ADAPTING GRAIN SORGHUM MANAGEMENT CONSIDERATIONS FOR OKLAHOMA IN THE PRESENCE OF PRODUCTION CHALLENGES

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Abstract:

Grain sorghum (*Sorghum bicolor (L.) Moench)*, is a crop commonly grown in Oklahoma and the southern Great Plains mainly because of its resilience and yield stability in the midst of drought conditions. However, due to the sugarcane aphid (*Melanaphis sacchari;* SCA) and low grain prices, ground allocated to grain sorghum production has been slowly shifting to the production of other crops. Two studies were conducted to evaluate various agronomic management practices to mitigate the production and price risks associated with growing grain sorghum in Oklahoma. The first study was designed to assess the effects that varying planting dates, applying and not applying insecticide, and planting susceptible and tolerant hybrids have on the yield of grain sorghum in the midst of SCA presence. Trials were conducted in 2016, 2017, and 2018 in Oklahoma. Results indicated that planting date had a significant impact on grain yield with the effects of hybrid selection and insecticide applications significantly benefiting yields when sorghum was planted later. Planting from mid-April through mid-May resulted in the highest yields. When sorghum was planted in early-June, yield was lost when no insecticide application was made and when a susceptible hybrid was planted. Planting in late-March resulted in lower yields four out of the five site-years, most likely due to low soil temperatures at planting. The second study was designed to evaluate the potential of utilizing grain sorghum residue left after harvest as forage for livestock in the time between the availability of high quality summer forages and high quality winter forages such as winter wheat. Trials were also conducted in 2016, 2017, and 2018 in Oklahoma. Adequate amounts of forage remained in the field after harvest ranging from 3829 kg ha^{-1} to 10129 kg ha^{-1}. However, the quality of the residue was low and may require supplementation for certain grazing animals. Nitrate toxicity is a common issue found in grazing plants in the sorghum genus. Throughout the study NO_3^- concentrations ranged from 310 ppm to 3727 ppm, with the highest amounts being found in regions prone to environmental stresses.

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CHAPTER I

INTRODUCTION

Sorghum (*Sorghum bicolor L.*) is a warm-season grass crop that possesses some level of tolerance to drought conditions (Assefa et al., 2004). Sorghum is grown as a grain or biomass crop. Its end-products are used in various ways throughout the world. Grain sorghum, the main sorghum type grown throughout the world, is used for direct consumption, primarily by livestock, with a smaller fraction used to produce ethanol. Forage sorghum is genetically similar to grain sorghum, but is grown for haying, grazing, and silage. A third type, sweet sorghum, is the least commonly grown sorghum type and is used for ethanol production (Rao et al., 2016).

Typically, sorghum crops are grown in arid regions of the world because of its ability to withstand moisture stresses (Rakshit et al., 2014). The United States is the top sorghum producing country in the world along with Nigeria, Sudan, Ethiopia, and Mexico (USDA-NASS, 2019). In the 2016-2017 season, the United States produced just over 12 million metric tons; Nigeria was the second largest producer at nearly 7 million metric tons produced (USDA-NASS, 2019).

The drought tolerant nature of sorghum is a beneficial characteristic for production in the Great Plains of the United States, predominately Kansas, Texas, Colorado, and Oklahoma (USDA-NASS, 2017a). Accordingly, in 2016, Oklahoma was the 4th largest sorghum producing state in the US, with 161,878 hectares planted (USDA-NASS, 2017b). In 2016, Oklahoma grain sorghum was worth $55,271,000 in sales and farm revenue (USDA-NASS, 2017b). In Oklahoma, grain sorghum production is concentrated in the western portion of the state, with Cimarron, Texas, Beaver, Grant, and Garfield counties leading in production (USDA-NASS and ODAFF, 2016). While sorghum is still a prominent crop in Oklahoma, overall hectares devoted to sorghum production have recently decreased with 121,408 hectares planted in 2018, down over 40,000 hectares since 2016 (USDA-NASS, 2019). This recent decline in hectares can be attributed to two primary issues, lower commodity prices and increased prevalence of a new aphid species.

According to the United States Department of Agriculture (USDA) Agricultural Prices Report from September of 2012, the price received by producers for grain sorghum in Oklahoma was \$0.27 kg^{-1}, differing from that of the same report for September of 2018 in which the price was \$0.13 kg^{-1} (USDA-NASS, 2012, USDA-NASS, 2018). The drastic changes in the price received for sorghum have caused producers to shift ground allocated to sorghum production to the production of other crops. Not only have prices decreased, but also a new aphid species has caused major losses within the past six growing seasons, deterring producers from planting sorghum.

Several species of aphids have been present in sorghum crops throughout the US for years. Greenbug (*Schizaphis graminum* Rodani) was a species of aphid that became very detrimental to US wheat and other cereal crops in the early 1900s and later became a pest of sorghum in the 1960’s (Brewer and Elliot, 2004; Royer et al. 2015). Recently sugarcane aphid (SCA), *Melanaphis sacchari* (Zehnter) has emerged as a sorghum pest that negatively affects production throughout the sorghum producing region of the United States. In 2013, this insect was observed in Texas, Louisiana, Mississippi, Oklahoma, and parts of northern Mexico on sorghum (Villanueva et al., 2014). Entomologists and other researchers have not been successful at determining the exact reason for the sudden presence of the aphid, and management options are still being researched.

The sugarcane aphid has the potential to cause an extreme amount of damage because of its rapid reproduction and its secondary products, particularly honeydew, a sticky substance that coats the sorghum leaves. In certain climates and conditions, sugarcane aphids are able to transition from birth to an adult in 4-12 days (Bowling et al., 2016). This quick life cycle allows for rapid infestations of fields, quickly exceeding economic thresholds.

Several chemical insecticides are available to producers that effectively control SCA. However, these insecticides are not a flawless management option for SCA control. The chemicals are expensive and may have to be used multiple times throughout the grain sorghum growing season. The time frames for proper insecticide applications are short and require the diligence and preparation of producers. The proper time for insecticide applications is often missed and results in less than adequate control of SCA or damage from the prolonged presence of aphids. Finally, both of the available insecticides have similar activity in the pest and pose a threat of insecticide resistance in SCA. After experiencing the effects of the sugarcane aphids and the amount of management necessary to control them, producers throughout the state have started to reevaluate their choice of a summer crop.

To overcome the low grain prices and the inevitability of SCA presence, management practices need to be improved to increase grain sorghum production in the state and its economic potential. No single practice will solve either issue, but a combination of several should be beneficial. Through this study, the objective is to re-evaluate agronomic practices in the presence of SCA that ensure maximum yield potentials. Similarly, in addition to grain production as the current sole form of profitability, this project will also explore a secondary practice to be used to maximize the economic potential of the grain sorghum system. The grazing of crops is a common practice in the southern Great Plains. Winter wheat is often used as a forage in Oklahoma throughout the winter months. Grain sorghum residue following harvest or a failed crop has the potential to serve as a dual-purpose crop by utilizing it as fall forage for livestock. The time at which grain sorghum is harvested often occurs when high quality summer forages are dwindling and before dual-purpose winter wheat is available. By using grain sorghum residue as forage, producers could potentially reduce feed purchases or use less of their stored feed for the winter. There is little information regarding the viability of this option. In addition, there are concerns regarding NO_3^- toxicity while grazing a sorghum exist. Therefore, it is intended, through biomass collection and quality testing, to evaluate the use of this practice in Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

SUGARCANE APHID (*Melanaphis sacchari*)

The sugarcane aphid (SCA), *Melanaphis sacchari* (Zehntner), is classified as Kingdom: Animalia, Phylum: Arthropoda, Subphylum: Hexapoda, Class: Insecta, Order: Hemiptera, Suborder: Sternorrhyncha, Superfamily: Aphidoidea, Family: Aphididae, Subfamily: Aphidinae, Tribe: Aphidini, Subtribe: Rhopalosiphina, Genus: *Melanaphis*, and Species: *sacchari* (Sullivan, 2006). It is one of nearly 4,000 aphid species in the Aphididae family (Sullivan, 2006). The SCA has been observed in around 34 different countries through Africa, Asia, Australia, North America, and South America (Singh et al., 2004).

Sugarcane aphids are small insects with a soft body ranging in size from 1-10 mm (Sullivan, 2006). They have been observed in colors of gray, tan, and light yellow (Bowling et al., 2016). Identifying characteristics of the SCA are dark antennae, dark cornicles protruding from the back of their abdomen, and dark tarsi or feet (Villanueva et. al, 2014). Winged sugarcane aphids have the same characteristics as the non-winged, but have additional black markings on their backs, hardened dark portions of their wings, and veins in their wings (Brewer et al., 2016).

Sugarcane aphids are able to rapidly reproduce within a field, making populations difficult to manage. The sugarcane aphids exhibit an anholocyclic life cycle, reproducing asexually through parthenogenesis, a form asexual reproduction that involves only female insects (Sullivan, 2006). This allows for quick reproduction because traditional sexual reproduction is not required. The adult females can produce up to 100 genetically identical young in as few as 13 days (Sharma et al., 2013). Another reason for the rapid reproduction is that sugarcane aphids are viviparous, meaning they give birth to live young (Singh et al., 2004). Once born, aphids undergo 4 to 5 molts (Sharma, et al., 2013) throughout 5 to 12 days, reaching maturity (Singh et al., 2004).

Aphid distribution highly depends on suitable climates and availability of host plants (Sullivan, 2006). Rapid reproduction and population growth is common in dry, warm climactic conditions (Brewer et al., 2016). Sugarcane aphids have been found to express host plant specialization, meaning they live and feed on closely related plants, such as plants from the same family, genus, or species (Nibouche et al., 2015). In North America suitable host plants for sugarcane aphids are found in the *Sorghum* genus, such as johnsongrass, *Sorghum halapense* (L.) Pers., and sorghum, *Sorghum bicolor* (L.) Moench (Armstrong et al., 2015). The reason for the sudden outbreak of the sugarcane aphid in the United States in 2013 is undetermined. Different researchers have theorized that the presence was brought on by an introduction of a completely new genotype through long distance migration or human introduction (Bowling et al., 2016), or a host plant shift through asexual reproduction (Nibouche et al., 2015; Harris-Schultz et al., 2017).

The genetic diversity of *M. sacchari*, has received increased attention over the last several years. Nibouche et al. (2014) identified five distinct multilocus lineages of SCA based on multilocus genotypes. However, geography, rather than host plant affiliation seemed to be a stronger influence on their worldwide distribution. There are various results on the genetic diversity of the species within the United States. Nibouche et al. (2014) identified one genetically distinct cluster; however, Medina et al. (2016) identified three genetically distinct clusters. The varying results could be due to different sample sizes within the research or the difference of years between the projects and the introduction of genetically different populations (Medina et al., 2016). Harris-Schultz et al. (2017) concluded that the population within the United States is a result of primarily one clone; this is in agreement with the Nibouche et al. (2014) findings.

Polymorphism, the occurrence of more than one phenotype of morph within a species in a habitat (Yazdani and Agarwal, 1997), is observed in the sugarcane aphid lifecycle through the existence of alate (winged) and apterous (not winged) aphids. The apterous phenotype reproduces to prolifically within a field, leading to the production of alate morphs (Brewer et al., 2016). A decrease in nutrient quality from the host plants, due to high aphid feeding, signals to the aphids to begin producing alate clones (Bowling et al., 2016; Yazdani and Agarwal, 1997). Alate clones are produced as a mechanism for migration to areas with more available nutrients. Winged aphids are able to fly short distances within a field and to surrounding fields, but because they are weak fliers, wind dispersal has been credited with long distance movement (Yazdani and Agarwal, 1997; Singh et al., 2004).

Aphids are sucking insects that remove nutrients from the phloem of their host plant (Sullivan, 2006). High populations of aphids cause direct injury to the host plant through feeding and indirectly through their waste excretions (Singh et al., 2004). Due to the low amino acid content in the sugary sap of the plant, aphids must consume high amounts of the food to sustain their daily dietary intake (Sullivan, 2006; Yazdani and Agarwal, 1997). Consumption of sugary food results in a sticky excretion called honeydew (Singh et al., 2004). The honeydew often causes issues with harvest and fosters growth of a sooty mold, which negatively affects the photosynthetic process taking place in the covered leaves and the ease of harvest (Brewer et al., 2016). Sooty mold is actually a several species complex that form and grow on high sugar surfaces, commonly from the *Cladosporium* and *Alternaria* genera.

Sugarcane aphids, in high populations, can reduce grain and forage yields depending on the timing of the infestation within the growing season, the duration of the infestation, and other stresses to the plants (Singh et al., 2004). High populations within a sorghum field before flowering and during grain fill have shown to result in decreased number of heads, lower seed weight, slower maturation, and even death of the plant (Bowling et al., 2016), see Table 1 below.

Table 1. Yield loss of grain sorghum at different growth stages in the presence of SCA.

Crop Stage at 20% SCA Infestations	Yield Loss when No Insecticide Applied (%)
Pre-boot	81-100
Boot	52-69
Emergence of Panicle	67
Soft Dough	21

Adapted from Catchot et al., 2015.

The extent of damage caused by heavy infestations post-flowering is lessened and has been observed to primarily influence harvestability rather than grain yield (Bowling et al., 2016). Bowling et al. (2016) estimates that a yield loss of 45 to 181 kg per hectare may be seen after a heavy infestation pre-flowering. Elliott et al. (2017) estimated that in 2014 Texas, Oklahoma, and Kansas experienced a joint loss of around 165,000 Mg in grain, worth $36,000,000, while also spending around $11,000,000 on insecticide applications. Zapata et al. (2017) studied the economic impact of the SCA outbreak in the Rio Grande Valley region of Texas and concluded that in 2014 there was an annual loss of \$29.77 ha^{-1} and \$22.70 ha^{-1}. Grain sorghum production has a slim profit margin, therefore, there is not much room to cover the added cost of SCA infestations due to grain losses and the necessary insecticide applications (Elliott et al., 2017).

INTEGRATED PEST MANAGEMENT OF SUGARCANE APHIDS:

Chemical control has been the primary option for managing SCA in US sorghum production. This was due to the lack of information on management options and the unknown potential of the commercially available sorghum hybrids' ability to offer host-plant resistance to the pest. Ultimately, concern for insect resistance to insecticide and harm to beneficial insects has become an emerging issue. The development of comprehensive pest management systems that integrate genetic resistance, management practices, and chemical control to manage SCA are crucial for the longevity of grain sorghum production in the southern Great Plains.

According to the United States Environmental Protection Agency, Integrated Pest Management (IPM) is "an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices" (USEPA, 2017). The purpose is to manage pests in an economic way without causing harm to people and the environment. The definition of IPM has changed throughout the years; however, the objectives remain the same.

In addition to insecticide applications, multiple management strategies have been suggested for an integrated SCA management plan; including host plant resistance, planting date, utilization of a seed treatment, introduction/conservation of SCA's natural predators, and usage of starter fertilizers (Colares et al., 2015; Bowling et al., 2016; Brewer et al., 2017; Lofton and Arnall, 2017; Hewlett et al., 2018; Szczepaniec, 2018). The combination of these control methods would provide a comprehensive strategy that fulfills the objectives of an IPM plan. Currently, the common management practices for controlling aphids include hybrid selection and chemical use (Bowling et al., 2016; Lofton and Arnall, 2017).

CHEMICAL CONTROL

When SCAs infested US sorghum in 2013, insecticides registered for use in sorghum did not provide adequate control (Zarrabi et al., 2014). As is common following the introduction of a new pest, studies were done to test different options for aphid control. Chlorpyrifos (Tradename Lorsban®; Dow AgroSciences), an organophosphate (sub-group of group 1 insecticides), was registered for sorghum but showed insufficient control (Zarrabi et al., 2014). Pyrethroids (sub-group of group 3 insecticides) show minimal efficacy to SCA and were found to be harmful to beneficial insects that are natural enemies to the SCA (Knutson et al., 2016). Sulfoxaflor (Tradename Transform® WG; Dow AgroSciences; Indianapolis, Indiana) and Flupyradifurone (Tradename SIVANTO® Prime; Bayer CropScience; Thane, India) were found to be effective at controlling aphid populations and were made available to sorghum growers for SCA control in 2014 and 2015, respectively (Bowling et al., 2016). Steckel and Stewart (2016) found that when compared to the untreated check, plots that were sprayed with Transform® 50 WG (Dow AgroSciences; Indianapolis, Indiana) or Sivanto 1.67 SL (Bayer CropScience; Thane, India) had an average of 97% fewer aphids 3 and 7 days after application, and 93% fewer aphids 13 days after applications.

These two chemistries are particularly effective against sucking insects, with a greater than 98% control of the SCA (Bowling et al., 2016). Sulfoxaflor, the active ingredient in Transform® WG (Dow AgroSciences; Indianapolis, Indiana), and flupyradifurone, the active ingredient in SIVANTO® prime (Bayer CropScience; Thane, India), are both classified as group 4 insecticides (IRAC, 2018). Group 4 insecticides target the nicotinic acetylcholine receptor (nAChR) acting as agonists, binding to the acetylcholine site causing extreme nerve reactions (Colares et al., 2016; IRAC, 2018). Sulfoxlaflor is in sub-group 4C, sulfoximines, while flupyradifurone is in sub-group 4D, butylenoids (IRAC, 2018). It is important to note that, after testing the toxicities of both products to the SCA natural predator, *Hippodamia convergens* Guérin-Méneville, they have been found to meet the criteria of integrated pest management programs (Colares et al., 2016).

Seed treatments are another insecticidal defense against SCA. Seed treatments may give the grower more flexibility by allowing fewer, less, or even removing the need for in-season management (Bowling et al., 2016). Jones et al. (2015) tested four different seed treatments and found that plants from treated seed had significantly fewer aphids than those of the non-treated check 26 days after planting and 33 days after planting.

Another study done in 2016 and 2017 showed that at a conventional planting date, seed treatment significantly decreased the average density of aphids throughout the 2017 season, no significant differences were observed in the early planted plots (Szczepaniec, 2018).

HYRID SELECTION

Through breeding and selection for host plant resistance, several SCA resistant hybrids have become commercially available to growers throughout the past few years. Initially, SCA resistance was discovered in the form of cross-resistance for greenbugs *Schizaphis graminum* (Rodani), which provided a preliminary pool of resistant germplasm to be incorporated into commercial lines (Armstrong et al., 2015). Through further evaluation and development, a collection of hybrids has been developed to express characteristics that inhibit high aphid population build-up or minimize the damage caused by aphids.

