoneville, MS. The first factor was seeding rate and included 99K, 148K, 198K, 247K, 296K, 346K, and 395K seed per hectare. The second factor was sugarcane aphid management and included treated plots and an untreated control. The treated plots received thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC) seed treatment and foliar insecticide applications of sulfoxaflor (Transform™ 50WG, Dow AgroSciences, Indianapolis, IN) when aphid densities reached the current Mississippi threshold (Catchot et al. 2016). Thiamethoxam was applied at 0.062 mg ai/seed. Sulfoxaflor was applied as a foliar spray at 35 g ai/ha. Insecticide foliar sprays were applied with a tractor mounted sprayer calibrated to deliver 93.5 L/ha at 448.16 kPa with TX-6 ConeJet VisiFlo® Hollow Cone nozzles (TeeJet Technologies, Springfield, Illinois).

Supplemental irrigation was utilized in Stoneville, but was not available in Starkville. Weeds were managed using a premix of S-metolachlor, atrazine, and mesotrione (Lexar EZ, Syngenta Crop Protection, Greensboro, NC) at 7.01 L/ha. One week before planting, 31.75 kg/ha of nitrogen was applied followed by 45.36 kg/ha four weeks after planting. All pests other than sugarcane aphid were managed according to the Mississippi State University Extension Service Insect Control Guide for Agronomic Crops (Catchot et al. 2016). Plots were scouted weekly for sugarcane aphid by observing 15 flag leaves (when available) and 15 lower canopy leaves per plot and counting the number of aphids found on each leaf. Plants were monitored until physiological maturity or aphid densities crashed. After sorghum grain attained physiological maturity and grain dried to harvestable moisture, the center two rows were mechanically harvested with a small plot combine. Weights from each plot were adjusted to 13% moisture.

Mean number of sugarcane aphid per leaf and yield were analyzed with regression analysis (PROC GLM, SAS 9.4) to determine the relationship between mean number of sugarcane aphid per leaf or yield, and plant population for each treatment. Additionally, analysis of covariance was used to test for differences in the slopes of regression equations between treatments.

Results

During 2015, aphid densities in Starkville began increasing in early July and peaked on 14 July, then declined sharply in mid-August (Figure 2.1). In 2016, aphid densities in Starkville started building in mid-July, peaked 28 July, then crashed in early August (Figure 2.1). During 2015, aphid densities in Stoneville began increasing mid-August and rapidly declined, never reaching an economically damaging threshold (Figure 2.1). During 2016, aphid densities in Stoneville started building during mid-July, peaked during early August, then crashed in mid-August (Figure 2.1). Due to the differences in infestation timings, each location and year were analyzed separately.

Starkville 2015

There was a significant relationship between plant population and average number of aphids per leaf ($F=15.51$; $df=3, 55$; $P<0.01$). The intercepts for treatment regimens were significantly different ($F=21.09$; $df=1, 5$; $P<0.01$), with fewer sugarcane aphids observed in the treated plots than the untreated plots (Figure 2.2). The plant population by treatment regimen interaction was not significant for sugarcane aphid densities ($F=0.26$; $df=1, 55$; $P=0.61$), suggesting that the slopes for the treatment regimens were similar across plant populations. Average number of sugarcane aphids per leaf in treated plots decreased by 0.58 aphids per 1000 plants per hectare increase compared to 0.70 aphids per 1000 plants per hectare increase in the untreated plots. There was a significant relationship between plant population and yield ($F=73.95$; $df=3, 55$; $P<0.01$). The plant population by treatment regimen interaction was significant suggesting that grain sorghum yields increased at different rates across plant populations in response to treatment regime ($F=5.73$; $df=1, 55$; $P=0.02$). In treated plots, grain sorghum yield increased by 9.38 kilograms per hectare for each 1000 plant population increase, and a 3.18 kilogram per hectare per 1000 plant population increase was observed in the untreated plots (Figure 2.3).

Starkville 2016

There was a significant relationship between plant population and average number of sugarcane aphids per leaf (F=43.57; df=3, 55; P <0.01). The intercepts for treatment regimens were significantly different (F=128.51; df=1, 55; P <0.01), with fewer sugarcane aphids observed in the treated plots than the untreated plots (Figure 2.4). The interaction between treatment regime and plant population was not significant (F=0.05; df=1, 55; P =0.82). Average number of sugarcane aphids per leaf in treated plots decreased by 0.18 aphids per 1000 plants and decreased by 0.25 aphids per 1000 plants in the untreated plots. There was a significant relationship between plant population and yield in Starkville (F=16.66; df=3, 55; P <0.01). The intercepts were significantly different among treatments regimes (F=49.38; df=1, 55; P <0.01), with treated plots yielding significantly higher than untreated plots (Figure 2.5). The interaction between treatment regime and plant population was not significant for yield (F=0.11; df=1, 55; P =0.74). However, the main effects of treatment regime was significant (F=49.38; df=1, 55; P <0.01). In treated plots, grain sorghum yields decreased by 2.47 kilograms per hectare as plant population increased and a 0.87 kilogram per hectare decrease was observed in the untreated plots.

Stoneville 2016

There was no relationship between plant population and average number of aphids per leaf (Figure 2.6, F=1.60; df=3, 55; *P* =0.28) or yield (Figure 2.7, F=2.18; df=3, 55; *P* =0.10) observed.

Discussion

With limited of insecticide options available for management of sugarcane aphid, cultural practices may be important tool to help maintain aphid densities below threshold or at manageable levels. Multiple experiments were conducted to evaluate different planting populations for optimal pest management in different crops. Several experiments suggest that plant populations higher than the recommended planting population result in higher yield better. Karel and Mchogho (1985) observed fewer insect pests and greater yields in common bean at a planting population of 200K plants per hectare compared to 100K plants per hectare. Ficht (1932) found more European corn borer eggs and adults per plant at 1 corn plant per hill than at 5 corn plants per hill. Five and four corn plants per hill yielded higher than 1-3 corn plants per hill (Ficht 1932). Aghaee et al. (2016) found that seeding rates of 112-168kg/ha of rice resulted in higher yields and had less rice water weevil damage compared to seeding rates of 56kg/ha. Stout et al. (2009) found less rice water weevils at rice seeding rates of 180kg/ ha than at 109kg/ha.

These results were similar to our findings with the sugarcane aphid populations in grain sorghum. Recommended plant population in Mississippi is 99K- 173K seeds per hectare for dryland sorghum and 173K- 247K for irrigated sorghum (Larson 2015). In Starkville during 2015 and 2016, a decrease in aphid numbers and grain yield declined as plant population increased regardless of treatment regime. Treated plots resulted in significantly higher yields than the untreated plots in Starkville during 2015 and 2016. During 2016 in Stoneville, aphid infestations occurred later in the growing season which led to different results than observed in Starkville. Aphid numbers and yield slightly increased but were not statistically different and were not affected by treatment and plant population. Excluding findings from Stoneville during 2016, these data suggest that plant population can play an important role in regulating sugarcane aphid densities in grain sorghum. However, management with insecticide seed treatments and foliar insecticide sprays were critical for maintaining optimum yield potential when significant sugarcane aphid densities occurred regardless of plant population. Growers should consider the economics of increasing seeding rates before making decisions because impacts on both sugarcane aphid populations and yield were minimal.