There are three main mechanisms that breeders focus on while selecting for resistance in a plant hybrid: antibiosis, non-preference or antixenosis, and tolerance (Painter, 1951; Sullivan, 2006). Antibiosis alters insect biology through plant composition properties, antixenosis deters insect activity, while tolerance allows plants to withstand insect pressure with little to no damage (Sullivan, 2006). Antibiosis through chemical compounds, lack of proper food, or lack of enough food, can cause multiple effects in insects after feeding on the resistant plant such as death, shortened life cycle, shortened or failed hibernation due to lack of food, decreased size, decreased fertility, and abnormal behavior (Painter, 1951). Non-preference or antixenosis is a mechanism of resistance that exploits unattractive physical features on the plant to discourage pests from inhabiting it (Painter, 1951). Tolerance is the ability of the plant to continue to grow and reproduce despite the presence of pests (Painter, 1951). Painter (1951) suggests that tolerance may be the most variable mechanism within a single variety because of the role that growth stages of the plant and the environment have on the ability of the plant to withstand pressures and stresses. It is also important to note that resistance in the form of tolerance to SCA can still pose issues; as yield damage may be insignificant, honeydew accumulation can still reduce harvest efficiency. Armstrong et al. (2016) found that out of the varieties tested, those least effected by aphid pressure showed all three mechanisms were present while those moderately effected by aphid pressure presented two to three of the resistance mechanisms. The three mechanisms, though separate, can have a combined effect on the plant-pest interactions (Painter, 1951).

PLANTING PRACTICES

Planting date has always been a critical practice for sorghum production. Most sorghum in Oklahoma is planted from later April through May. These planting dates have been used as a means to pair critical physiological stages of anthesis and grain filling with more favorable conditions experienced in June and August, rather than July. Furthermore, higher SCA populations after flowering are less detrimental to grain set, while still affecting harvest efficiency and the quality of grain (Bowling et al., 2016). In recent years, after the initial infestations of sugarcane aphids, some producers have been planting their grain sorghum earlier so that the time frame with the highest risk of SCA infestation falls later in the growth stages of their crop (Bean, 2017).

The practice of planting earlier has the potential to minimize the damage caused by sugarcane aphid infestations; however, there are other challenges that may arise when planting early. Soil temperature, soil moisture, and air temperature are all important factors when making decisions on time of planting (Ciampitti et al., 2017). It is advised to plant sorghum into soil with a temperature of at least 15.5°C (Bean, 2017) or in between 15°C and 23°C (Ciampitti et al., 2017). In some years, the soil temperatures may be below what is recommended until the conventional planting date, making the earlier planting dates unavailable. Planting into cold soil can cause delayed germination, seedling emergence, early-season plant growth, and maturation, which would nullify the value of early planting (Bean, 2017).

Double-crop sorghum, planting sorghum in following the harvest of winter wheat, production is practiced in Oklahoma. While this may be a successful potentially profitable practice, there are several risks associated. If planted a month past the optimum-planting window, yield potential is diminished (Bean, 2018). Heat and drought stresses are common throughout important growth stages in late-planted sorghum, as well as the increasing potential for the first freeze to fall before maturity (Ciampitti et al., 2017). Risks associated with these late planting dates have increased in recent years. Not only are the threats of harsh climatic conditions increased in late-planted sorghum, but the likelihood of peaked SCA infestations at vulnerable earlier growth stages are heightened (Bean, 2018). While the risks are higher, it is yet to be known whether the challenges associated with these later planting dates could be overcome with successful resistant hybrid and chemical control.

SORGHUM USES:

Grain sorghum has a variety of uses in the United States. The principle use is as an energy source in beef cattle finishing rations and in diets of lactating cows. As previously mentioned, grain sorghum can serve as a productive, low input crop when compared to corn. This is important when considering the feed value of the sorghum grain, as it is relatively comparable to corn in terms of crude protein (CP), total digestible nutrients (TDN), and net energy for gain (NEg) (Gaylean et al., 2010). Continued focus on water use in the face of dynamic climatic conditions will place a stronger emphasis on the use of grain sorghum as an alternative crop energy source to corn for livestock production (Warren et al., 2017).

Grain sorghum is believed to have great potential for sustainable biofuel production because of its water use efficiency, ability to grow in marginal lands, nutrient use efficiency, and its high lignocellulose content (Mathur et al., 2017). Sorghum is a unique crop because it can be used for its starch, sugar, or cellulose (Rooney et al., 2007). The high starch content of the sorghum grain, consistency of the oil during the liquefying process, as well as the short amount of time needed for the liquefying process are characteristics of grain sorghum that are beneficial to ethanol production (Rao et al., 2016).

Several situations suggest that grain sorghum residue could be a good source of roughage for livestock. A unique practice in the southern Great Plains is the utilization of wheat not only as a grain crop, but also forage for cattle (Lollato et al., 2017). This practice is referred to as "dual-purpose" and allows for increased profitability when compared to a sole grain or forage wheat crop (Lollato et al., 2017). Productivity and digestibility of warm season forage grasses diminish throughout the summer leaving a need for additional feedstocks for livestock. The lag in production between the dwindling warm season forages and the availability of the dual-purpose wheat pasture offers an opportunity for a more sustainable approach to grain sorghum production. Not only will the producer profit from the cattle gains, but also save by not having to purchase additives or supplemental rations.

Additionally, failed sorghum crops are a concern in the face of variable climatic conditions. The utilization of crop residue can be seen as a method of recovering some economic potential of the crop by providing a source of livestock feed. In terms of restrictive grain prices, supplemental income from a sorghum crop can be advantageous to producers as well. Grazing or haying sorghum residue provides an option for further income after a growing season.

According to Gaylean et al. (2010), average feed values of grain sorghum hay contain 8.95% CP, 54.5% TDN, 36.49% ADF, and 0.65 Mcal/kg of NEg. When utilizing sorghum residue as hay, consideration should be given to the concentration of nitrates (NO_3^-) and hydrogen cyanide/prussic acid (HCN) in the plant material. Toxic concentrations of NO_3^- for most ruminant animals are around 9000 ppm (Kellems and Church, 1998), while a more conservative value of around 5000 ppm was given by Strickland et al. (2017). Nitrate concentrations are greatest in the lower portion of stalks, while prussic acid concentrations are highest in leaves (Rasby et al., 2014).

High NO_3^- concentrations of forages may result in nitrite (NO_2^-) poisoning in the grazing livestock (Gleadow et al., 2016). Nitrite poisoning in animals occurs when the nitrite breaks down into ammonia that enters the bloodstream and binds with hemoglobin rendering it useless for carrying oxygen (Cash et al., 2006). Nitrogen (N) fertilization combined with drought conditions result in elevated levels of NO_3^- within the forage, leading to a risk of nitrite poisoning in livestock that consume it (Kellems and Church, 1998; Coblentz and Phillips 2004; Rasby et al., 2014). Prussic acid concentrations often become elevated in the new regrowth or young plants that have been in stressed conditions such as drought or frost (Barnhart, 2011; Whittier, 2011). Prussic acid mainly affects ruminant animals because of the increased release of the hydrogen cyanide from the bacteria in the rumen (Blasi et al., 1998; Barnhart, 2011; Whittier, 2011).

CHAPTER III

VARYING PLANTING DATES AS A METHOD OF SCA CONTROL

ABSTRACT

Sugarcane aphids (SCA) have become a major insect pest in most grain sorghum production areas in the United States and although effective chemical control options are available, complete reliance on insecticides is risky. Shifting planting dates as well as using SCA tolerant hybrids are strategies that could minimize cost while still managing SCA, potentially without the use of insecticide. However, there is little information available regarding the effectiveness of these practices on managing SCA or how adopting these practices would impact productivity of the crop. Trials were established in Oklahoma during 2016, 2017, and 2018. Four hybrids were seeded across four different planting dates with half of the plots receiving insecticide while the other half did not. Hybrids planted included two tolerant (SP 73B12; DKS 37-07) and two susceptible (KS 585; BH 3822 in 2016 and 2018; SP 34A19 in 2017). The planting dates ranged from late-March through early-June. Insecticide applications were made if and when SCA populations in the susceptible treatments reached critical threshold. Sulfoxaflor (Tradename Transform® WG; Dow AgroSciences; Indianapolis, Indiana) insecticide was used as the insecticide at all locations when applications were made. Plant stands were

taken for each plot 30 days after planting by counting the number of plants in the middle two rows out of a four row plot. Stands were taken again at harvest by counting all harvestable heads. Harvest timings varied for each plot due to the different planting dates as each were harvested when mature. An estimate of yield was determined by collecting grain from the middle two rows of a four-row plot using a small plot combine. All statistical analysis was done using SAS 9.4. Planting date had the largest influence on grain yield throughout all site years. The Mid-April and mid-May planting dates yielded an average of 41% higher than late-March and early-June planting dates. Hybrid selection and insecticide applications had less of an effect in the earlier planting dates; however, the later the planting date, the more influential hybrid and insecticide become. Significant differences in yield were observed between the treated tolerant hybrid and the non-treated susceptible hybrid of the early-June planting date. The treated tolerant hybrid averaged a 78% yield increase over the non-treated susceptible hybrid. Plant loss varied within each site-year. It was found that yield loss was related to the loss of viable plants during the season. In the mid-May and early-June planting dates, the non-treated susceptible hybrid yielded, on average, 64% less than the treated tolerant hybrid and lost an average of 61% more plants throughout the season. Planting between mid-April and mid-May can help mitigate potential SCA risks and maintain the crop's economic potential. When planting later, such as in a double cropping system, the utilization of insecticide and a tolerant hybrid becomes beneficial to maximize yields. Through optimizing planting dates as well as incorporating insecticide applications and tolerant hybrids, grain sorghum producers in the southern Great Plains have the potential to not only optimize yields but also successfully manage SCA.

METHODOLOGY

Field experiments at the EFAW research station northwest of Stillwater, Oklahoma in 2016 and 2017 and the Oklahoma State University North Central Research Station west of Lahoma, OK in 2016, 2017, and 2018. Temperatures and rainfall for each year and location are given in Figures 1-5. The dominant soil series and soil descriptions for the different site years are listed in Table 2. Prior to plot establishment, soil samples were collected across the trial area and submitted to the Soil, Water, and Forage Analytical Laboratory at Oklahoma State University. These samples were used to guide nutrient applications.

The field trials were established as a split plot design evaluating three treatments: planting dates, grain sorghum hybrid selection, and insecticide application. These will be referred to as planting date, hybrid, and insecticide treatment for the remainder of the chapter. Planting dates served as the main plots, and the subplots were a two-way factorial between hybrid and insecticide treatments assigned randomly within each main plot. At each location, the treatments and all interactive effects were replicated four times. Planting date treatments were late-March, mid-April, mid-May, and June, exact planting dates differed slightly for each location and year and are highlighted in Table 3. The hybrid treatment included four hybrids; two SCA susceptible hybrids and two SCA tolerant hybrids. The two SCA susceptible hybrids used in 2016 were KS 585 and BH 3822, in 2017, KS 585 and SP 34A19 were used, and in 2018, KS 585 and BH 3822 were used. The use of SP 34A19 in 2017 was due to the lack of available seed of BH 3822 in 2017. The two SCA tolerant hybrids used for all three years were SP 73B12 and DKS

37-07. The insecticide treatments were split into non-treated and treated plots. Sulfoxlaflor (Tradename Transform® WG; Dow AgroSciences; Indianapolis, Indiana) was used as the insecticide treatment at a rate of 0.73 L ha^{-1}. Insecticide applications were made when aphid populations were 50-125 aphids per leaf on 20% of plants before head emergence or 30% of pants after head emergence (Royer, 2018). Due to the absence of SCA pressure in Lahoma in 2018, insecticide treatments were not applied, therefore, will be omitted from analysis.

Plots were established using a Monosem (Monosem Inc.; Edwardsville, Kansas) planter in 2016 and 2017 and with a John Deere MaxEmerge 2 planter (John Deere; Moline, Illinois) in 2018. Plots measured 6.1 meters long and 3.3 meters wide, composed of four rows set 76.2 cm apart. All plots were seeded at 105,760 seeds ha^{-1}. At planting, a combination of S-metolachlor and atrazine (Bicep Lite II Magnum- 324 g a.i. L^{-1} of atrazine and 395 g a.i. L^{-1} of S-metolachlor; Syngenta; Basel, Switzerland) were applied at the rate of 4.23 L ha^{-1}, all in-season weeds were physically removed. Throughout the season, all agronomic management was conducted through best management practices in accordance with Oklahoma Cooperative Extension Service.

Thirty days following planting, stand counts were taken by counting the number of plants along 3.5 m of row for both rows for each plot. At harvest, additional stand counts were collected in a similar manner to those taken following planting; however, for the stands at harvest, only plants with a harvestable primary stem were counted. If plants did not have a viable reproductive structure or the structure was not fully mature it was not counted. An additional population measurement was calculated by subtracting the stands thirty days after planting from the stands at harvest. This measurement was used to determine the shift of in-season plant stands associated with implemented treatments. At physiological maturity and less than 30% grain moisture, all plots within an individual planting date were desiccated using a 1,728 g a.e. ha^{-1} application of glyphosate (Roundup PowerMAX; Monsanto; St. Louis, Missouri). Fourteen days following application, plots were harvested using a Wintersteiger small plot combine (Wintersteiger; Ried im Innkreis, Austria). Plot weights were used to estimate yield on a per hectare basis.

STATISTICAL ANALYSIS:

Statistical analysis was performed using SAS v9.4 (SAS Institute Inc., Cary, NC) to determine the impact of planting date, hybrid, and insecticide treatments on yield, initial plant populations, final plant populations, and the difference in plant populations between populations thirty days after planting and at harvest. For analysis, the data collected as averaged across the two tolerant hybrids and the two susceptible hybrids to create a single value for the two categories of hybrid. Planting date, hybrid, and insecticide treatments as well as their interactive effects were designated as fixed variables while replication, site location, year, and their interactions were treated as a random effect. As analysis was not consistent for location between years, all years were tested independently. Analysis of variance was conducted using Procedure Mixed (PROC MIXED). Post-hoc analysis was done with a Tukey adjustment with a Slice option, where appropriate, to determine differences between the individual mean values. All analysis was done with $\alpha = 0.05$. Regression analysis was done using Procedure

Regression (PROC REG) in SAS v9.4 (SAS Institute Inc., Cary, NC) with final plant population as the independent variable and yield as the dependent variable.

Table 2. Locations, soil series, and soil descriptions for trials in Chapter III.

Year	**Location**	**Latitude and Longitude**	**Soil Series**	**Description**
2016	EFAW	36°07'54.9"N 97°06'18.7"W	EASPUR	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC FLUVENTIC HAPLUSTOLLS
	Lahoma	36°23'21.6"N 98°06'34.9"W	GRANT	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
2017	EFAW	36°07'54.9"N 97°06'18.7"W	NORGE	FINE-SILTY, MIXED, ACTIVE, THERMIC UDIC PALEUSTOLLS
	Lahoma	36°23'21.6"N 98°06'34.9"W	GRANT	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
2018	Lahoma	36°23'21.6"N 98°06'34.9"W	GRANT	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS

Table 3. Important dates 2016-2018 for trials in Chapter III.

Year	**Location**	**Planting Date Treatment**	**Date of Planting**	**Date of Insecticide Application**	**Date of Harvest**
2016	EFAW	Late-March	March 23rd	July 26th	September 17th
		Mid-April	April 22nd	July 26th	September 17th
		Mid-May	May 18th	August 9th	September 17th
		Early-June	June 16th	August 30th	September 17th
2016	Lahoma	Late-March	March 29th	August 9th	September 22nd
		Mid-April	April 22nd	August 9th	September 22nd
		Mid-May	May 13th	August 9th	October 3rd
		Early-June	June 21st	September 7th	October 3rd
2017	EFAW	Late-March	March 28th	August 9th	October 11th
		Mid-April	April 14th	August 9th	October 11th
		Mid-May	May 10th	August 9th	October 11th
		Early-June	June 3rd	August 23rd	October 11th
2017	Lahoma	Late-March	March 31st	August 17th	September 19th
		Mid-April	April 22nd	August 17th	September 19th
		Mid-May	May 18th	August 17th	October 5th
		Early-June	June 10th	August 17th	October 5th
2018	Lahoma	Late-March	March 30th	N/A	September 20th
		Early-May	April 30th	N/A	September 20th
		Early-June	June 1st	N/A	September 20th

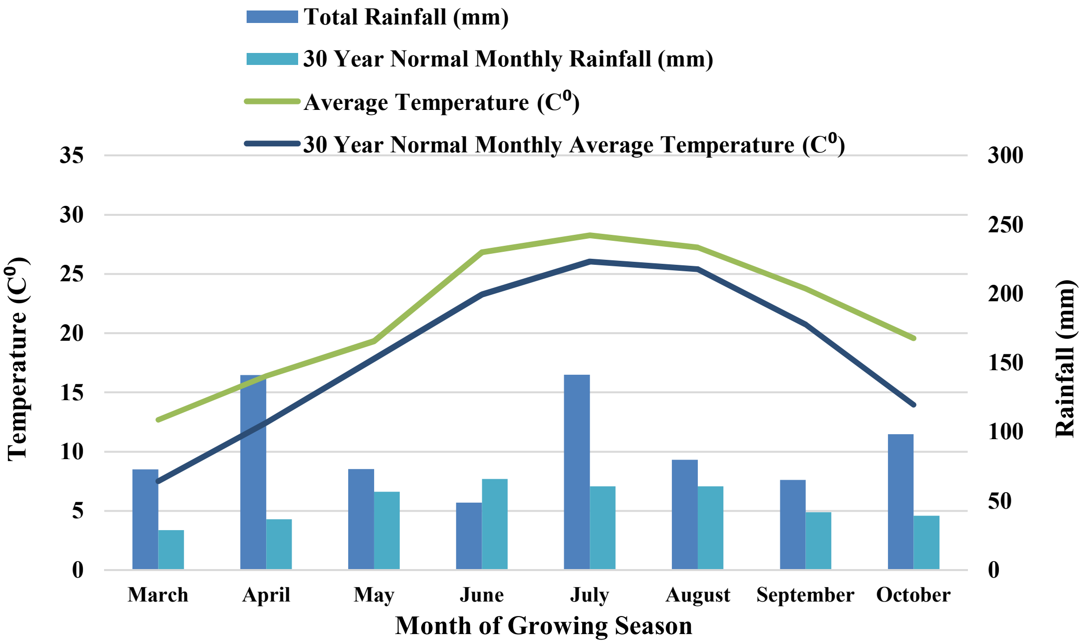

Figure 1. Temperature and rainfall observed throughout the 2016 growing season at EFAW in Stillwater, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

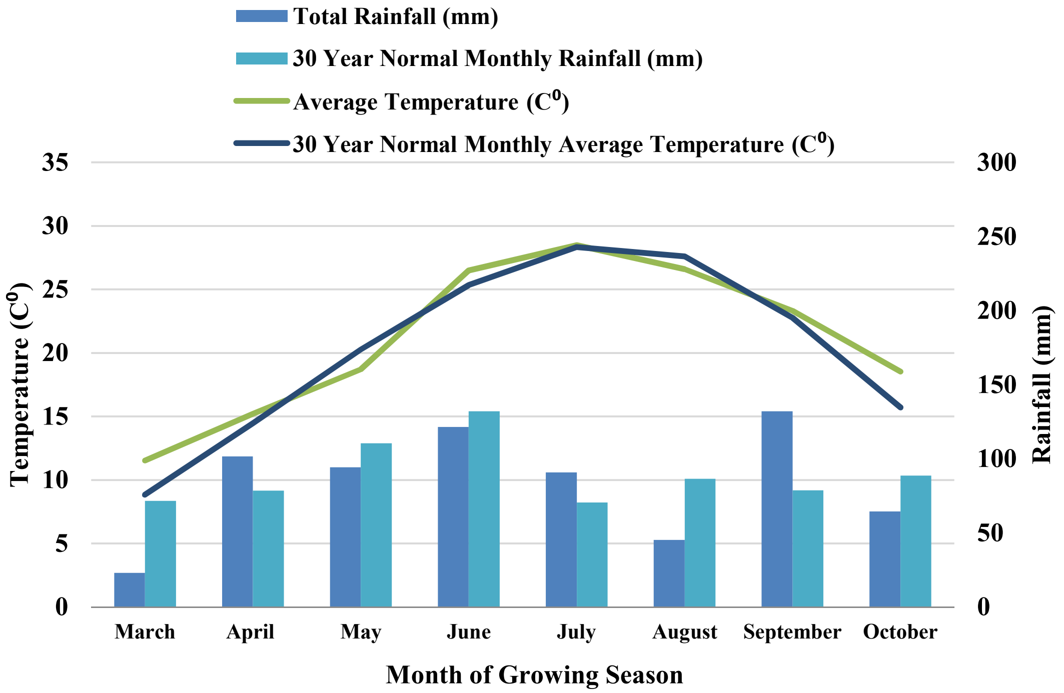

Figure 2. Temperature and rainfall observed throughout the 2016 growing season at Lahoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

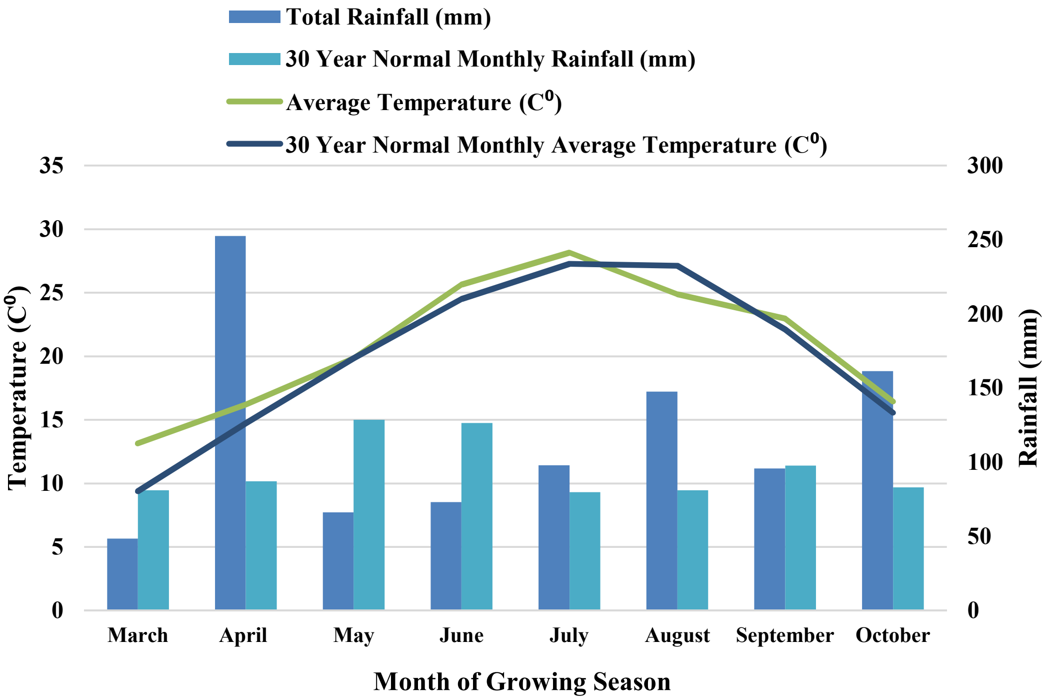

Figure 3. Temperature and rainfall observed throughout the 2017 growing season at EFAW in Stillwater, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

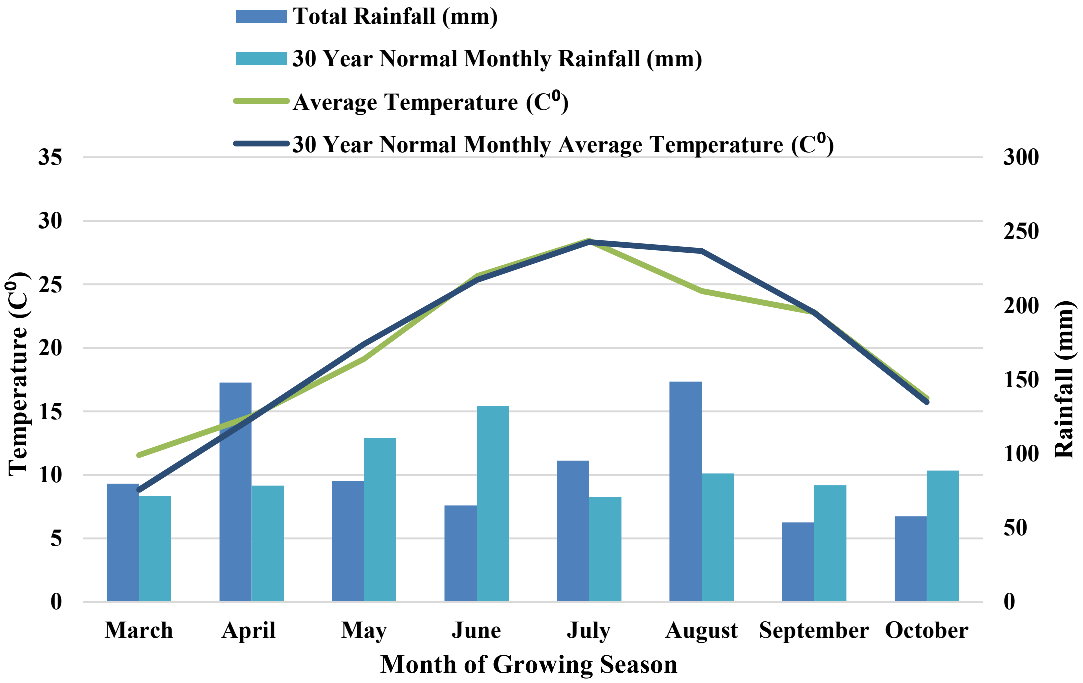

Figure 4. Temperature and rainfall observed throughout the 2017 growing season at Lahoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

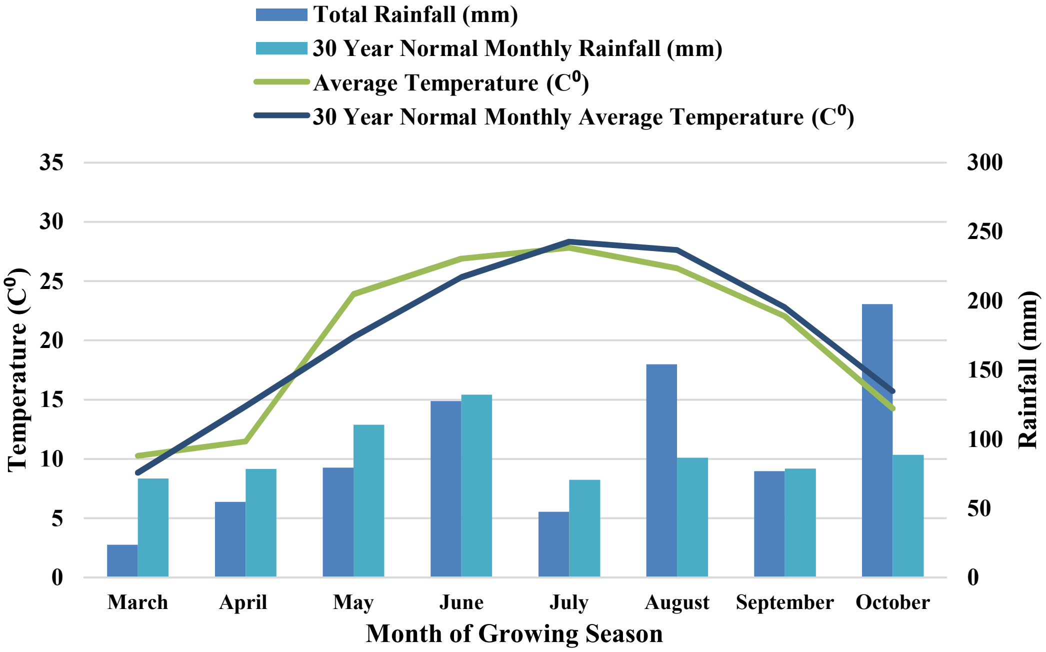

Figure 5. Temperature and rainfall observed throughout the 2018 growing season at Lahoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

RESULTS

YIELD

Yield was highly variable between years, locations, and treatments. In 2016 yields at EFAW averaged 3054 kg ha^{-1}, and ranged from 438 kg ha^{-1} to 5802 kg ha^{-1} while yields at Lahoma averaged 3050 kg ha^{-1}, and ranged from 560 kg ha^{-} to 5118 kg ha^{-1}. In 2017 yields at EFAW averaged 3277 kg ha^{-1}, and ranged from 10 kg ha^{-1} to 7058 kg ha^{-1} while Lahoma yielded an average of 3423 kg ha^{-1}, with a range of 12 kg ha^{-1} up to 7524 kg ha^{-1}. Lahoma yielded an average of 4152 kg ha^{-1} in 2018, with a range of 1955 kg ha^{-1} to 6799 kg ha^{-1}. It is important to note that the very low yields at both locations in 2017 could be attributed to adverse environmental conditions at planting and will be addressed again in the discussion section. Lahoma received more precipitation during the critical months of May and June than EFAW in 2017, which could have led to the higher yields at Lahoma.

EFAW 2016

Yield at EFAW was significantly influenced by a three-way interaction between planting date, hybrid, and insecticide applications (Figure 6). With the exception of the non-treated susceptible hybrid, which was not significantly different from both the treated and non-treated tolerant hybrids of the mid-May planting date, all treatments in the mid-April planting date yielded significantly higher than all other insecticide treated hybrids from the other planting dates. The non-treated susceptible hybrids at the mid-April and mid-May planting dates both yielded significantly lower than the other treatments within their respective planting dates. At the mid-April planting date, the non-treated susceptible hybrid yielded 22% lower than the treated susceptible hybrid and 23% lower than the non-treated tolerant hybrid. At the mid-May planting date, the non-treated susceptible hybrid yielded 41% lower than the treated susceptible hybrid and 47% lower than the non-treated tolerant hybrid. Significant yield loss occurred in all treatments at the both the late-March and early-June planting dates when compared to the mid-April planting. When averaged across treatments, the late-March planting date yielded 47% lower than the mid-April planting date while the early-June planting date yielded 64% lower than the mid-April planting date. Within the late-March planting date, the non-treated tolerant hybrid significantly out-yielded the treated tolerant hybrid by 797 kg ha^{-1}; there were no other significant differences between treatments at that planting date. Within the early-June planting date, the susceptible hybrids both yielded significantly lower than the tolerant hybrids, but were not significantly different from each other.

Likewise, the tolerant hybrids of the early-June planting date were not significantly different from each other.

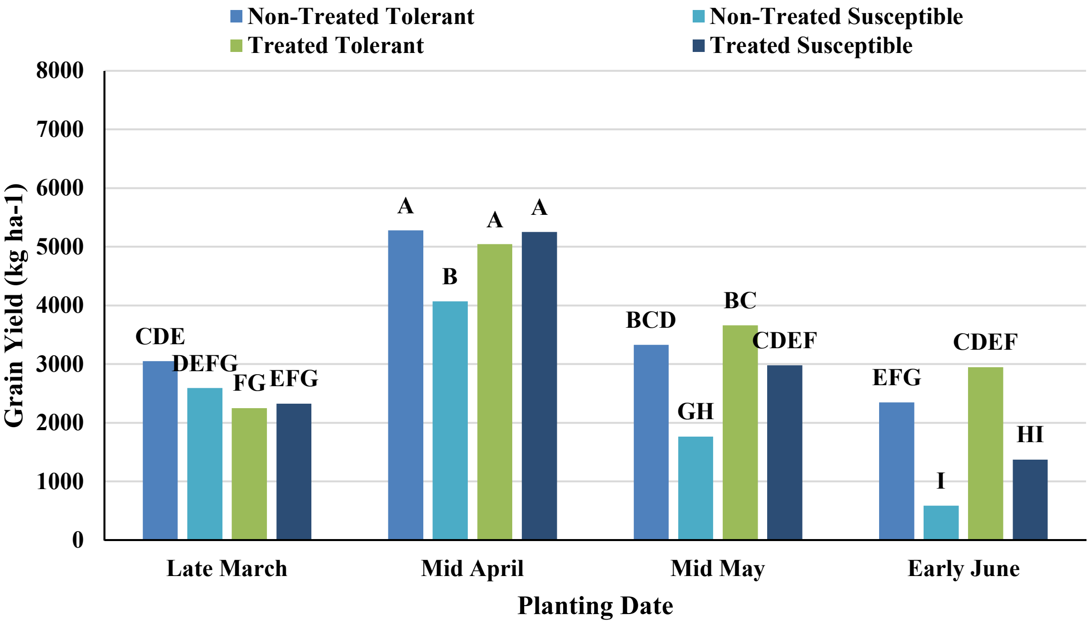

Figure 6. Yield results at EFAW in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of the three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

LAHOMA 2016

A significant three-way interaction existed between the planting dates, insecticide treatments, and hybrid selection at Lahoma in 2016 (Figure 7). Across all treatments, planting dates had the largest impact grain yield. The mid-April planting date out-yielded the other planting dates for all treatments, with the exception of the treated tolerant hybrid, which had similar yields at April and May planting dates, only a 12% difference. The yields of the mid-April planting date varied from the mid-May planting date by 18% in the non-treated tolerant hybrid, 63% in the non-treated susceptible hybrid, 12% in the treated tolerant hybrid, and 22% in the treated susceptible hybrid; all differences were significant with the exception of the treated tolerant hybrid. The lowest yielding planting dates varied between treatments. The late-March planting date yielded significantly lower than all other planting dates in the treated tolerant hybrid. However, with the non-treated tolerant hybrid and the treated susceptible hybrid, there were no significant differences between the late-March and early-June planting dates, which both produced significantly lower yields than the other planting dates. Within the non-treated susceptible hybrid, the mid-May and early-June planting dates were not significantly different, producing the lowest yields of 1397 kg ha^{-1} and 802 kg ha^{-1} respectively. Within the non-treated susceptible treatments, the early-June planting date was significantly different than all other planting dates; however, the mid-May planting date was not significantly different than the late-March planting date.

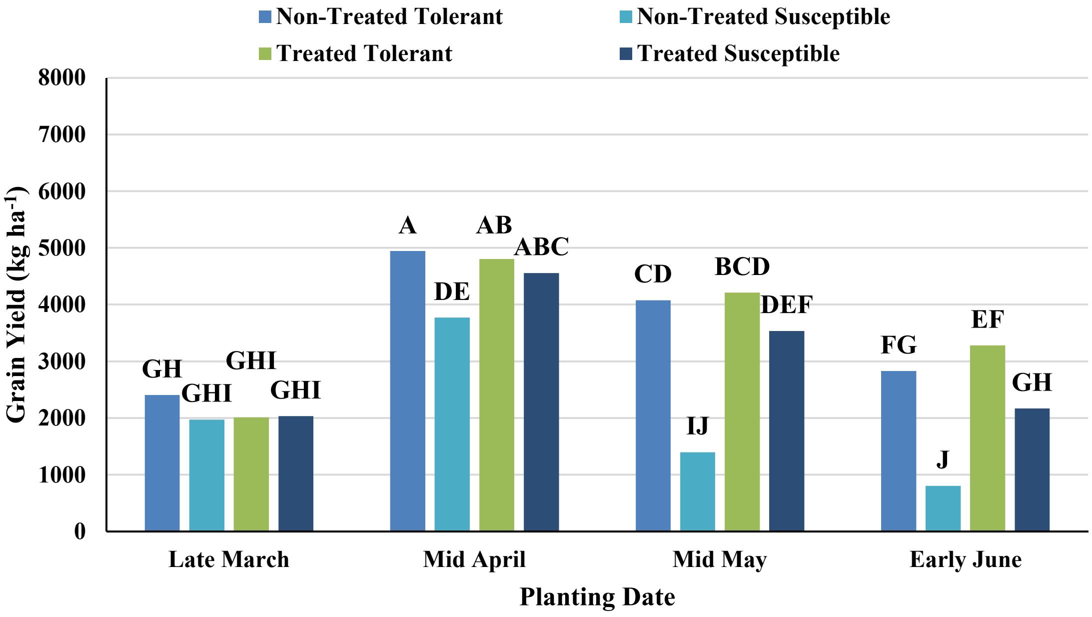

Figure 7. Yield results at Lahoma in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

EFAW 2017

Yield at EFAW in 2017 was influenced by a three-way interaction between planting date, hybrid, and insecticide treatments (Figure 8). The late-March planting date resulted in stand failure due to cooler soil conditions at planting; therefore, yield was significantly lower than all other planting dates and will not be referred to again in this section. For every similar hybrid-insecticide treatment combination, the mid-May planting date significantly outperformed the mid-April, which yielded significantly higher than the early-June planting date. The non-treated tolerant hybrid of the mid-May planting date yielded highest out of all treatment combinations in all planting dates, including the treated tolerant hybrid of the same planting date. The difference between yields was greater between the mid-April and early-June planting date than between the mid-May and mid-April planting dates. This was particularly seen in the non-treated susceptible hybrids, with the mid-April planting date yielding 28% less than the mid-May planting date, but out-yielding the early-June planting date by 76%. The non-treated susceptible hybrid at the early-June planting date was the lowest yielding treatment of all with the treated susceptible hybrid of the same planting date, although significantly higher than the non-treated, still significantly lower than the rest. The non-treated susceptible hybrid at the early-June planting date yielded significantly lower than all other treatments for each planting date.