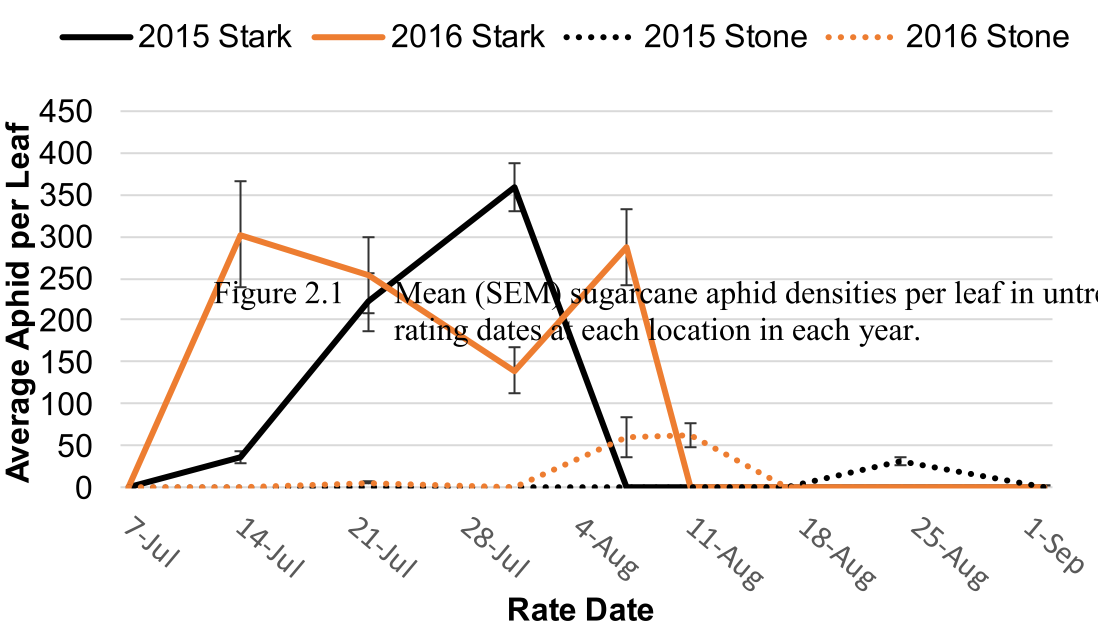


Figure 2.1 Mean (SEM) sugarcane aphid densities per leaf in untreated plots across rating dates at each location in each year.

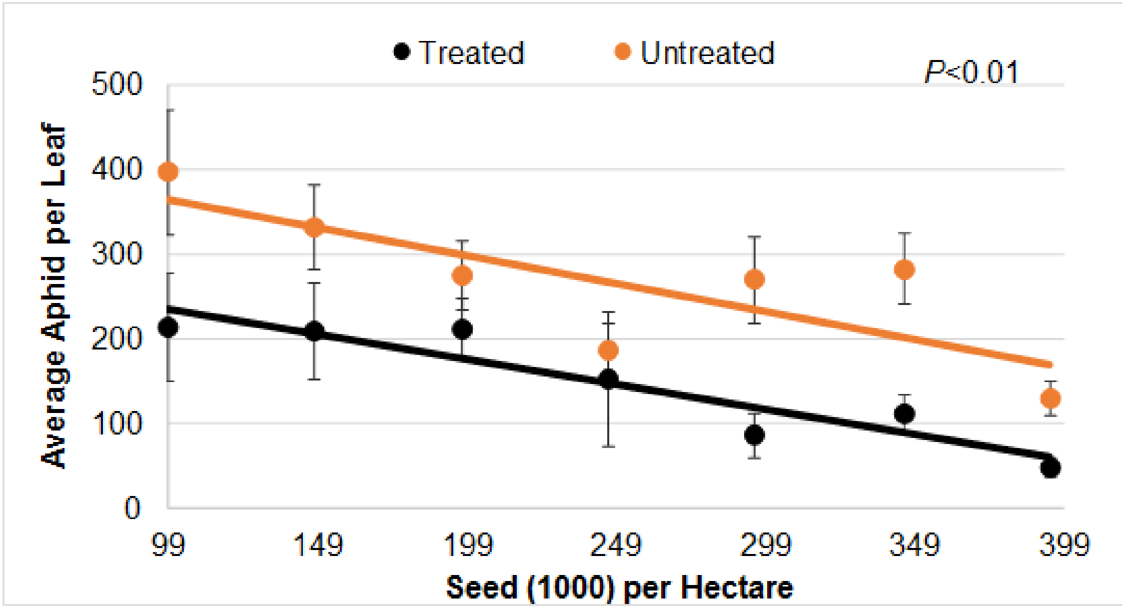


Figure 2.2 Relationship between planting population and seasonal mean (SEM) number of sugarcane aphid in grain sorghum in Starkville, MS during 2015

(Treated: Intercept = 290.31, Slope = -0.58) (Untreated: Intercept = 436.69, Slope = -0.70)

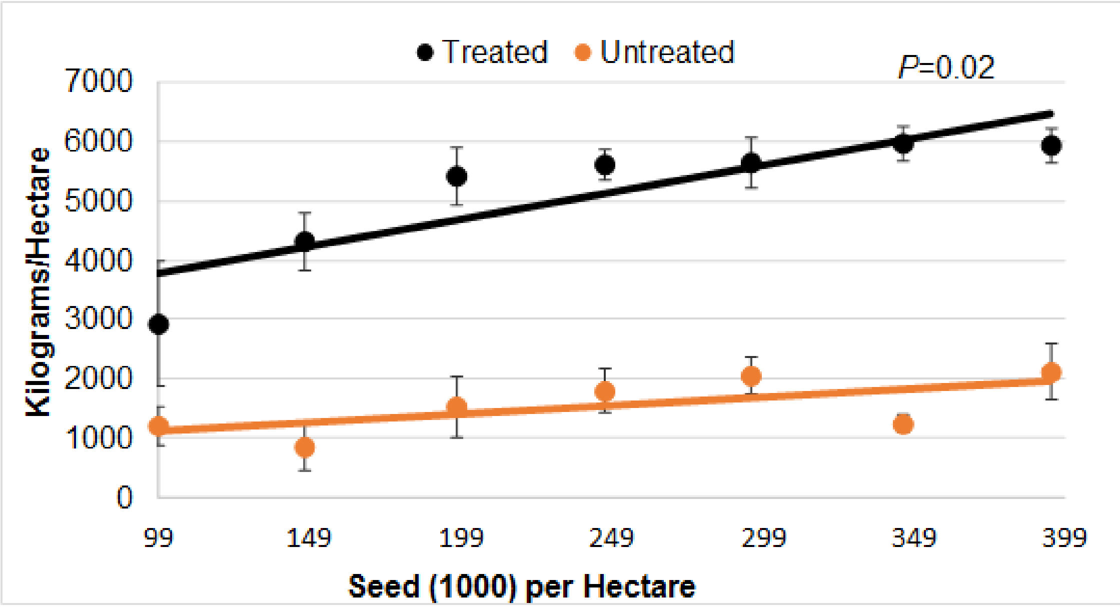


Figure 2.3 Relationship between planting population and mean (SEM) grain sorghum yields in Starkville, MS during 2015