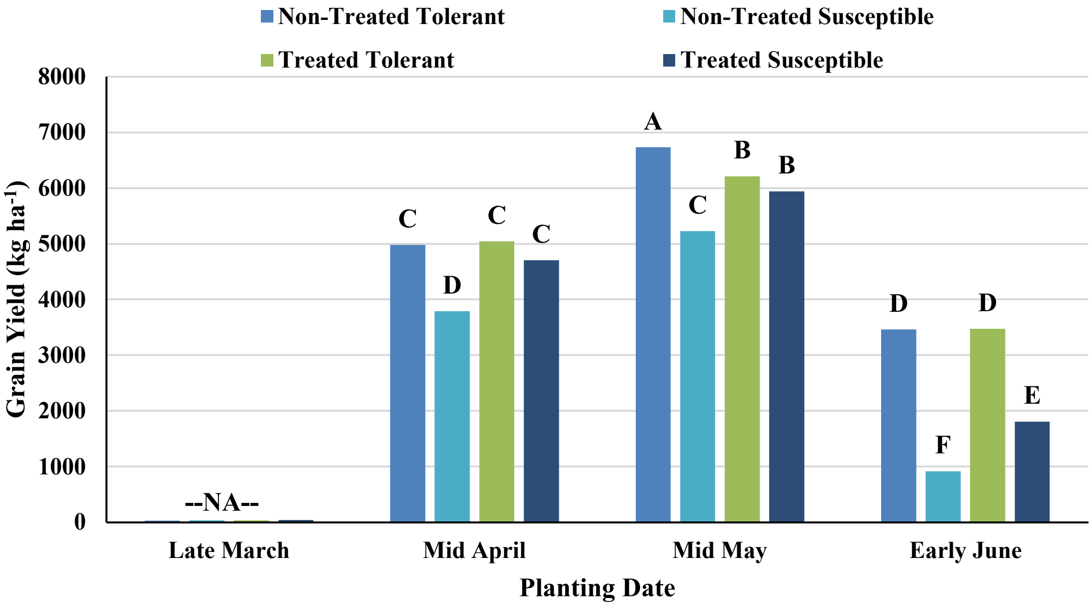

Figure 8. Yield results at EFAW in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. ($\alpha = 0.05$).

LAHOMA 2017

Similar to EFAW in 2017, there was a significant three-way interaction between planting date, hybrid, and insecticide treatments at Lahoma in 2017 (Figure 9). The late-March planting date resulted in stand failure due to similar cooler conditions at planting; therefore, yield was significantly lower than all other planting dates and will not be referred to again in this section. The highest yielding treatment, significant from all others, was the treated tolerant hybrid in the mid-May planting date yielding 7113 kg ha^{-1}. For each planting date, the treated tolerant hybrid yielded highest out of all other treatments while the non-treated susceptible hybrid yielded the least. The differences between these treatments were 36% in the mid-April planting, 79% in the mid-May planting, and 82% in the early-June planting. For every treatment, except for the non-treated susceptible hybrid, the mid-May planting yielded higher than the equivalent treatment in both the mid-April and mid-July planting dates. The non-treated susceptible hybrid of the mid-April planting date yielded 4042 kg ha^{-1}, significantly higher than the same treatment of the mid-May and early-June plantings yielding 1523 kg ha^{-1} and 954 kg ha^{-1} respectively. The yields of the non-treated tolerant hybrid were not statistically different than the yields of the treated susceptible hybrid in both the mid-April and mid-May planting dates. A difference in yield was still seen with the non-treated tolerant hybrid yielding 7% higher than the treated susceptible hybrid in the mid-April treatment and 10% higher in the mid-May planting. A significant difference was present in the early-June planting date with the non-treated tolerant hybrid yielding 29% higher than the treated susceptible.

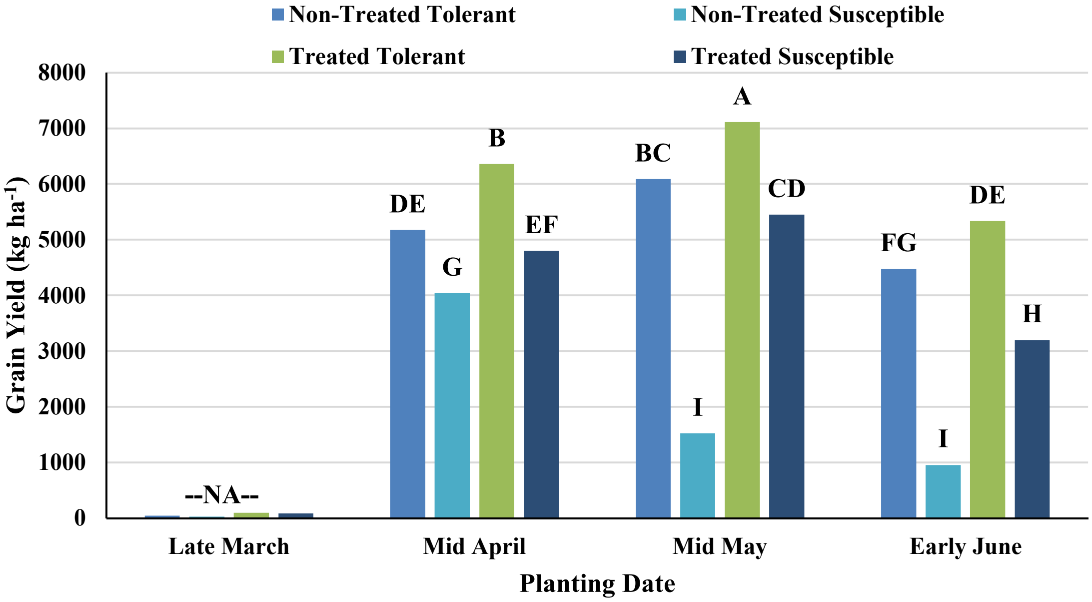

Figure 9. Yield results at Lahoma in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

LAHOMA 2018

A single main effect was present at Lahoma in 2018 with the planting date having a significant impact on yield (Figure 10). Hybrid selection did not have a significant impact on yield. The yields of the late-March and late-April planting dates were significantly higher than the yields of the early-June planting date. The late-March and late-April planting dates produced average yields 34% and 40% higher than the early-June planting date respectively. Late-March had an average yield of 4504 kg ha^{-1}, late-April averaged 4965 kg ha^{-1}, and early-June averaged 2986 kg ha^{-1}.

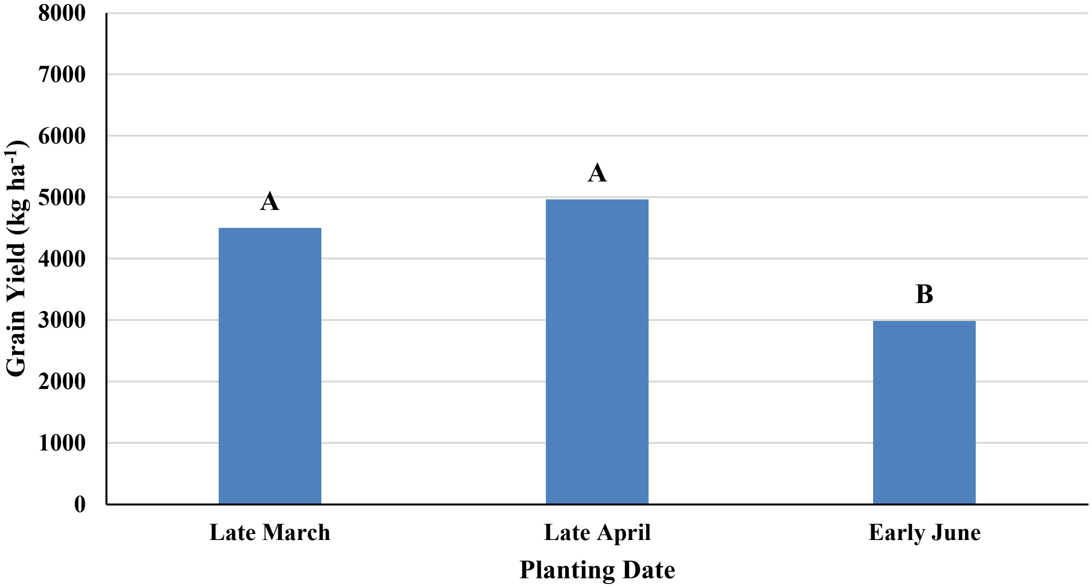

Figure 10. Yield results at Lahoma in 2018 in terms of planting date. Letters denote significant differences between yields as a result of a main effect of planting dates. (α = 0.05).

INITIAL PLANT POPULATION

EFAW 2016

There was a two-way interaction between planting date and hybrid at EFAW in 2016 that effected initial plant populations (Figure 11). Initial plant populations ranged from 54286 plants ha^{-1} to 86371 plants ha^{-1}. The tolerant and susceptible hybrids in the mid-April planting date, as well as the susceptible hybrid in the mid-May planting date had significantly higher plant populations than the others. The tolerant hybrid of the late-March planting date and both hybrids of the early-June planting date had the lowest number of plants ha^{-1} at their respective initial stand counts. Regardless of hybrid, the mid-April and mid-May planting dates had significantly higher initial plant populations than the early-June planting date. The mid-April planting date had significantly higher plant populations than all others with the exception of the susceptible hybrid of the mid-May planting date, which was not significantly different.

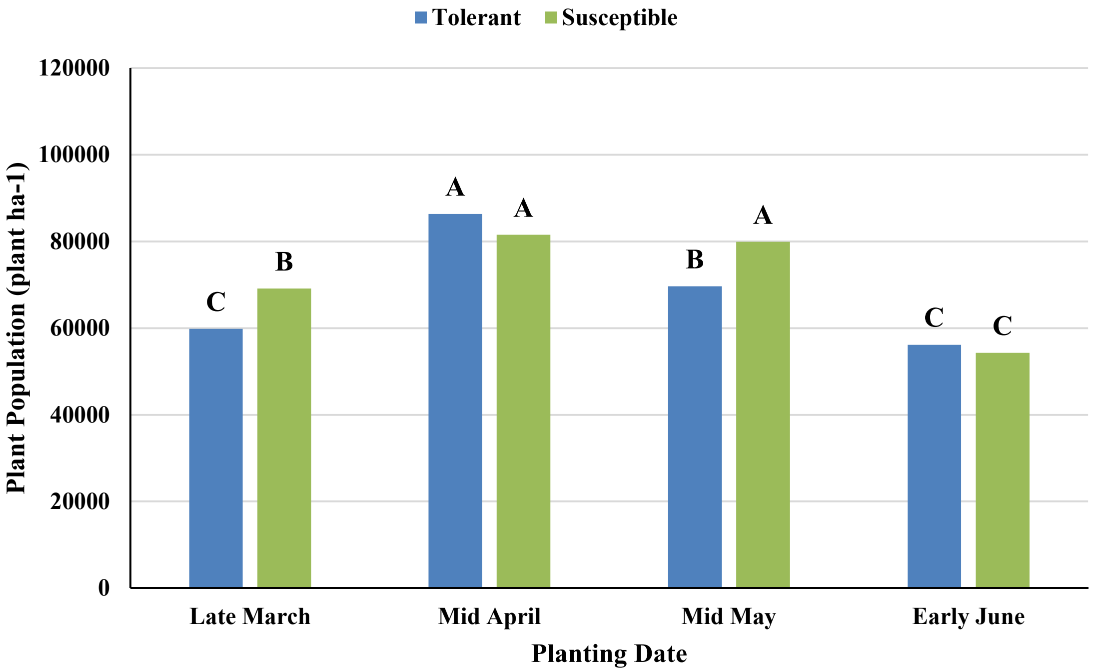

Figure 11. Initial plant populations at EFAW in 2016 in terms of planting date and hybrid. Letters denote significant differences between initial plant populations as a result of a two-way interaction between planting date and hybrid. ($\alpha = 0.05$).

LAHOMA 2016

Like EFAW, there was a two-way interaction between planting date and hybrid at Lahoma in 2016 that influenced initial plant populations (Figure 12). The tolerant hybrid in mid-April had the highest initial plant population of 78093 plants ha^{-1}, although it was not significantly different than the susceptible hybrid of the same planting date. Both hybrids of the late-March and early-June planting dates had the lowest initial plant populations, with no significant differences between these dates and hybrids. All hybrids in the mid-April and mid-May planting dates had significantly higher initial plant populations than the late-March and early-June planting dates. The tolerant hybrid of the mid-April planting date had 35% more plants than the susceptible hybrid at the early-June planting date, which had the fewest plants at the initial stand counts.

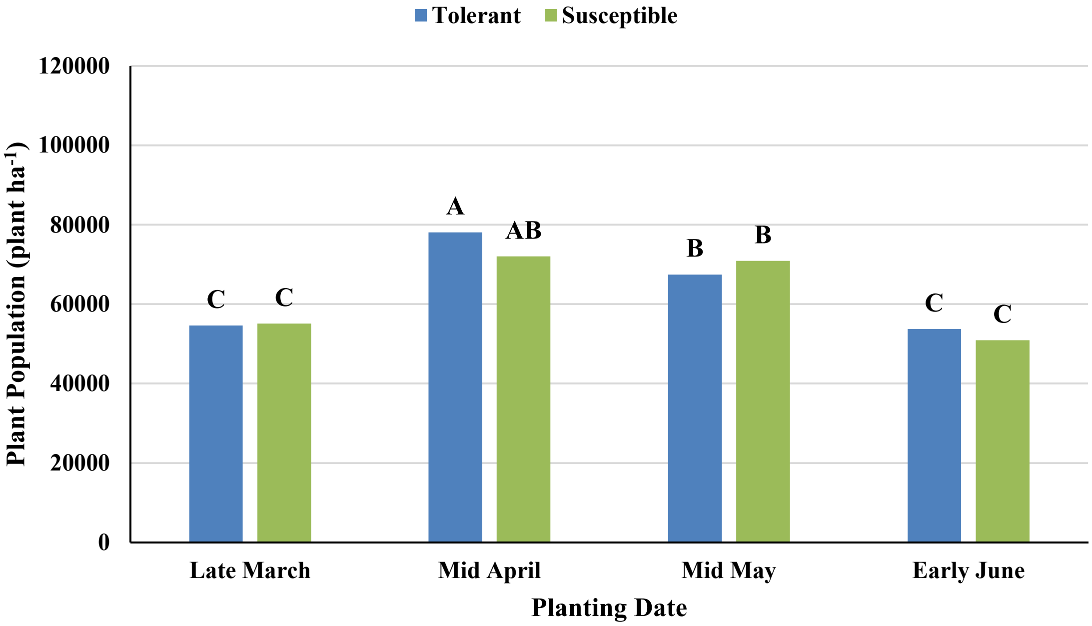

Figure 12. Initial plant populations at Lahoma in 2016 in terms of planting date and hybrid. Letters denote significant differences between initial plant populations as a result of a two-way interaction between planting date and hybrid. ($\alpha = 0.05$).

EFAW 2017

Planting date and hybrid both significantly influenced yield separately as main effects, with no significant interactive effect (Figures 13 and 14). No stand counts were taken from the late-March planting date due to stand failure. The mid-May planting date had the highest initial plant population with an average of 96195 plants ha^{-1}, 19% higher than the mid-April planting date and 24% higher than the early-June planting date. The initial plant populations of the mid-April and early-June planting dates were not significantly different than each other. The main effect of hybrid resulted in the tolerant hybrid having a significantly higher initial plant population of an average of 63827 plants ha^{-1}, 6% higher than the susceptible hybrid.

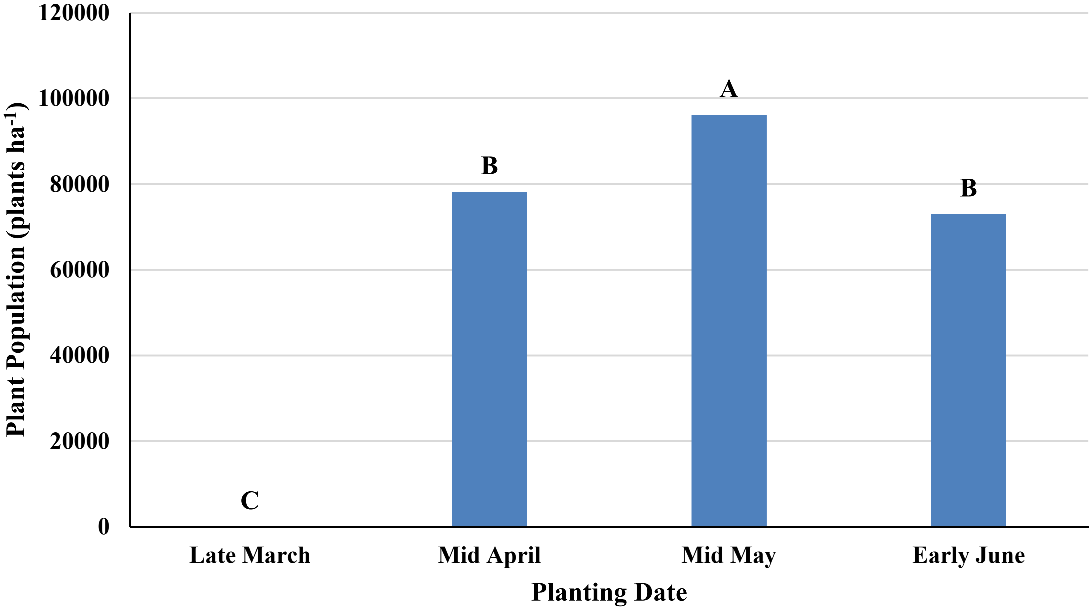

Figure 13. Initial plant populations at EFAW in 2017 in terms of planting date. Letters denote significant differences between initial plant populations as a result of a main effect of planting date. ($\alpha = 0.05$).

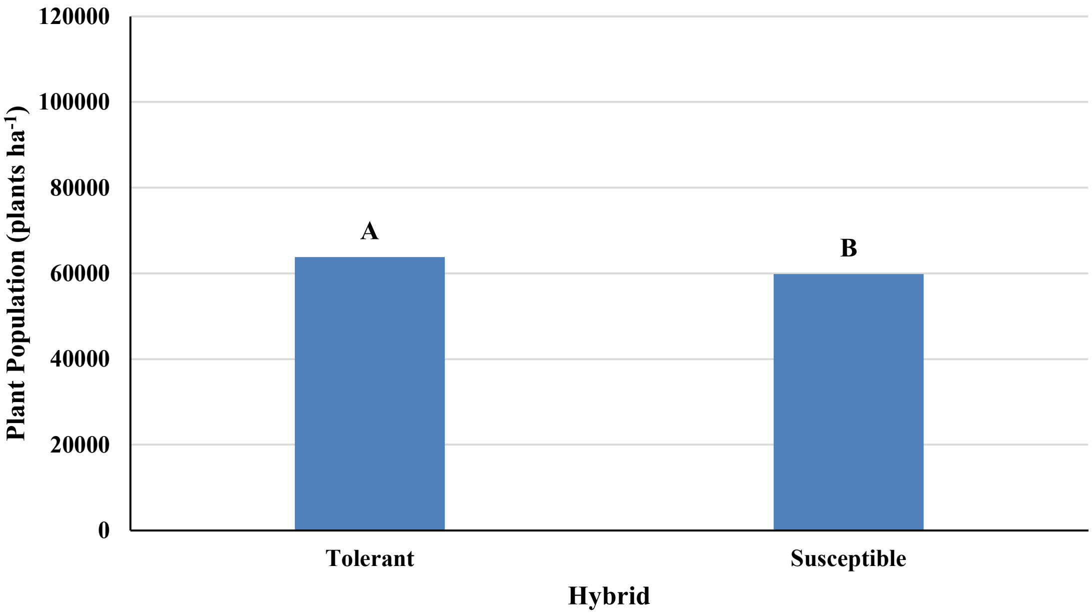

Figure 14. Initial plant populations at EFAW in 2017 in terms of hybrid. Letters denote significant differences between initial plant populations as a result of a main effect of hybrid. ($\alpha = 0.05$).

LAHOMA 2017

Stand failure occurred in the plots of the late-March planting date at Lahoma in 2017 just like at EFAW in 2017; therefore, initial stand counts were not taken for that planting date. Significant differences in initial plant populations were present due to a two-way interaction between planting dates and hybrids (Figure 15). The tolerant hybrid of the mid-May planting date had a significantly higher initial plant population than all other treatments with an average of 104517 plants ha^{-1}. Although significantly lower than the tolerant hybrid, the population of the susceptible hybrid in the mid-May planting date was significantly higher than both hybrids of the mid-April and early-June planting dates.

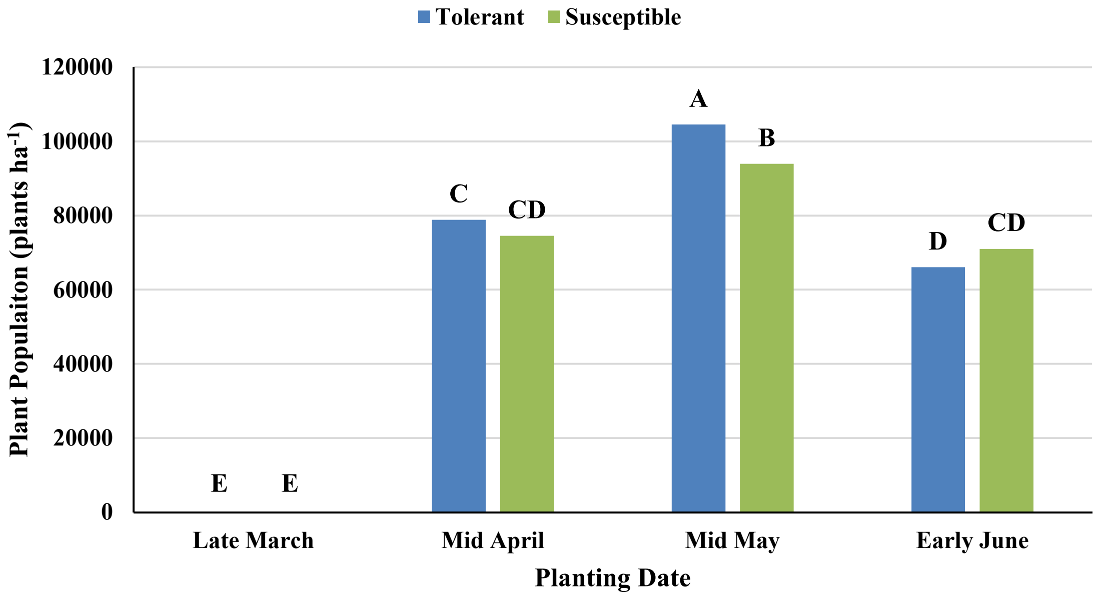

Figure 15. Initial plant populations at Lahoma in 2017 in terms of planting date and hybrid. Letters denote significant differences between initial plant populations as a result of a two-way interaction between planting date and hybrid. ($\alpha = 0.05$).

FINAL PLANT POPULATION

EFAW 2016

Final plant populations ranged from 75105 plants ha^{-1} down to 12599 plants ha^{-1}. This difference can be attributed to a three-way interaction between planting date, insecticide treatments, and hybrid (Figure 16). Tolerant hybrids planted in mid-April had significantly higher final plant populations than all other treatments. The susceptible hybrids at the mid-April planting date had either significantly higher or not significantly different final plant populations to all treatments in other planting dates. The non-treated susceptible hybrid of the early-June planting date had the lowest final plant population. Within the mid-May and early-June planting date, the not-treated susceptible hybrid was significantly lower than the other treatments. The treated susceptible hybrids were significantly higher; however, they were statistically lower than both tolerant hybrids by

40% in the mid-May planting date and 47% in the early-June planting date. All treatments in the early-June planting date had significantly lower final plant populations than their similar treatments in the other planting dates.

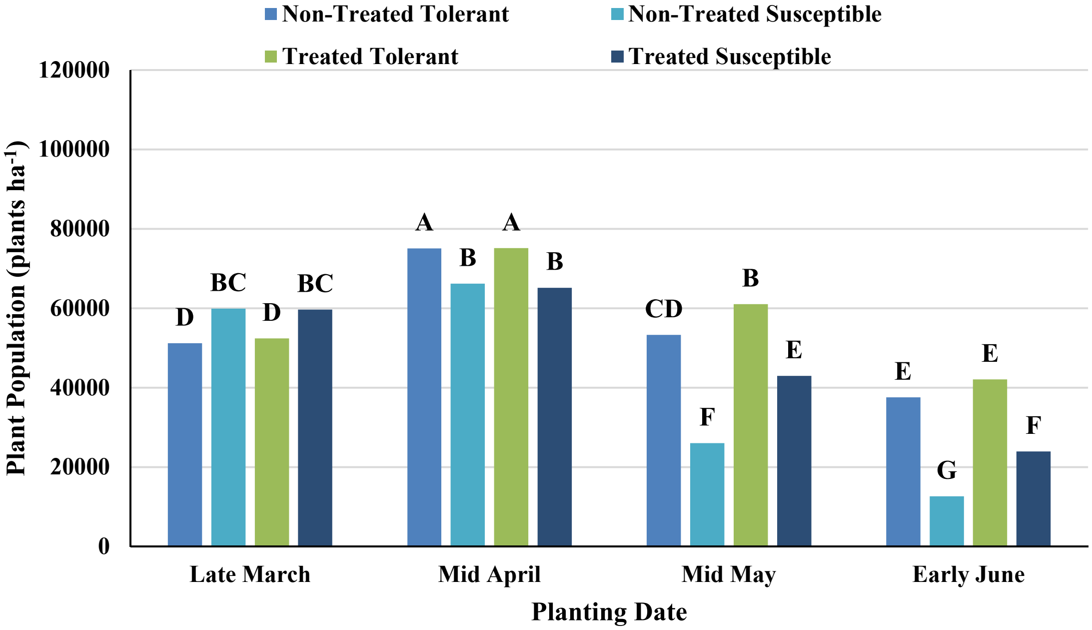

Figure 16. Final plant populations at EFAW in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

LAHOMA 2016

Very similar to EFAW, Lahoma final plant populations were highly variable and associated with a three-way interaction between planting date, insecticide treatments, and hybrid selection (Figure 17). The plant populations ranged from 67894 plants ha^{-1} down to 13959 plants ha^{-1}. Like EFAW, the tolerant hybrids of the mid-April planting date had significantly higher final plant populations than all other treatments. Likewise, the susceptible hybrids of the mid-April planting date had significantly higher or not significantly different final plant populations than all other treatments. The non-treated susceptible hybrid had significantly lower final plant populations than all other treatments in both the mid-May and early-June planting dates, 35% and 38% lower than the treated susceptible hybrid of each respective planting date. The early-June planting date had significantly lower final plant populations than like treatments of all other planting dates.

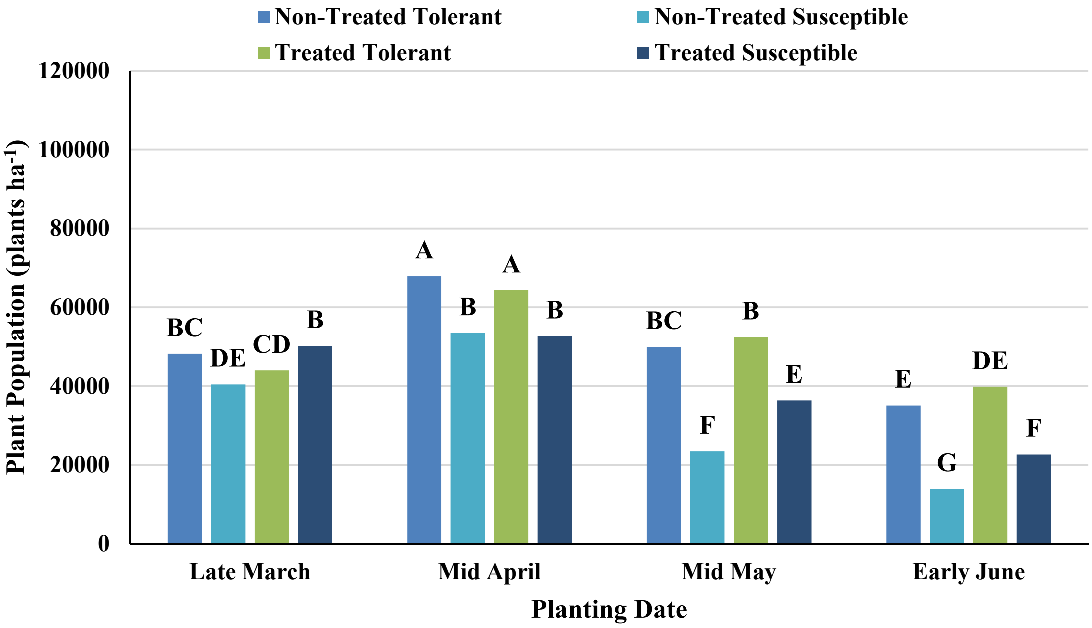

Figure 17. Final plant populations at Lahoma in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

EFAW 2017

There was a three-way interaction between planting date, insecticide treatments, and hybrid selection that had an effect on the final plant populations at EFAW in 2017 (Figure 18). Stand failure resulted in no data being collected from the late-March planting date. Final plant populations ranged from 82600 plants ha^{-1} in the non-treated tolerant hybrid of the mid-May planting date down to 23550 plants ha^{-1} in the non-treated susceptible hybrid of the early-June planting date. The non-treated susceptible hybrids had the lowest final plant populations between treatments in all planting dates. The non-treated susceptible hybrid had a similar final plant population to the treated-susceptible in the mid-May planting date. The non-treated susceptible hybrid at the early-June planting date had the lowest final plant population, differing from the same treatment of the mid-April planting date by 54% and 63% from the same treatment of the mid-May planting date. Disregarding the non-sprayed susceptible hybrids, the final plant populations of the mid-April and mid-May planting dates were similar and few significantly differed.

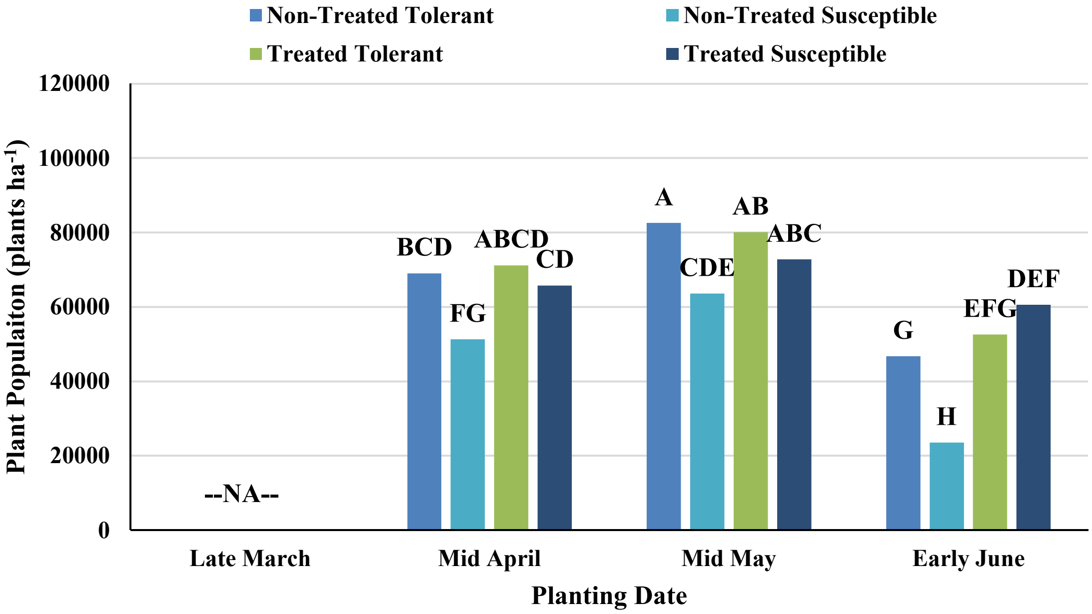

Figure 18. Final plant populations at EFAW in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

LAHOMA 2017

A three-way interaction between planting date, hybrid, and insecticide treatements influenced final plant populations at Lahoma in 2017 (Figure 19). Final plant populations varied greatly, ranging from an average of 85473 plants ha^{-1} in the non-treated tolerant hybrid of the mid-May planting date down to 20960 plants ha^{-1} in the non-treated susceptible hybrid of the early-June planting date. No stand counts were collected from the mid-March planting date due to stand failure. With the exception of the non-treated susceptible hybrid, the mid-May planting date had higher plant populations regardless of treatment. The non-treated susceptible hybrid had a significantly lower final plant population than all others within the mid-May planting date, 53% lower than the treated susceptible hybrid and 55% lower than the treated-tolerant hybrid as well as the non-treated tolerant hybrid. With exception of the non-treated tolerant hybrid of the mid-May planting date, all treatments within the early-June planting date had final plant populations similar to or significantly lower than all other treatments.

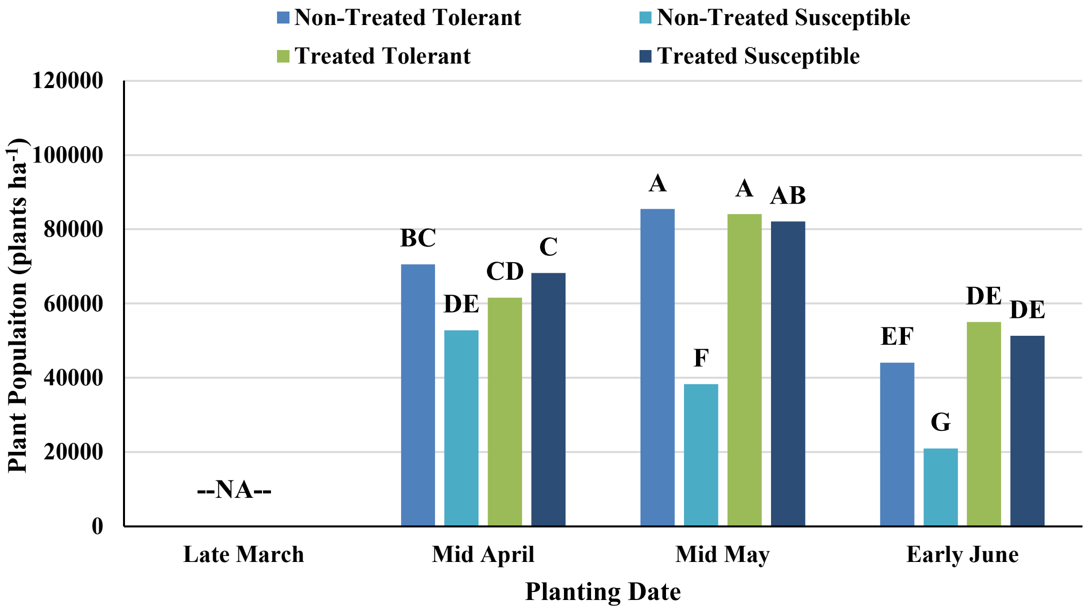

Figure 19. Final plant populations at Lahoma in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

DIFFERENCES IN PLANT POPULATION

Significant differences in plant populations existed at all locations in both 2016 and 2017. For each site year the differences between treatments compared to each other will be discussed as well as the differences of treatments compared to the treated tolerant hybrid within the same planting date, the complete control treatment. The treated tolerant hybrid represents the control for this experiment.

EFAW 2016

Differences in plant populations between final stand counts and initial stand counts varied between treatments due to a three-way interaction between planting date, insecticide treatments, and hybrids at EFAW in 2016 (Figure 20). The differences ranged from 6825 plants ha^{-1} all the way up to a loss of 63110 plants ha^{-1}. High losses occurred mainly in the non-sprayed susceptible hybrids of the later two planting dates, mid-May and early-June with a loss of 63110 plants ha^{-1} and 46719 plants ha^{-1} respectively. The treated susceptible hybrids of the same planting dates had significantly lower losses than the non-treated susceptible hybrids; however, their losses were significantly higher than all other treatments. Few significant differences in plant loss existed in the remaining treatments. The treated and non-treated susceptible hybrids of the mid-May and early-June planting dates all differed significantly from the treated tolerant hybrid of their respective planting date.