(Treated: Intercept 2819.14, Slope 9.38) (Untreated: Intercept 770.64, Slope 3.18)

Figure 2.4 Relationship between planting population and seasonal mean (SEM) number of sugarcane aphid in grain sorghum in Starkville, MS during 2016

(Treated: Intercept 74.78, Slope -0.19) (Untreated: Intercept 427.86, Slope -0.25)

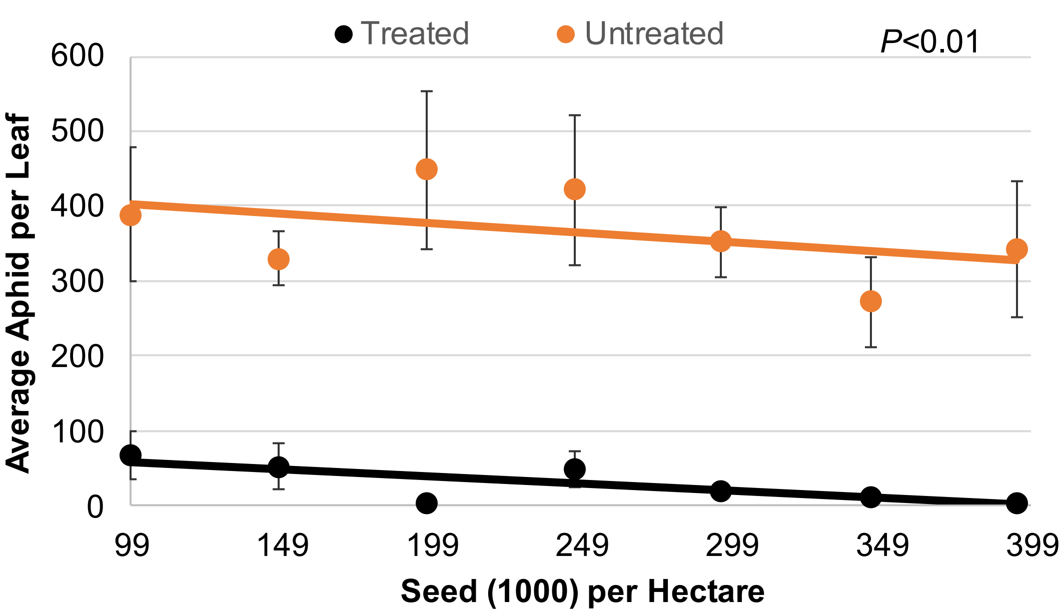


Figure 2.5 Relationship between planting population and seasonal mean (SEM) grain sorghum yields in Starkville, MS during 2016

(Treated: Intercept 5055.43, Slope -2.47) (Untreated: Intercept 1333.06, Slope -0.87)

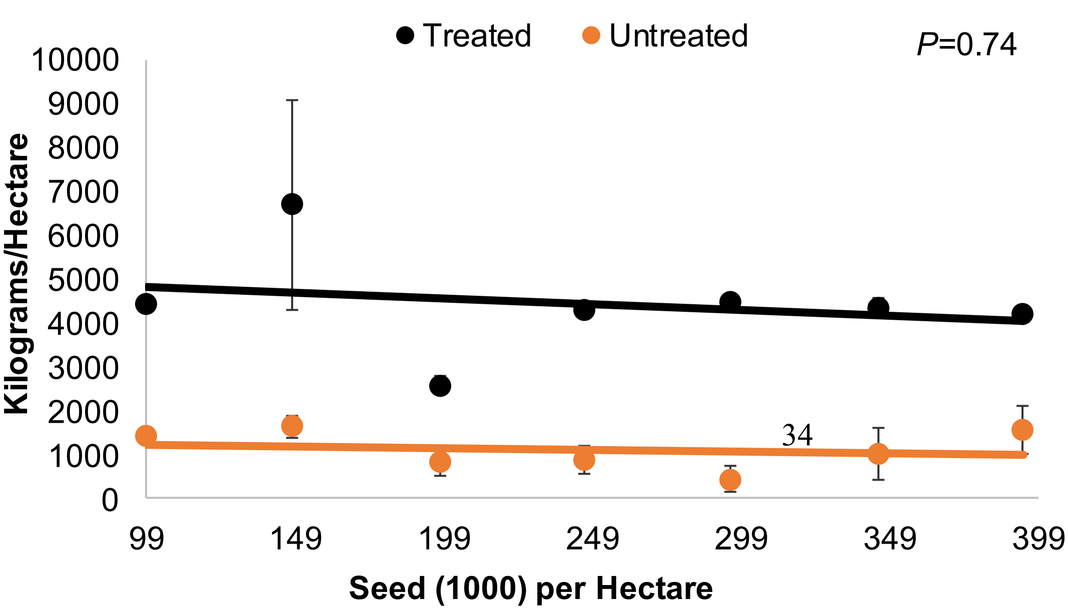


Figure 2.6 Relationship between planting population and seasonal mean (SEM) number of sugarcane aphid grain sorghum in Stoneville, MS during 2016

(Treated: Intercept 20.87, Slope 0.01) (Untreated: Intercept -16.46, Slope 0.23)