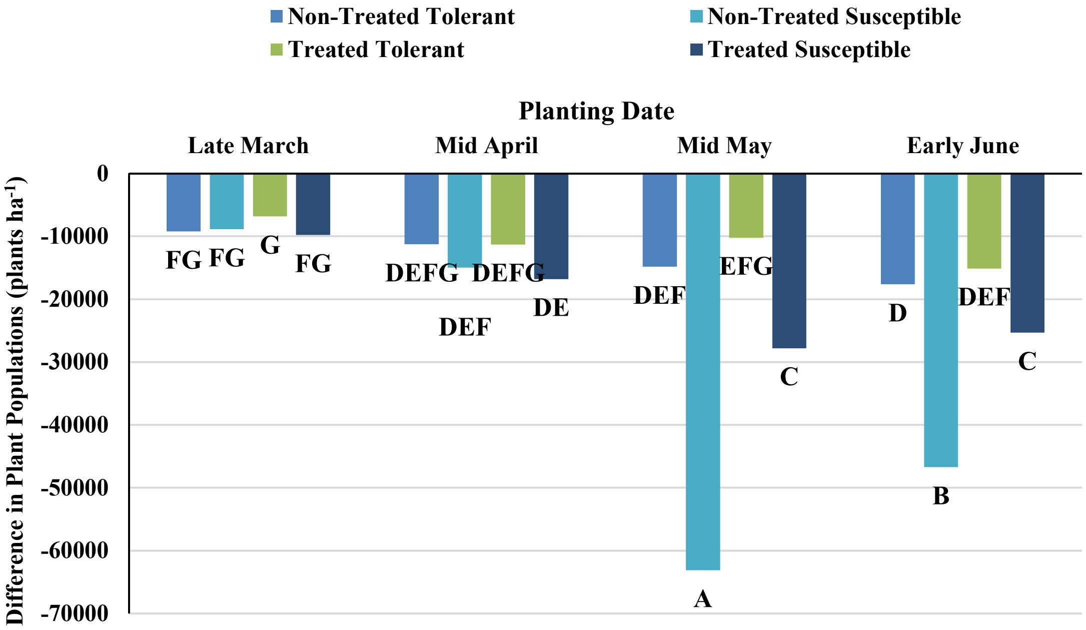

Figure 20. Differences in initial and final plant populations (final-initial) at EFAW in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

LAHOMA 2016

Similar to EFAW, Lahoma had high variation in number of plants lost from the initial stand counts to the final stand counts due to a three-way interaction between planting date, insecticide treatments, and hybrid selection (Figure 21). Plant loss ranged from 8337 plants ha^{-1} in the non-treated tolerant hybrid in the late-March planting date up to 56390 plants ha^{-1} in the non-treated susceptible hybrid in the mid-May planting date. The susceptible hybrids of the mid-April planting date had significantly higher plant loss than the tolerant hybrids of the same planting date. Within the mid-April planting date, the non-treated susceptible hybrid lost 39% more plants than the non-treated tolerant hybrid and the treated susceptible hybrid lost 34% more plants than the treated tolerant hybrid. Both susceptible hybrids, treated and non-treated, in the mid-May and early-June, though significantly different from each other within planting dates, had significantly higher plant loss than all other treatments. The treated and non-treated susceptible hybrids of the mid-April, mid-May, and early-June planting dates all differed significantly from the treated tolerant hybrid of their respective planting date.

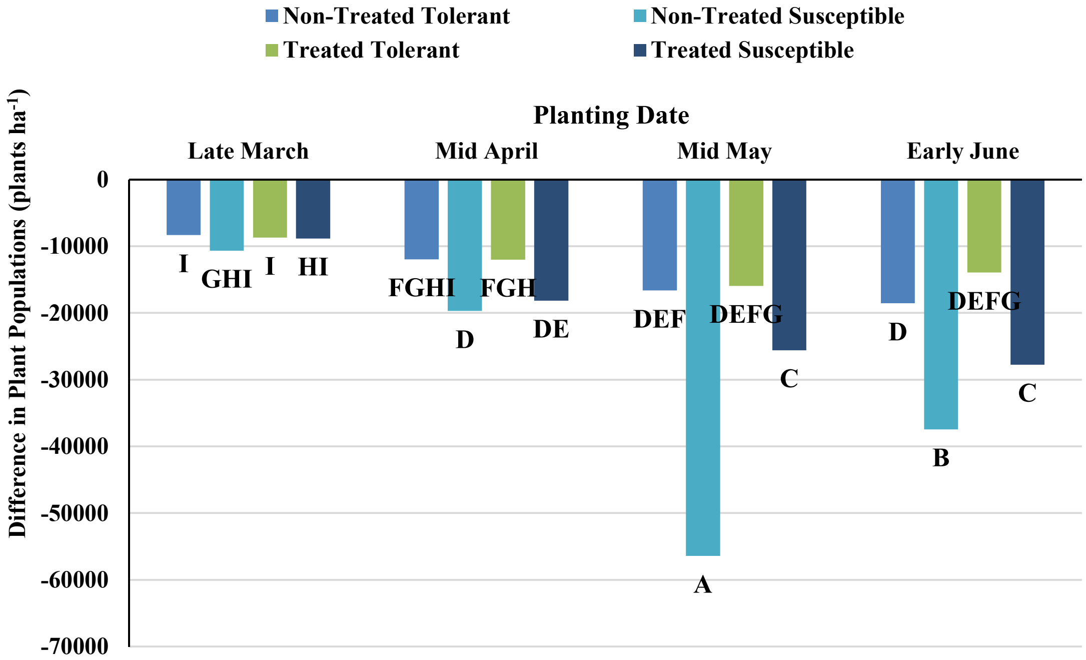

Figure 21. Differences in initial and final plant populations (final-initial) at Lahoma in 2016 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. ($\alpha = 0.05$).

EFAW 2017

A three-way interaction between planting date, hybrid, and insecticide treatment influenced the difference in plant populations between the end of the season and the beginning (Figure 22). No results are given for the late-March planting date due to stand failure. Over all treatments, the mid-April planting date had either significantly lower plant loss or similar plant loss as all other treatments and no significant differences were observed between treatments within the planting date. The non-treated susceptible hybrid of the early-June planting date had significantly higher plant loss than all other treatments with a loss of 39444 plants ha^{-1}. The non-treated tolerant hybrid also lost significantly more plants than both treated hybrids of the early-June planting date. Conversely, the two susceptible hybrids at the mid-May planting date lost significantly more plants than the tolerant hybrids. At the mid-May planting date, the non-treated susceptible hybrid lost 21% more plants than the non-treated tolerant hybrid and the treated susceptible lost 31% more plants than the treated tolerant hybrid. The treated and non-treated susceptible hybrids at the mid-May and early-June planting dates as well as the non-treated tolerant hybrid at the early-June planting date all differed significantly from the treated tolerant hybrid at their respective planting date.

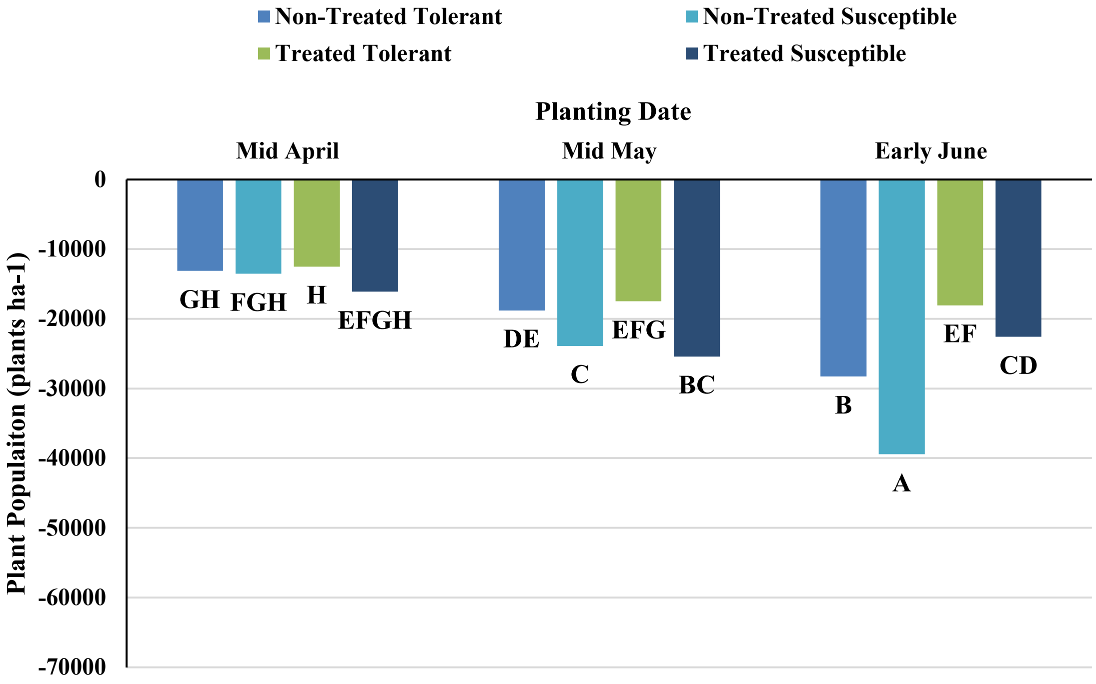

Figure 22. Differences in initial and final plant populations (final-initial) at EFAW in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. ($\alpha = 0.05$).

LAHOMA 2017

Like all other site years, there was a three-way interaction between planting date, hybrid, and insecticide treatments that influenced the difference in plant population at the end of the season (Figure 23). No data was collected from the late-March planting date due to stand failure. The highest plant loss occurred in the non-treated susceptible hybrids of the mid-May and early-June planting dates with losses of 51871 plants ha^{-1} and 52789 plants ha^{-1} respectively. The treated hybrids of the mid-April planting date had either significantly lower or similar plant losses to all other treatments with the tolerant hybrid losing 10464 plants ha^{-1} and the susceptible hybrid losing 10230 plants ha^{-1}. The non-treated susceptible hybrid of the mid-April planting date, as well as the non-treated susceptible hybrid of the mid-May and early-June planting dates all differed significantly from the treated tolerant hybrid of their respective planting date.

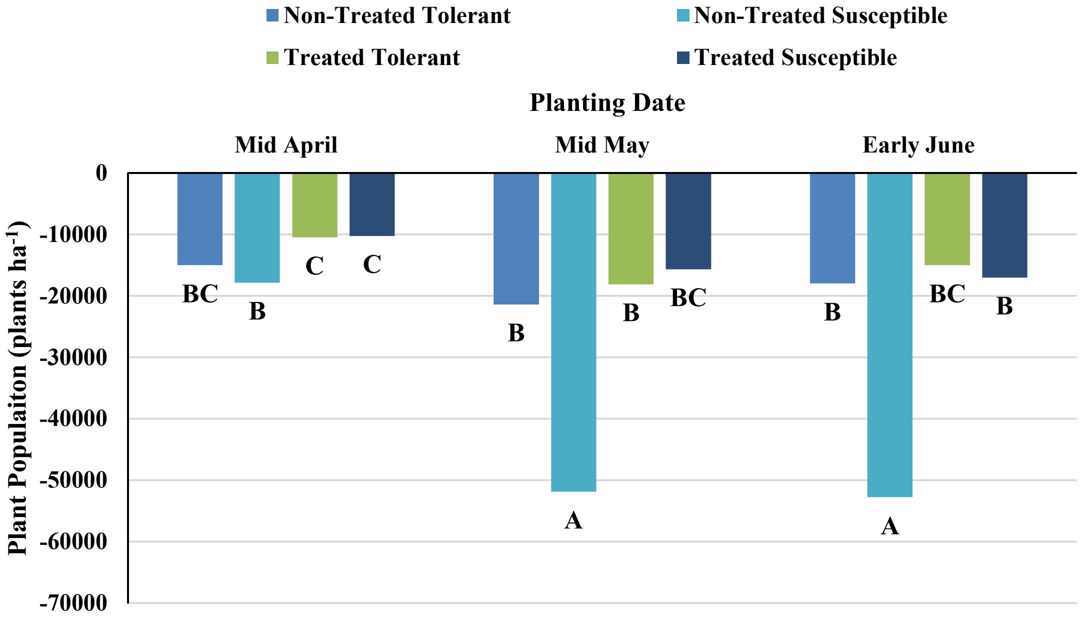

Figure 23. Differences in initial and final plant populations (final-initial) at Lahoma in 2017 in terms of planting date, hybrid, and insecticide treatments. Letters denote significant differences between yields as a result of a three-way interaction between planting date, hybrid, and insecticide treatments. (α = 0.05).

DISCUSSION

The presence of sugarcane aphids in Oklahoma paired with diminished grain prices have caused many producers to shift land once dedicated to sorghum to other crops. While traditional management practices are available for managing sugarcane aphids, the cost associated with chemical management has caused a need for alternative practices. Furthermore, because sugarcane aphids have become a perennial threat in US sorghum production regions, it is critical to determine how to manage grain sorghum in the presence of the pest. Planting date consistently had the most influence on yield and plant populations with the effects of hybrid selection and insecticide applications becoming greater in the mid-May and particularly early-June planting dates. This was evident with overall trends throughout trials following planting dates and trends within each planting date following hybrid selection and insecticide treatments. Szczepaniec (2018) found that planting date had less effect on sugarcane aphid population density in Texas, but noted that sorghum planted further north may see an effect and benefit from earlier planting. This is likely due to SCA populations becoming higher later in Oklahoma allowing the benefits of planting early to have its full effect.

The reasons for early planting is to allow time for the sorghum to mature before large infestations of SCA occur and to allow the sorghum plants to flower prior to the hottest part of the summer, July. As was shown in Table 1 in Chapter II, 81-100% yield loss may occur when a high number of aphids infests a sorghum crop pre-boot stage while with the same type of infestation at the soft dough stage only causes 21% yield loss (Catchot, 2015). Sorghum plants that are flowering or about to flower are vulnerable to stresses. Bowling et al. (2016) mentions that high infestations of aphids on grain sorghum before flowering or during grain fill can cause lighter seed weight, fewer numbers of heads, and even plant loss; all of which could affect yield. Yield losses are beyond the impact from SCA, but result in physiological shifts/changes. Prasad et al. (2008) found that yield loss occurred when sorghum experienced heat stress right before flowering and during flowering mainly due to a decrease of seed number. The decrease in seed number was likely a result of poor ovule fertilization (Prasad et al., 2008).

Yield results in this study showed significant differences in yields with the mid-April and mid-May planting dates yielding higher than the early-June planting date regardless of treatment. These results show the importance that time of planting has on yield, potentially due to the timing of aphid pressure and/or heat stresses in the development of grain sorghum. Ciampitti et al. (2017) and Bean (2018) discuss that climate stresses commonly occur at vulnerable growth stages of the grain sorghum when planted too late. Nelson et al. (1977) highlighted the potential issues of late planting. They found that through all four years of their study, grain sorghum planted at the later planting date (as a double crop behind wheat or barley) resulted in lower yields than sorghum planted at the conventional planting date (Nelson et al., 1977). Another study showed that earlier planted sorghum had higher yields than late planted sorghum due to higher numbers of tillers and increased grain weight (A. Blum, 1972). Sorghum is photoperiod sensitive and flowers when experiencing short days (Wolabu and Tadege, 2016). When planted later into June, sorghum experiences short days sooner in its development than if it was planted earlier, causing a decrease in biomass production and tillers, often resulting in lower grain yields. This suggests that sugarcane aphids are not the only reason for lower yields at such late planting.

Late planting is not the only issue associated with sorghum planting dates. Planting too early can cause drastic yield loss and in some years even crop failure, as seen in the late-March planting date at both locations in 2017. Bean (2017) and Campitti et al. (2017) both suggest planting grain sorghum into soils of at least around 15°C. In certain years and locations in Oklahoma, the soil temperature may be below the critical temperature in March and makes earlier planting risky.

The mid-April planting date generally produced greater yields than all others in 2016; however, the mid-May planting date produced greater yields in most treatments in 2017. For final plant populations in 2016, the mid-April planting date had a greater amount of plants than the mid-May planting date at both locations. The mid-May planting date had significantly higher final plant populations at both locations in 2017 in most treatments. Through regression analysis, it was found that grain yield was strongly correlated with final plant population at EFAW in 2016 (r^2=0.72), Lahoma in 2016 (r^2=0.62), EFAW in 2017 (r^2=0.60), and Lahoma in 2017 (r^2=0.52) (Figure 24).

Drastic yield loss was observed where high numbers of plant loss occurred throughout the season, particularly in the two later planting dates when a susceptible hybrid was planted and no insecticide application was made. This conclusion is evident through comparing the non-treated susceptible hybrids of the mid-May and early-June planting date to the treated tolerant hybrid of the same planting dates (Table 4). It is evident that both insecticide applications and the use of a tolerant hybrid become very important the later the sorghum is planted.

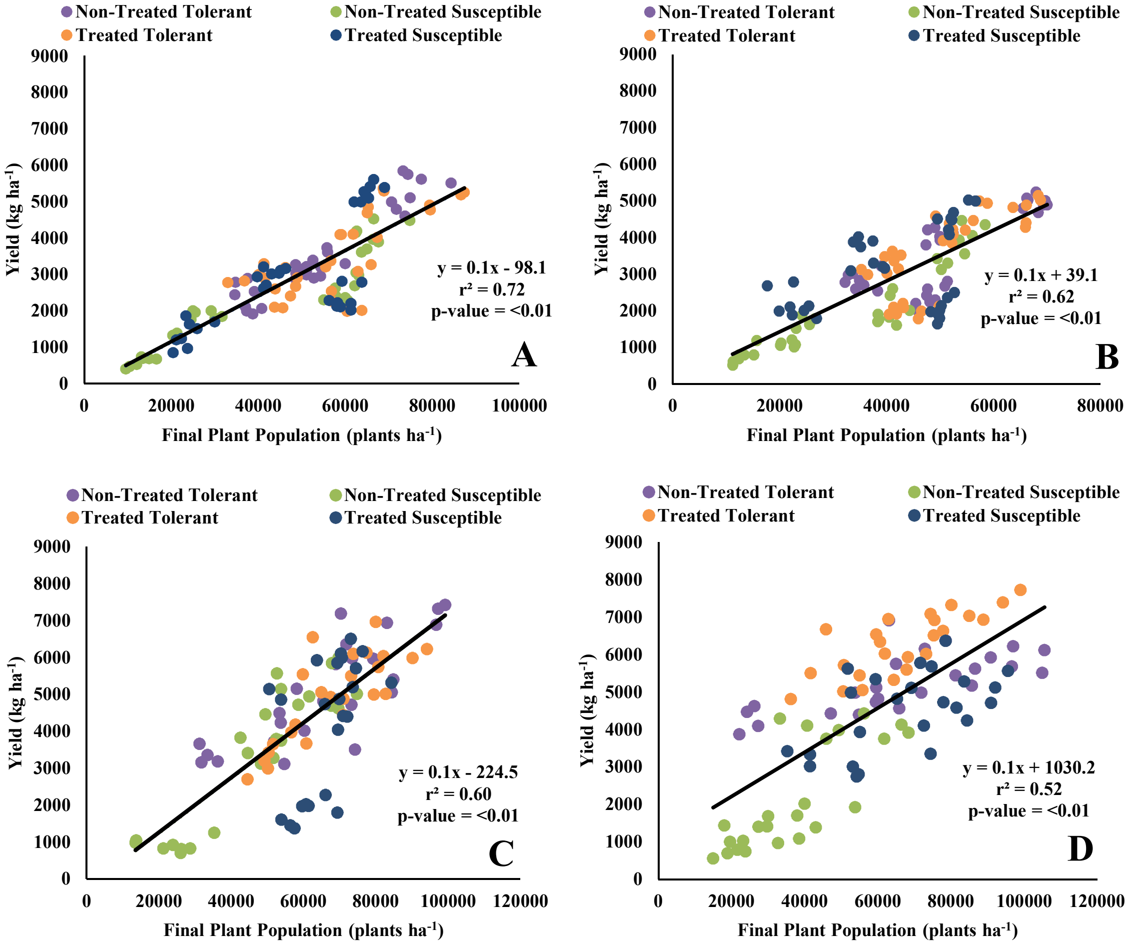

Figure 24. Correlation between yield and final plant populations for EFAW 2016 (A), Lahoma 2016 (B), EFAW 2017 (C), and Lahoma 2017 (D) with final plant population (plants ha^{-1}) as the independent variable and yield (kg ha^{-1}) as the dependent variable.

Table 4. The percent difference of plant loss and yield between the treated-tolerant hybrid and the non-treated susceptible hybrid of the mid-May and early-June planting dates at EFAW 2016 and 2017, and Lahoma 2016 and 2017.

Planting Date	**Year**	**Location**	**Percent Difference in Plant Loss**	**Percent Difference in Yield**
Mid-May	2016	EFAW	77%	47%
	2016	Lahoma	71%	67%
	2017	EFAW	27%	16%
	2017	Lahoma	65%	79%
Early-June	2016	EFAW	62%	75%
	2016	Lahoma	63%	76%
	2017	EFAW	54%	74%
	2017	Lahoma	72%	82%

Planting later into June often resulted in the lowest crop yields, even when tolerant hybrids were used and insecticide was applied, while the effects of using the tolerant hybrid and insecticide were more apparent in the early-June planting date. However, in the earlier planted sorghum, the effects of insecticide applications were not observed. Bowling et al. (2016) found that sulfoxlafor (Transform® WG; Dow AgroSciences; Indianapolis, Indiana) showed greater than 98% control of SCA. The effects of hybrid were very similar to those of insecticide with their effects becoming more apparent in the later planting dates. Sullivan (2006) described that through host plant resistance, plants may receive only minimal damage in the presence of insect pests or may deter insects all together. As was discussed in reference to the lack of effect of insecticide, because of the yield similarities between the susceptible and non-susceptible hybrids at the earlier planting dates, it is logical to assume aphids were not present at the vulnerable growth stages. This lack of yield difference between the hybrids also shows that in ideal situations, with no aphids, yield potential of tolerant and susceptible hybrids are comparable.

CONCLUSIONS

Sugarcane aphids are an inevitable part of sorghum production in Oklahoma and the southern Great Plains. Therefore, growers need to evaluate cost-effective ways to manage sorghum in the midst of the pest in order to optimize production and profitability. Planting between mid-April and mid-May is a good option to mitigate potential SCA risks as well as maintain economic potential of the crop. It was found that on average, the highest yielding planting date (mid-April or mid-May) yielded 41% higher than the low yielding planting date (late-March or early-June) for each site year. Planting earlier into March may be an option in certain years; however, the risk of cool soil temperatures makes the option inconsistent as seen by the stand failures in the late-March planting dates of 2017. If planting is delayed until early June yield potential will be lowered, due to environmental conditions and crop physiology. However, in these conditions when planting is delayed, using a tolerant hybrid and insecticide applications to manage SCA have a greater impact on grain sorghum yields compared to earlier planting dates. This is highlighted by the treated, tolerant hybrid yielding on average 78% higher than the non-treated susceptible hybrid when planted in early-June.

Overall, grain sorghum can be successfully grown in Oklahoma even in the presence of sugarcane aphids. Implementing basic agronomic practices, such as timely planting and using quality genetics, not only can benefit yield in terms of environmental and physiological aspects, but can also successfully mitigate risks associated SCA pressure.

CHAPTER IV

DUAL-PURPOSE GRAIN SORGHUM TO MAXIMAIZE ECONOMIC POTENTIAL

ABSTRACT

Grazing of various crops is a common practice in the southern Great Plains and has allowed the production of those crops to remain economically viable options in the midst of low grain prices or unfavorable growing conditions. Grain sorghum residue could be a potential source of feed for livestock in between the availability of high quality summer pastures and high quality winter wheat fields. Limited information is currently available on the viability of utilizing sorghum residue as a forage and concerns of low quality and NO_3^- toxicity exist. To evaluate the potential for this practice in Oklahoma sorghum production systems, biomass was collected from the Oklahoma State Grain Sorghum Hybrid Evaluation Trials in 2016, 2017, and 2018. After the trials were harvested, residue was collected from two hybrids, an SCA susceptible hybrid (KS 585) and an SCA tolerant hybrid (DKS 37-07). In a one meter squared area, all stalks were cut at the soil surface and all residue remaining on the ground was collected and weighed. After weighing, samples were dried and re-weighed. Total biomass production was calculated and samples were submitted to the Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL) to be tested for crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), and NO_3^- concentrations.

Average biomass throughout site years was 7087 kg ha^{-1}, CP was 8.5%, ADF was 40%, TDN was 56%, and NO_3^- was 2311 ppm. While quality may be marginal, with supplementation, the residue could serve as a good forage source with plenty of biomass to sustain cattle for the fall. Nitrate toxicity can be an issue in sorghum grazing systems; however, overall high levels of NO_3^- were not observed in this study. High variability in NO_3^- concentrations was seen within locations. It is necessary to test sorghum residue before releasing any livestock to graze.

METHODOLOGY

FIELD TRIALS:

Forage samples were taken throughout Oklahoma in 2016, 2017, and 2018. In 2016, samples were collected from the Hybrid Performance Trial at the Southwest Agronomy Research Station southeast of Tipton, Oklahoma. In 2017, samples were collected from three different Hybrid Performance Trials, one at the Southwest Agronomy Station, the OSU North Central Research Station west of Lahoma, Oklahoma, and a third at a cooperator's field northeast of Dacoma, Oklahoma. In 2018, samples were collected from four different Hybrid Performance trials, one at the Cimarron Valley Research Station in Perkins, Oklahoma, a second at the OSU North Central Research Station, a third at the Southwest Agronomy Station, and a fourth at a cooperator's field eat of Adams, Oklahoma. Temperatures and rainfall for each year and locations are given in Figures 25-32. The dominant soil series and soil descriptions for the different site years are listed in Table 5.

All forage samples were taken from select plots in the Oklahoma Sorghum Performance Trials. Plots in the Oklahoma Sorghum Performance Trials measured 1.7 m wide and 10.7 m long but the plots were trimmed to 7.6 m prior to harvest. At each location, all hybrids were replicated 4 times; however, forage samples were only collected from three replications at each location. Management of all trials was in accordance to Oklahoma Cooperative Extension Service, and highlighted by the hybrid performance trial documents for the individual years (Beedy et al., 2017; Lofton et al., 2018; Lofton and Strickland, 2019). At maturity, plots were desiccated using a 1,728 g a.e. ha^{-1} application of glyphosate (Roundup PowerMAX; Monsanto; St. Louis, Missouri). Fourteen days following application, all plots were mechanically harvested with a small plot combine (Wintersteiger, Salt Lake City, Utah), with the header being right below the inflorescence, but above the last vegetative leaf. During and following harvest, sorghum residue was not altered prior to sample collection.

Forage samples were collected directly after grain harvest at all locations in 2016 and 2017, and in Perkins, Lahoma, and Adams in 2018. However, the Tipton trial was not harvested due to a crop failure; therefore, whole plant samples were collected. Two hybrids were selected for analysis. These hybrids were chosen based on their susceptibility (KS 585; S&W Seed; Sacramento, California) and tolerance (DKS 37-07; Bayer, Inc.; Leverkusen, Germany) to SCA. Residue that remained after harvest or the failed crop was collected from a m^2 area with standing stalks being cut down to the soil surface and any residue that laid on the ground collected. After being collected, the samples were weighed, dried for at least 168 hours at 37.8°C, and reweighed. After being dried and weighed, the residue gathered from the square meter was separated into two different unique samples. Each sample was then submitted to the Oklahoma State University Soil, Water and Forage Analytical Laboratory (SWFAL) to be tested for protein, acid detergent fiber (ADF), total digestible nutrients (TDN), and nitrate (NO_3^-) content. According to Zhang and Henderson (2018), after SWFAL receives the forage samples, they are weighed, dried for 12 hours, and then weighed again to calculate moisture content. They are then ground to pass through a 1-mm screen and dried overnight to determine moisture content (Zhang and Henderson, 2018). Crude protein is calculated by multiplying the total nitrogen, found using a dry combustion Carbon/Nitrogen Analyzer (NFTA, 1993), by 6.25 (Zhang and Henderson, 2018). ADF is found using an Ankom Fiber Analyzer (Ankom Technology, Macedon, NY, 2011) and TDN is calculated by multiplying the ADF value found by 0.799 and subtracting the product by 88.9 (Zhang and Henderson, 2018).

STATISTICAL ANALYSIS:

Statistical analysis was performed using SAS v9.4 (SAS Institute Inc., Cary, NC) to determine the impact of cultivar and sample location on the impact of sorghum residue quality and nitrate content. Both cultivar and sample location were designated as fixed variables while replication was treated as a random effect. Sample location was utilized as a fixed variable to be used as a proxy for yearly conditions. Analysis was conducted independently for each year due to different locations for each year. Analysis of variance was conducted using Procedure Mixed. Post-hoc analysis was done to determine significant differences between treatment means using a LSD with a Tukey Adjustment and an $\alpha = 0.1$.

Table 5. Locations, soil series, and soil descriptions for trials in Chapter IV.

Year	**Location**	**Latitude and Longitude**	**Soil Series**	**Description**
2016	Tipton	34°26'29.7"N 99°08'00.6"W	TIPTON	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS
2017	Tipton	34°26'29.7"N 99°08'00.6"W	TIPTON	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS
	Dacoma	36°41'24.8"N 98°33'39.1"W	GRANT (45%)	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
			MILAN (25%)	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
	Lahoma	36°23'21.6"N 98°06'34.9"W	GRANT	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
2018	Tipton	34°26'29.7"N 99°08'00.6"W	TIPTON	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS
	Lahoma	36°23'21.6"N 98°06'34.9"W	GRANT	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS
	Perkins	35°59'31.3"N 97°02'45.4"W	KONAWA (45%)	FINE-LOAMY, MIXED, ACTIVE, THERMIC ULTIC HAPLUSTALFS
			TELLER (35%)	FINE-LOAMY, MIXED, ACTIVE, THERMIC UDIC ARGIUSTOLLS
	Adams	36°44'22.9"N 101°00'25.1"W	DALHART	FINE-LOAMY, MIXED, SUPERACTIVE, MESIC ARIDIC HAPLUSTALFS

Table 6. Planting and Harvest Dates of trials for Chapter IV.

Year	Location	Planting Date	Harvest Date
2016	Tipton	April 25, 2016	August 26, 2016
2017	Tipton	April 11, 2017	August 28, 2017
	Dacoma	May 17, 2017	September 9, 2017
	Lahoma	May 18, 2017	September 19, 2017
2018	Tipton	May 8, 2018	N/A
	Lahoma	May 1, 2018	September 12, 2018
	Perkins	April 23, 2018	August 8, 2018
	Adams	June 6, 2018	November 5, 2018

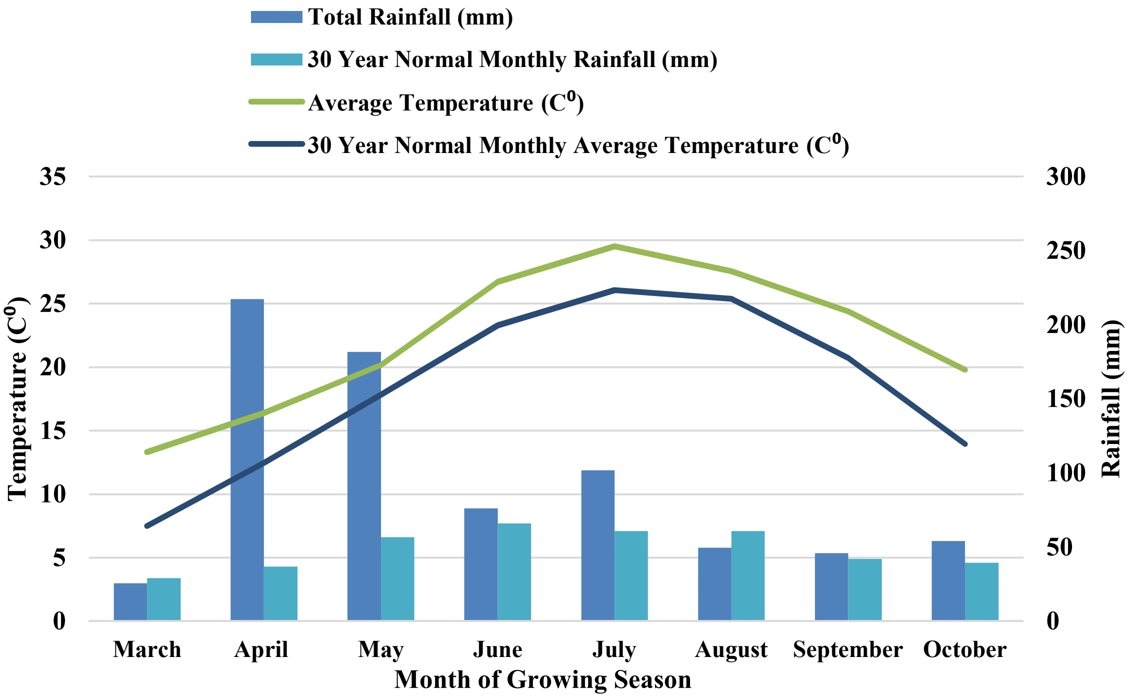

Figure 25. Temperature and rainfall observed throughout the 2016 growing season at Tipton, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

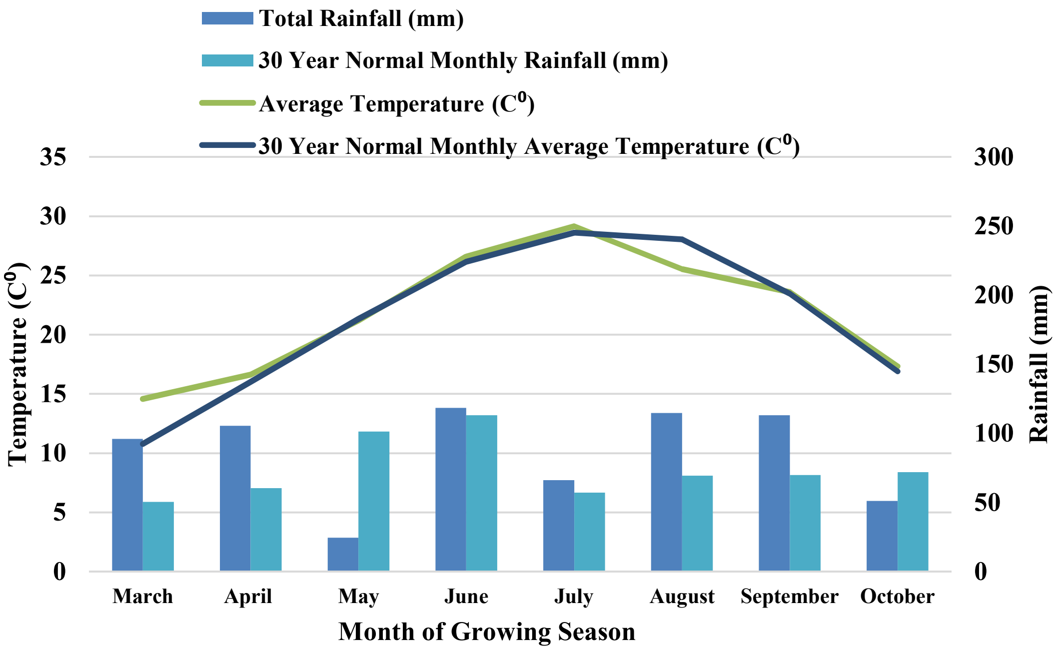

Figure 26. Temperature and rainfall observed throughout the 2017 growing season at Tipton, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

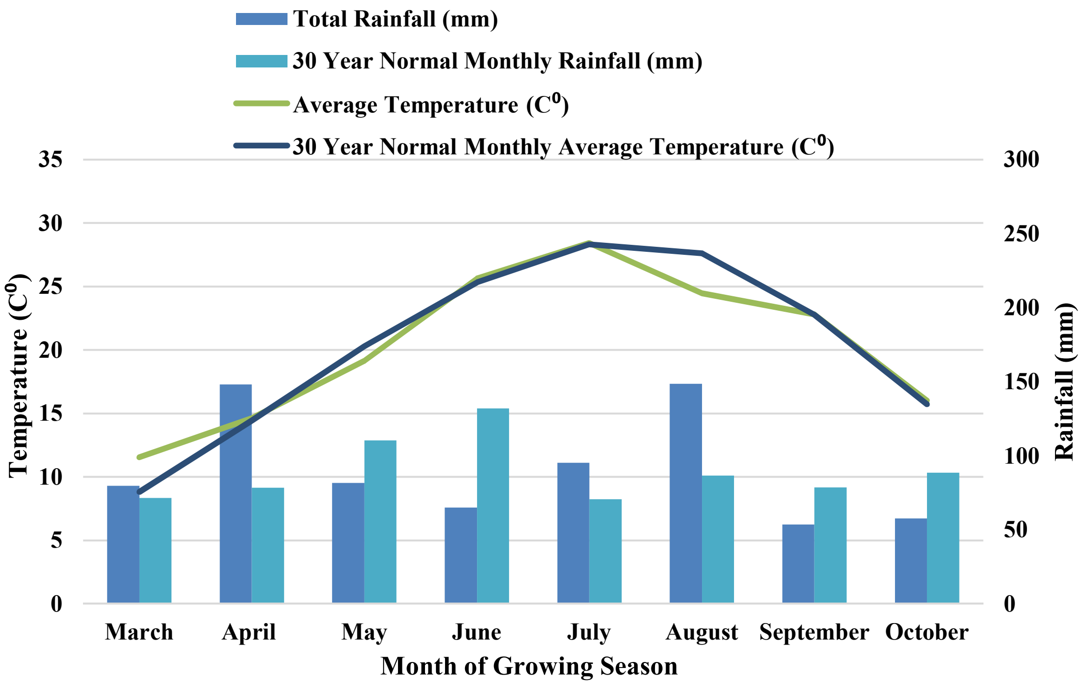

Figure 27. Temperature and rainfall observed throughout the 2017 growing season at Lahoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