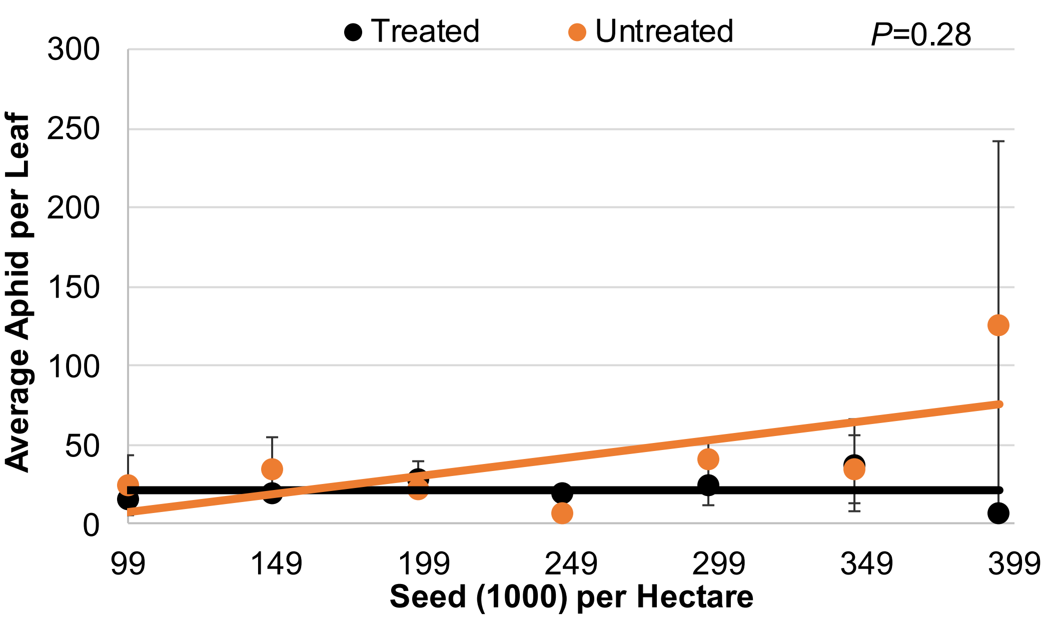
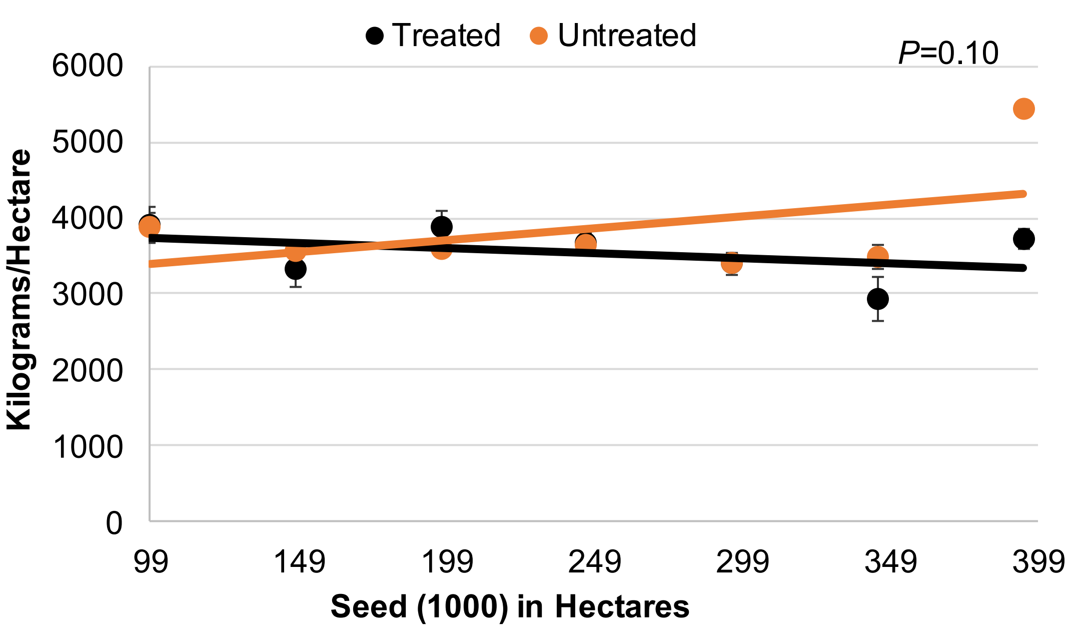


Figure 2.7 Relationship between planting population and seasonal mean (SEM) grain sorghum yields in Stoneville, MS during 2016

(Treated: Intercept 3872.40, Slope -1.32) (Untreated: Intercept 3883.74, Slope 1.27)



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CHAPTER III

EVALUATION OF PLANTING DATE, HYBRID, AND INSECTICIDAL TREATMENT ON SUGARCANE APHID (HEMIPTERA: APHIDIDAE) POPULATIONS IN GRAIN SORGHUM

Abstract

Experiments were conducted to determine if cultural control practices and insecticide treatments can reduce sugarcane aphid, *Melanaphis sacchari* (Zehntner), densities in grain sorghum, *Sorghum bicolor* L. Moench. Planting date, hybrid, and insecticide treatment were evaluated to determine their impact on aphid densities. Limited effective foliar insecticides may lead to increased reliance on the use of cultural practices and/or host plant resistance to control aphid infestations. This study was conducted at two locations in Mississippi to evaluate planting date, seed treatment, and hybrid on sugarcane aphid management in grain sorghum. Hybrid Pioneer™ 84P80 (susceptible) and Pioneer™ 83P17 (tolerant) with and without seed treatment and foliar insecticides for sugarcane aphid were planted at 5 planting dates: early-April, late-April, mid-May, early-June, and late-June. No differences in insecticide treated plots compared to untreated plots were observed at either location due to low aphid numbers. At both locations, the early and late April planting dates yielded significantly higher than mid-May, early-June and late-June planting dates regardless of hybrid. Although Pioneer™ 83P17 was considered an ‘aphid tolerant’ hybrid, aphid numbers were too low at both test

locations to fully evaluate. This research indicates that aphid populations begin to rise in early to mid-July depending on location. Early to mid-April planting dates allow plants to mature prior to sugarcane aphid infestations reaching economically damaging densities.

Introduction

Grain sorghum, *Sorghum bicolor* L. Moench, has a waxy cuticle to prevent the leaves from losing excess water during drought; making it a preferred crop in semi-arid environments (Martin et al. 1976). Sorghum also allows alternative pesticides to be used for insect and weed management that are not commonly used in cotton and soybean (Cronholm et al. 1998). In 2015, 8.42 million hectares of sorghum were harvested in the United States which decreased in 2016 to 6.62 million hectares (NASS 2016). This decrease is likely due to lower commodity prices and a new pest found in 2013, the sugarcane aphid, *Melanaphis sacch*ari (Zehntner), (Larson 2016).

In 2013, the sugarcane aphid was found in Texas, Louisiana, and Mississippi on grain sorghum (Elliot et al. 2015). Four years after the initial discovery of sugarcane aphid on grain sorghum, 97% of grain sorghum planted in the southern U.S. was infested (Bowling et al. 2016). Currently, it is not clear if sugarcane aphid infesting U.S. grain sorghum resulted from a host switch from sugarcane or an introduced biotype from overseas that prefers sorghum (Bowling et al. 2016).

Sugarcane aphid has black tarsi, short cornicles with black tips, and are yellow to brown in color which distinguishes it from other aphid species in sorghum (Bowling et al. 2016). Sugarcane aphids can mature in as little as four days, live up to 28 days, and produce an average of 30-60 nymphs, often leading to exponential population growth (van Rensburg 1973, Singh et al. 2004, Bowling et al 2016).

Sugarcane aphid feeds on the underside of leaves causing yellowing and necrosis of the plant due to the loss of nutrients (Narayana 1975, Singh et al. 2004). Economic losses as high as $432 per hectare were recorded in 2014 and 2015 (Bowling et al. 2016). Other management problems associated with sugarcane aphid include reduced grain quality, uneven heading, and honeydew accumulation (Singh et al. 2004). Uneven heading creates management problems for other pest such as sorghum midge because insecticide applications must be timed at bloom to be effective (Cronholm et al. 1998). Sugarcane aphids produce copious amounts of excess sugars from plant material that are not digested and excreted as honeydew (Singh et al. 2004). Honeydew provides an excellent environment for sooty mold and has been documented to reduce yield by up to 50% in 2014 and 2015 (Singh et al. 2004, Bowling et al. 2016). Honeydew is a sticky substance, and if present at harvest, can get coated on plant residue and cause mechanical failures during harvest by not allowing plant debris to pass through the machine correctly. Mechanical failures caused by honeydew can reduce harvest efficiency and cause equipment failure (Bowling et al. 2016).

When sugarcane aphid was first discovered in grain sorghum, no immediate control options were available. Mississippi has successfully applied for a Section 18 emergency exemption for sulfoxaflor (Transform™ 50WG, Dow AgroSciences, Indianapolis, IN) each year since 2014. In 2015, a Section 3 label was granted for flupyradifurone (Sivanto™ 200 SL Bayer CropScience, Leverkusen, Germany). Currently, these are the only foliar insecticides recommended for control of sugarcane aphid in grain sorghum (Catchot et al. 2016).

Neonicotinoid seed treatments are used as a preventative measure to manage early season aphid populations (North 2016). Late season populations are managed with foliar insecticides (North 2016). With minimal of foliar insecticide control options, cultural practices need to be incorporated to reduce insecticide exposure and delay the onset of resistance. Cultural practices have commonly been used to reduce pest densities (Buntin 2009). For example, crop rotation allows alternative chemicals to be used in the different crops as well as may reduce the buildup of sorghum pests (Buntin 2009). Tillage may destroy overwintering sites as well as weeds that could potentially be an early season problem (Buntin 2009). Other cultural practices include manipulating planting population, planting date, water management, and fertility management (Hill 1989). Many of these cultural practices have not been studied for sugarcane aphid management in grain sorghum and need to be investigated.

Materials and Methods

To determine the effects of planting date, hybrid, and insecticidal treatment on sugarcane aphid densities in grain sorghum, field studies were conducted in 2015 and 2016 at the R. R. Foil Research and Demonstration Center in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS. Experiments were in a randomized complete block design replicated 4 times with a factorial arrangement of treatments. Plot size was 15.24 meters by 3.86 meters on 96.52 cm beds in Starkville, MS and 15.24 meters by 4.06 meters on 101.6 cm beds in Stoneville, MS. Factor A was planting date and consisted of 5 planting dates. Planting dates were early-April, late-April, mid-May, early-June, and late-June. Factor B was hybrid and included a tolerant and susceptible hybrid. Pioneer 84P80 was used as the susceptible hybrid and Pioneer™

83P17 was used as the tolerant hybrid. Factor C was insecticide treatment and consisted of untreated control plots or plots treated with thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC) seed treatment and sprayed with foliar insecticide applications of sulfoxaflor (Transform™ 50WG, Dow AgroSciences, Indianapolis, IN) when aphid densities reached the current Mississippi threshold (Catchot et al. 2016). Thiamethoxam was applied at 0.062 mg ai/seed and sulfoxaflor was applied at 35 g ai/ha. Insecticide foliar sprays were applied with a tractor mounted sprayer calibrated to deliver 93.5 L/ha at 448.16 kPa with TX-6 ConeJet VisiFlo® Hollow Cone nozzles (TeeJet Technologies, Springfield, Illinois). Grain sorghum was non-irrigated in Starkville and irrigated in Stoneville. Weeds were managed using S-metolachlor + atrazine + mesotrione (Lexar EZ, Syngenta Crop Protection, Greensboro, NC) at 7.01 L/ha applied at planting. One week before planting, 31.75 kg/ha of nitrogen was applied followed by 45.36 kg/ha four weeks after planting. All incidental pests were managed using the Mississippi State University Extension Service Insect Control Guide for Agronomic Crops (Catchot et al. 2016). Plots were scouted weekly for sugarcane aphid by estimating aphid densities on 15 flag leaves (when available) and 15 lower canopy leaves in each plot. Number of aphids found on each leaf was then converted to average number of aphids per leaf. Plants were monitored until shortly after physiological maturity or aphid densities crashed. After grain reached physiological maturity and dried sufficiently to harvest, the center two rows were mechanically harvested with a small plot combine. Weights from each plot were adjusted to 13% moisture.

Mean aphids per leaf and yields were analyzed using a general linear mixed model analysis of variance (PROC GLIMMIX and PROC MEANS, SAS ver. 9.4, SAS

Institute, Cary, NC). Planting date, hybrid, insecticide treatment, and their interactions were considered fixed in the model. Replication and replication nested in planting date were considered random effects. Because aphid infestation timing varied between locations, locations were analyzed separately. Fisher's Protected LSD was used to separate means at the 0.05 level of significance.

Results

Experiment sites in Stoneville in 2015 and Starkville in 2016 were excluded from the study due to very low of aphid infestation levels and heavy bird depredation. Aphid populations remained below threshold at Stoneville during 2016. Locations were analyzed separately due to extreme differences in aphid densities between the two site years (Figure 3.1 and 3.2). There were no interactions for mean number of sugarcane aphid per leaf between planting date, hybrid, and treatment in Starkville 2015 and Stoneville 2016 (F=0.11; df=4, 620; P=0.98), (F=0.76; df=4, 236; P =0.55). Also, there were no interactions for yield between planting date, hybrid, and treatment in Starkville 2015 and Stoneville 2016 (F=0.94; df=4, 54; P=0.45), (F=1.14; df=4, 60; P =0.35). There were no significant interactions for mean number of sugarcane aphid per leaf in Starkville during 2015 between planting date by hybrid (F=1.21; df=4, 620; P =0.31), planting date by treatment (F=0.55; df=4, 620; P =0.69), or hybrid by treatment (F=0.67; df=1, 620; P =0.41). There were no significant interactions for mean number of sugarcane aphid per leaf in Stoneville during 2016 between planting date by hybrid (F=1.34; df=4, 236; P =0.26), planting date by treatment (F=0.71; df=4, 236; P =0.58), and hybrid by treatment (F=0.53; df=1, 236; P =0.46). There were no significant interactions for yield in Starkville during 2015 between planting date by treatment

(F=0.86; df=4, 54; P =0.49) or hybrid by treatment (F=0.37; df=1, 54; P =0.54). However there was a significant interaction for yield between planting date by hybrid (F=3.22; df=4, 54; P =0.02) (Figure 3.3). There were no differences in yield between plots planted to Pioneer™ 83P17 and plots plant to Pioneer™ 84P80 on the early-April, late-April, mid-May, and late-June planting dates. However, plots planted on early-June Pioneer™ 83P17 yielded significantly higher than plots planted to Pioneer™ 84P80. Plots planted in early-April and late-April yielded significantly higher than those planted in mid-May, early-June, or late-June regardless of hybrid. There were no significant interactions for yield in Stoneville during 2016 between planting date by treatment (F=0.12; df=4, 60; P =0.97) or hybrid by treatment (F=0.51; df=1, 60; P =0.48). However, there was a significant interaction for yield between planting date by hybrid (F=5.50; df=4, 60; P <0.01) (Figure 3.4). Pioneer™ 83P17 yielded significantly higher than the Pioneer™ 84P80 at the late-June planting date. Plots planted on early-April and late-April yielded significantly higher than those planted on mid-May, early June, or late June regardless of hybrid. There was no significant effect of insecticide treatment (seed treatment and foliar) during 2015 in Starkville or 2016 in Stoneville for mean number of sugarcane aphid per leaf (F=3.00; df=1, 620; P=0.08), (F=0.14; df=1, 236; P =0.71) or yield (F=0.00; df=1, 54; P=0.99), (F=0.08; df=1, 60; P =0.77). There was no significant effect of hybrid during 2015 in Starkville or during 2016 in Stoneville for mean number of sugarcane aphid per leaf (F=2.58; df=1, 620; P=0.11), (F=0.18; df=1, 236; P =0.67). During 2015 in Starkville, a significant effect of planting date was observed for mean number of aphids per leaf (F=11.89; df=4, 620; P <0.01). Significantly more aphids were observed in the early-April planting date than any other planting date (Figure 3.5). For plots in the early-April planting date, aphid densities peaked after grain had reached physiological maturity (Figure 3.1). When rating dates that occurred after plots reached physiological maturity were excluded and data were reanalyzed, plots planted on early-April and late-April had significantly lower mean aphids per leaf than the mid-May, early-June, or late-June planting date (F=2.55; df=4, 572; *P* =0.04) (Figure 3.6). There were no significant effects of planting date in Stoneville during 2016 (F=1.32; df=4, 236; *P* =0.26).

Discussion

Cultural practices can be an extremely important tool to manage insect pests in many crops. Castro et al. (2000) found more sorghum midge damage in mid-March planted grain sorghum, but it resulted in greater yields than other planting dates. Adams et al. (2013) found more tarnished plant bugs in mid-June planted cotton than in mid-April planted cotton.

In Starkville during 2015, peak aphid pressure occurred during August 1-15. During this time, the early-April planting date had reached physiological maturity. Although, aphid populations expanded in the earliest planted sorghum in Starkville after physiological maturity, this was not a common occurrence in our research. Management of sugarcane aphid is recommended after physiological maturity because when aphid densities increase, excess honeydew in the grain can reduce harvest efficiency causing loss of grain and mechanical failures. Early-April and late-April planted sorghum had significantly fewer aphids per leaf prior to physiological maturity than all other planting dates regardless of hybrid. Pioneer™ 83P17 yielded significantly higher than the Pioneer™ 84P80 when planted in early-June. Because sugarcane aphid never reached threshold in Stoneville during 2016, no differences were observed across planting dates for mean aphids per leaf. Regardless of hybrid, the early-April and late-April planted grain sorghum yielded significantly higher than grain sorghum at all other planting dates. Pioneer™ 83P17 yielded significantly higher at the late-June planting date than Pioneer™ 84P80. Planting date may be beneficial to help maximize yield as well as require less foliar insecticide applications throughout the growing season by avoiding peak aphid occurrence. Although it is well documented that sugarcane aphid can cause substantial yield loss in grain sorghum, infestations were not high enough to separate treated from untreated plots in these studies.

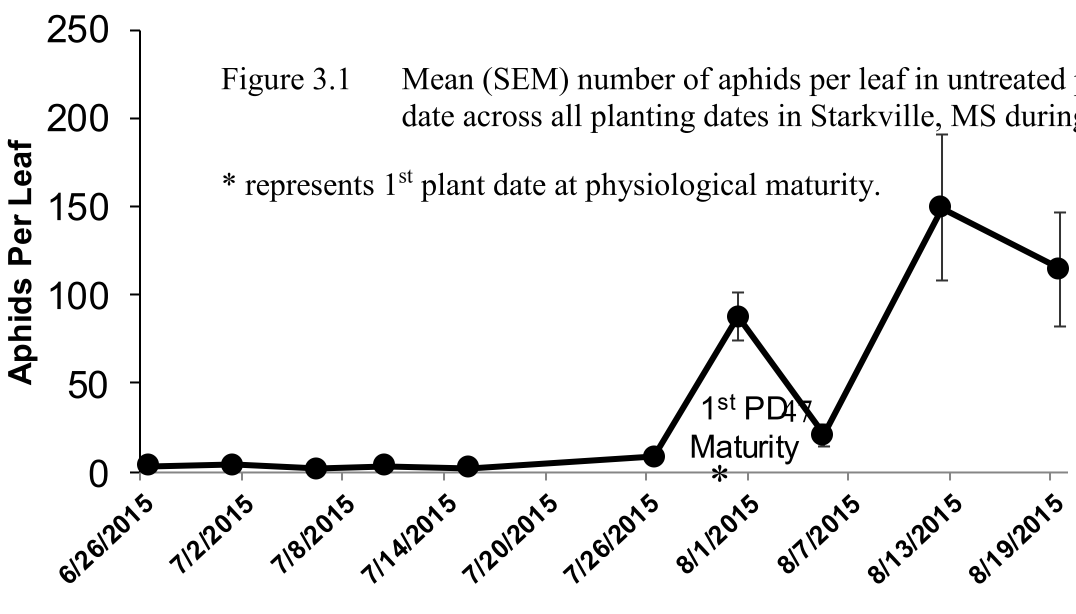
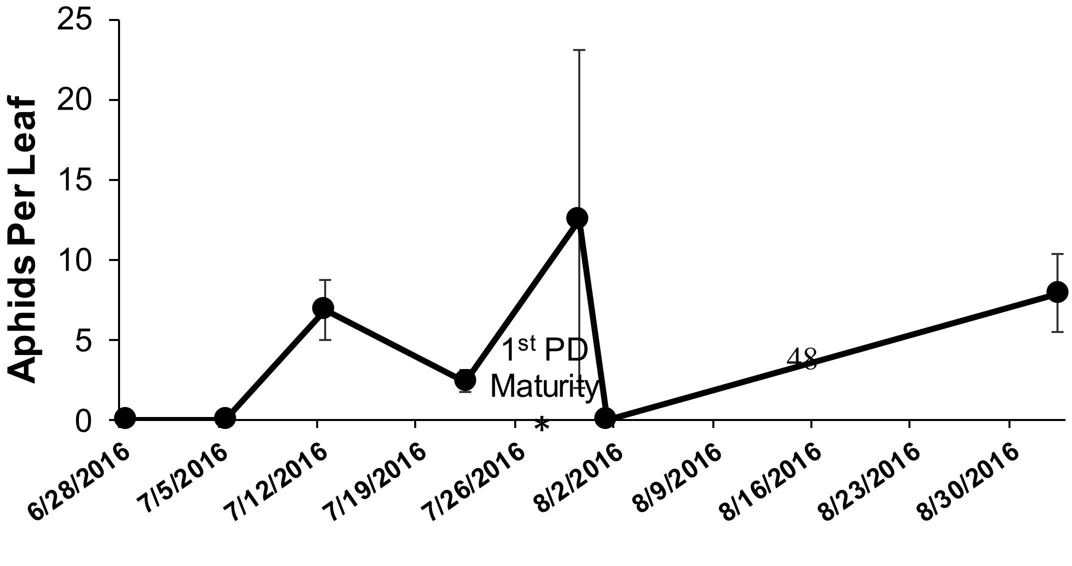


Figure 3.1 Mean (SEM) number of aphids per leaf in untreated plots at each sampling date across all planting dates in Starkville, MS during 2015

* represents 1st plant date at physiological maturity.

Figure 3.2 Mean (SEM) number of aphids per leaf in untreated plots at each sample date across all planting dates in Stoneville, MS during 2016

* represents 1st plant date at physiological maturity.



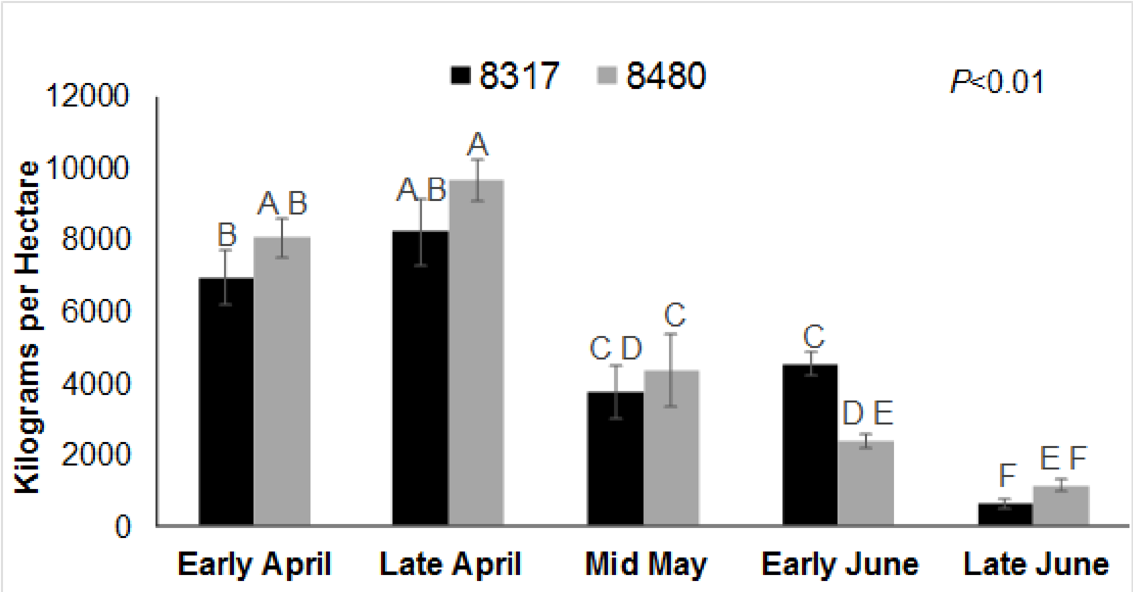
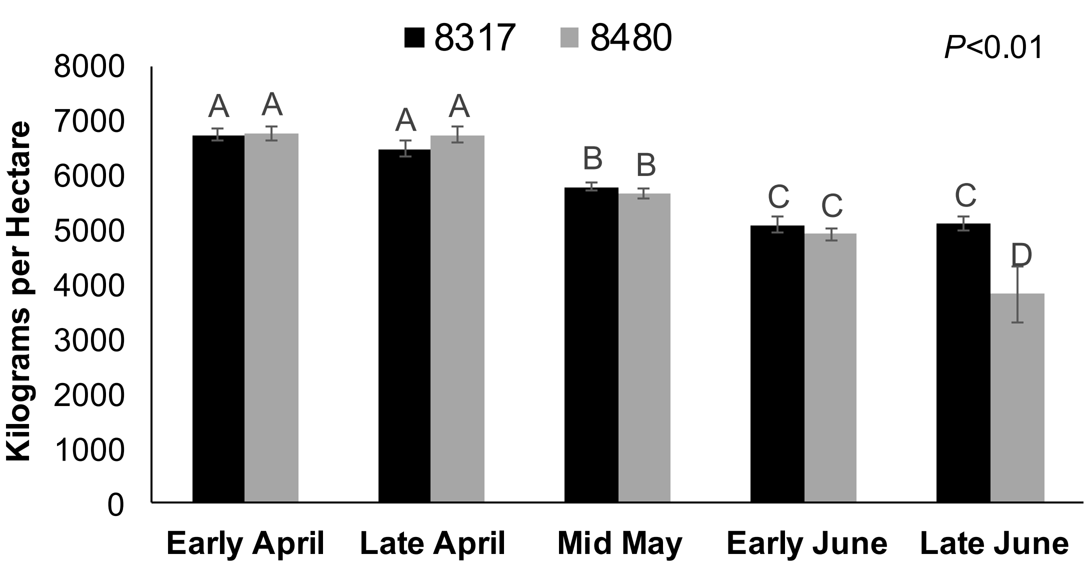


Figure 3.3 Impact of hybrid*planting date on grain sorghum yield (SEM) in Starkville, MS during 2015

Means with a common letter are not significantly different (α = 0.05).

Figure 3.4 Impact of hybrid*planting date on grain sorghum yield (SEM) in Stoneville, MS during 2016

Means with a common letter are not significantly different (α = 0.05).



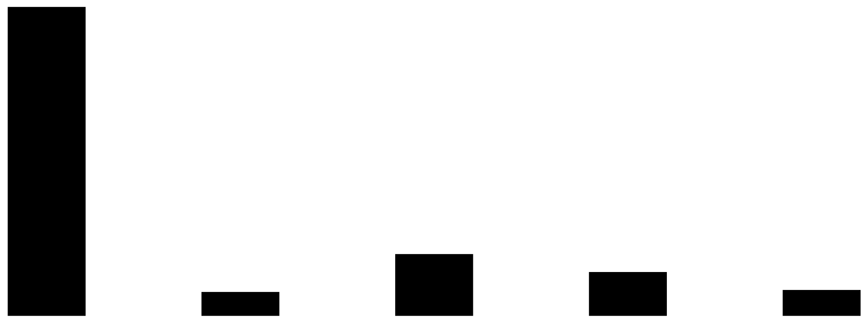


Figure 3.5 Impact of grain sorghum planting date on seasonal mean (SEM) number of sugarcane aphid per leaf in Starkville, MS during 2015

Means with a common letter are not significantly different (α = 0.05).

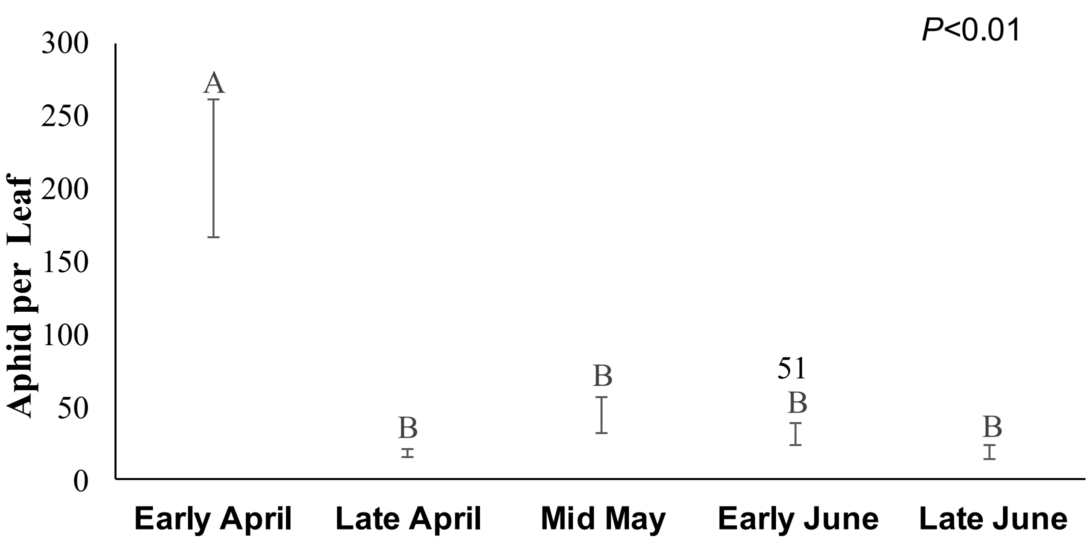
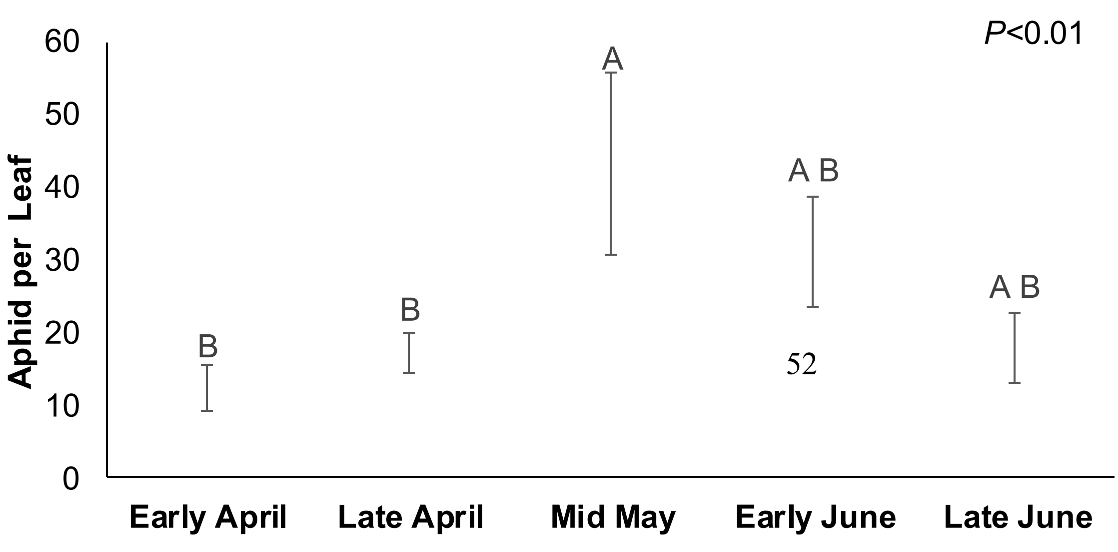


Figure 3.6 Impact of grain sorghum planting date on seasonal mean (SEM) number of sugarcane aphid per leaf in Starkville, MS during 2015 with sampling dates after physiological maturity excluded

Means with a common letter are not significantly different (α = 0.05).



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CHAPTER IV

SUMMARY

Sugarcane aphid is a new pest on grain sorghum in the United States. Aphid species have a long history of rapidly becoming resistant to insecticides due to short generation time, and increasing exposure to insecticides. This prompted research to evaluate cultural practices and treatment scenarios to control sugarcane aphid and to better understand how environmental factors such as temperature may impact efficacy of available insecticides currently used to control sugarcane aphids. Environmental temperatures can influence the efficacy of sulfoxaflor and flupyradifurone. Low temperatures negatively impacted control of sugarcane aphid. In most situations, flupyradifurone provided better control than sulfoxaflor. When making a foliar insecticide application, producers must be aware of temperatures, especially if cooler temperatures are in the forecast. Cultural practices may also be implemented to further manage sugarcane aphid infestations. In higher plant populations, a decrease in the number of aphids per leaf was observed. There was also considerable yield advantage for controlling sugarcane aphid in grain sorghum compared to untreated grain sorghum. Using a neonicotinoid seed treatment is important to incorporate into management strategies to prolong the use of foliar insecticides and possibly reduce insecticide applications prior to flowering. Higher plant populations may be beneficial to reduce losses associated with sugarcane aphid damage, however this should be further researched in a large field setting. Differences were also observed in aphid populations due to planting date. Early-April and late-April planted grain sorghum avoided peak aphid pressure during stages when the crop was most vulnerable to direct yield loss and yielded significantly higher than sorghum planted on mid-May, early-June, and late-June. Hybrid differences were observed during peak aphid infestations. In both years of the study, aphid numbers began to increase in mid-July. Planting dates that allow sorghum to reach hard dough or physiological maturity before sugarcane aphid infestations are less susceptible to yield loss, will likely lead to fewer insecticide applications and potentially less yield loss from sugarcane aphid. Although direct yield loss does not typically occur after sorghum reaches the hard dough stage, we did document infestations that moved into mature grain sorghum after physiological maturity in the earliest planting date in one location. Managing aphids after physiological maturity may be necessary to increase harvest efficiency.