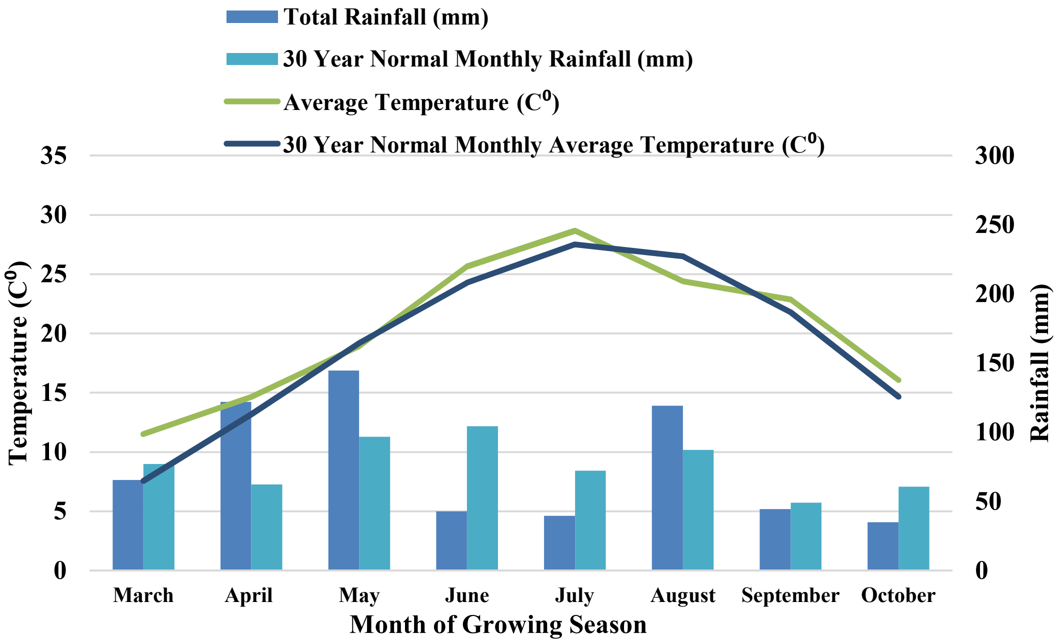

Figure 28. Temperature and rainfall observed throughout the 2017 growing season at Dacoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

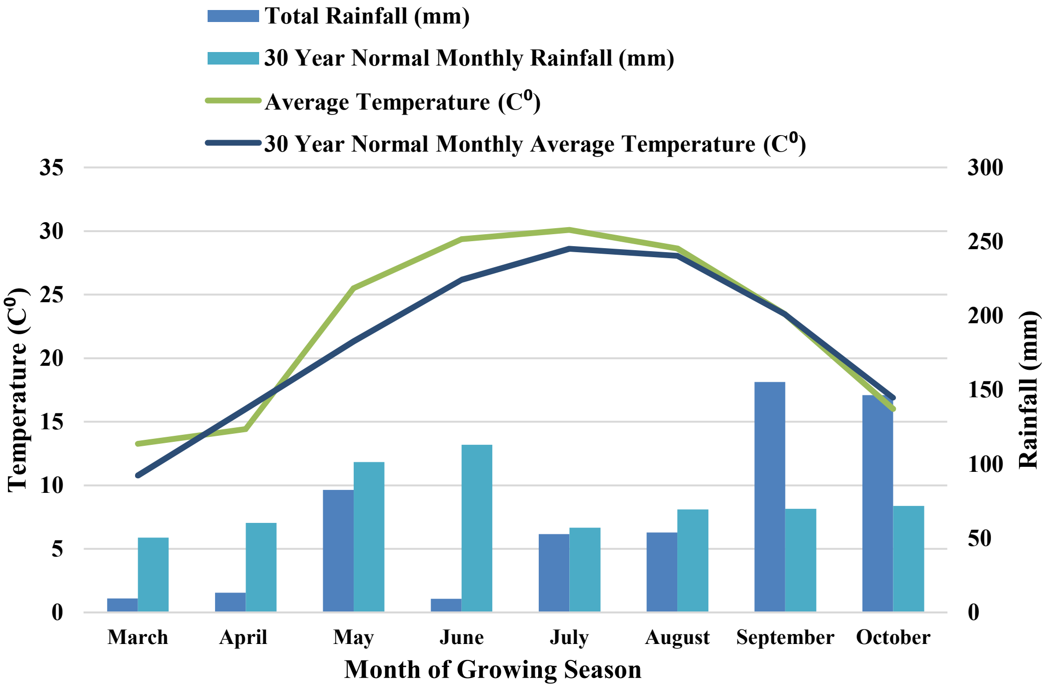

Figure 29. Temperature and rainfall observed throughout the 2018 growing season at Tipton, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

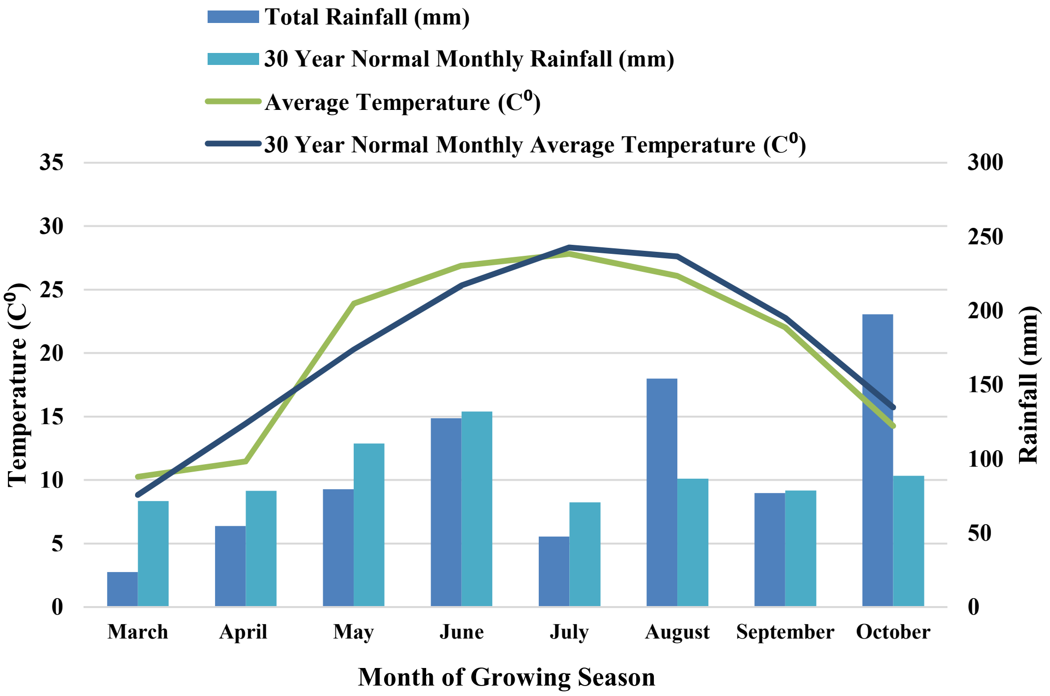

Figure 30. Temperature and rainfall observed throughout the 2018 growing season at Lahoma, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

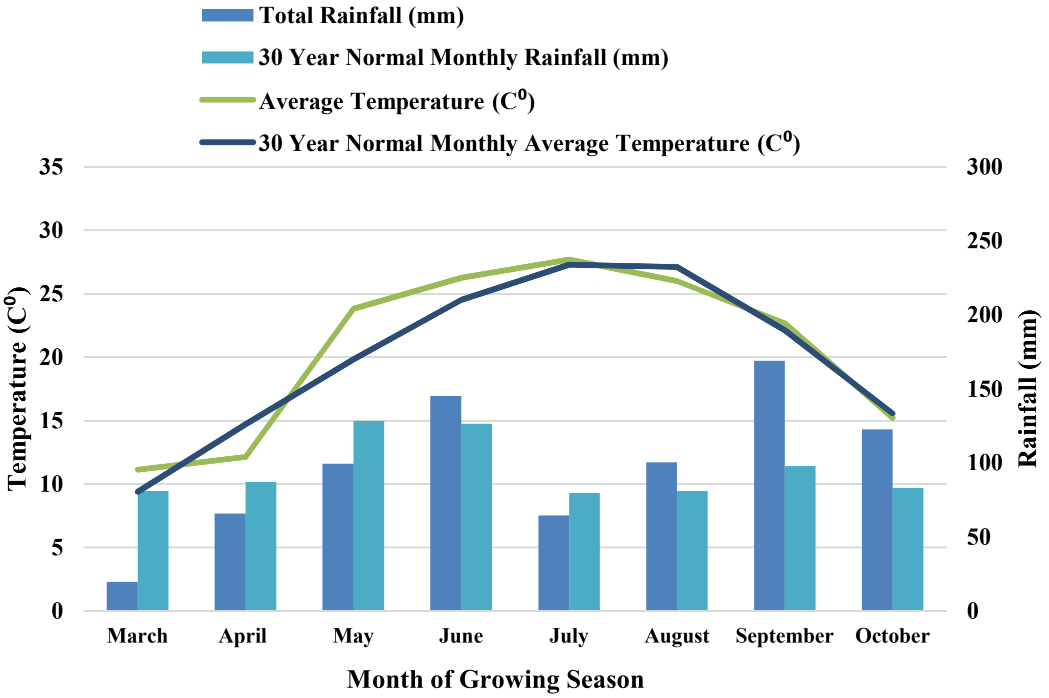

Figure 31. Temperature and rainfall observed throughout the 2018 growing season at Perkins, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

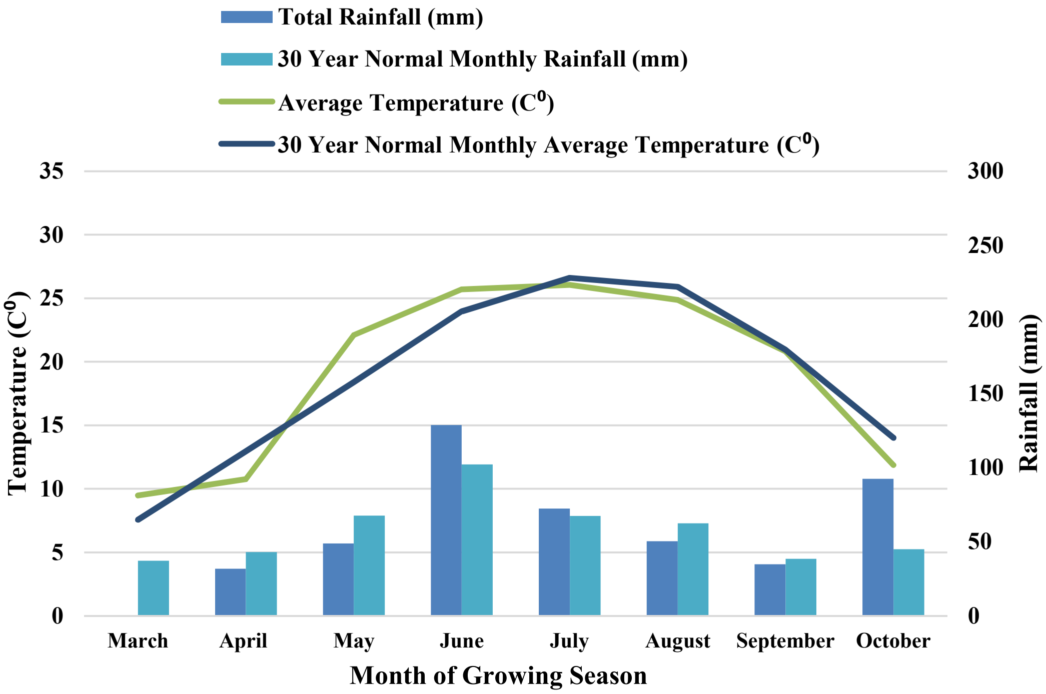

Figure 32. Temperature and rainfall observed throughout the 2018 growing season at Adams, Oklahoma (2018, MESONET) and the 30-year normal temperature and rainfall for each month (2010, NOAA).

RESULTS

BIOMASS

The amount of biomass left in the trials after harvest varied greatly throughout 2016, 2017, and 2018. Average amounts ranged from 4291 kg ha^{-1} at Tipton in 2017 up to 10129 kg ha^{-1} at Lahoma in 2017. Biomass data was separated into years for analysis due to variability in site locations and number of sites tested each year.

Tipton was the only location sampled in 2016, therefore no interaction was evaluated. A significant difference in biomass production was found between hybrids at Tipton in 2016 (Figure 33). The biomass remaining after harvest of the tolerant hybrid, DKS 37-07, was 5936 kg ha^{-}, while for the susceptible hybrid, KS 585, 3867 kg ha^{-} remained.

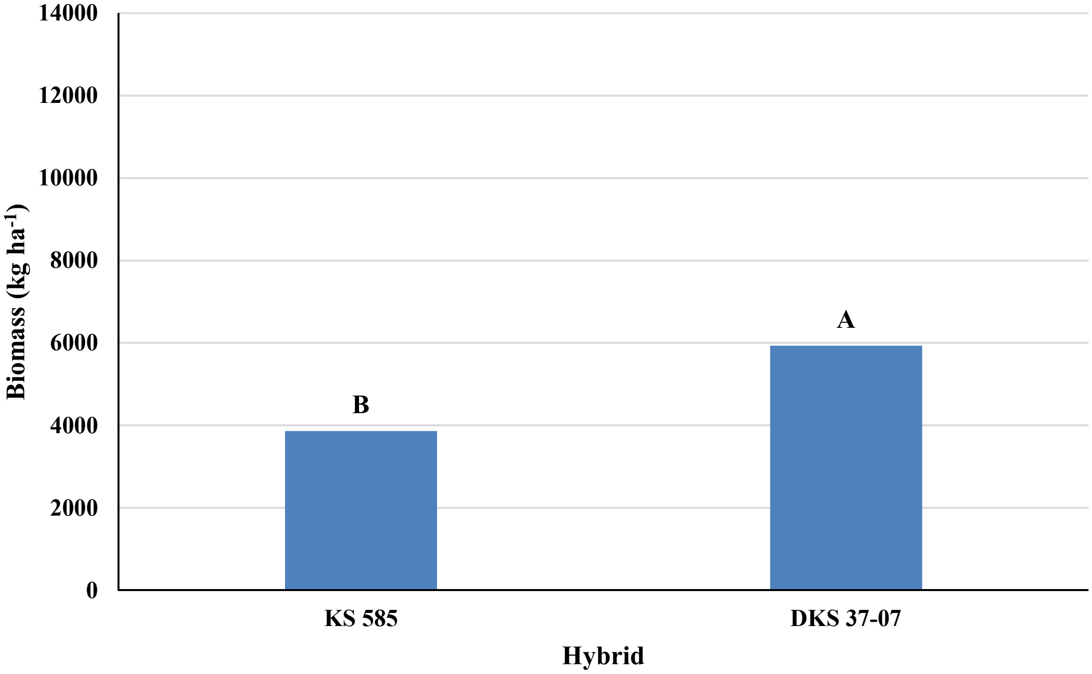

Figure 33. Biomass amounts (kg ha^{-1}) at Tipton in 2016 in terms of hybrid. Letters denote significant differences in biomass production as a result of a main effect of hybrid ($\alpha = 0.10$).

A significant difference in amounts of biomass remaining in the field after harvest existed between locations in 2017 (Figure 34). Hybrid did not have a significant effect on biomass; therefore, biomass measurements were averaged across hybrid for analysis. Biomass weights at the Tipton location were significantly lower than both Dacoma and Lahoma, with an average weight of 4291 kg ha^{-1}. Total biomass between Dacoma and Lahoma were not significantly different, with averages of 6933 kg ha^{-1} and 6102 kg ha^{-1} respectively.

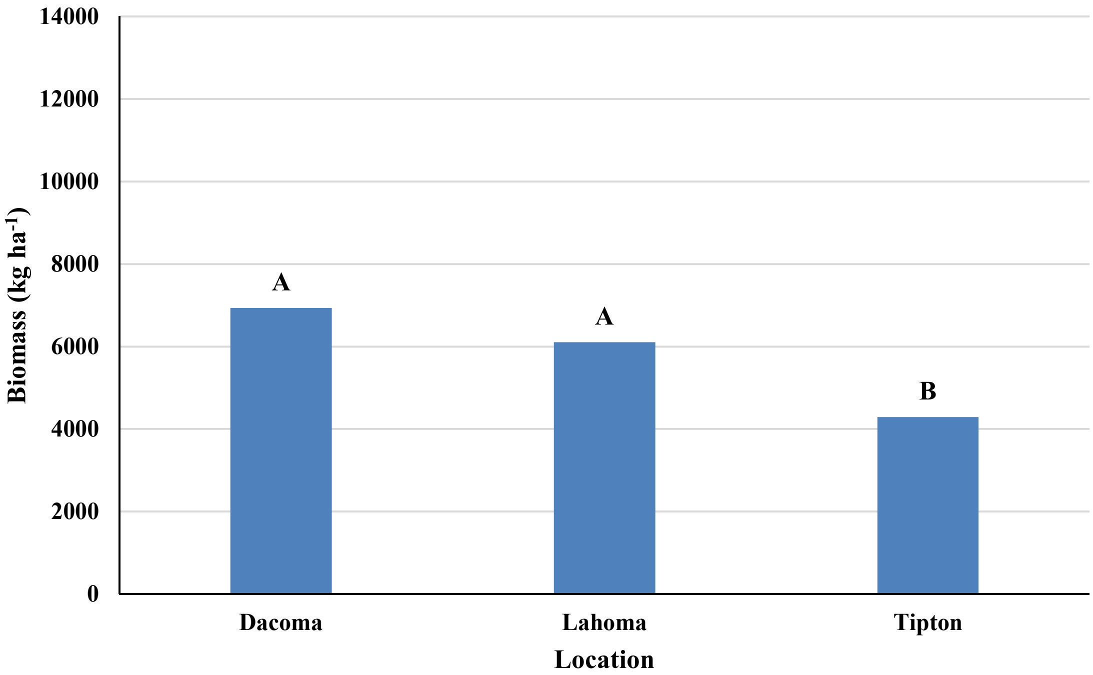

Figure 34. Biomass amounts (kg ha^{-1}) at all locations in 2017 averaged across hybrid in terms of location. Letters denote significant differences in biomass production as a result of a main effect of location ($\alpha = 0.10$).

2018

A significant two-way interaction between hybrid and location were found 2018 (Figure 35). Forage biomass for the Tipton location was significantly lower than all other locations, with the exception of DKS 37-07 at the Perkins location. Highest biomass production was found accumulated by DKS 37-07 at the Lahoma location; however, it did not significantly differ from biomass production of KS 585 at the Perkins location as well as both hybrids at the Adams location. The only location that had a significant difference between hybrids was at Lahoma, where DKS 37-07 was found to have significantly greater biomass compared to KS 585.

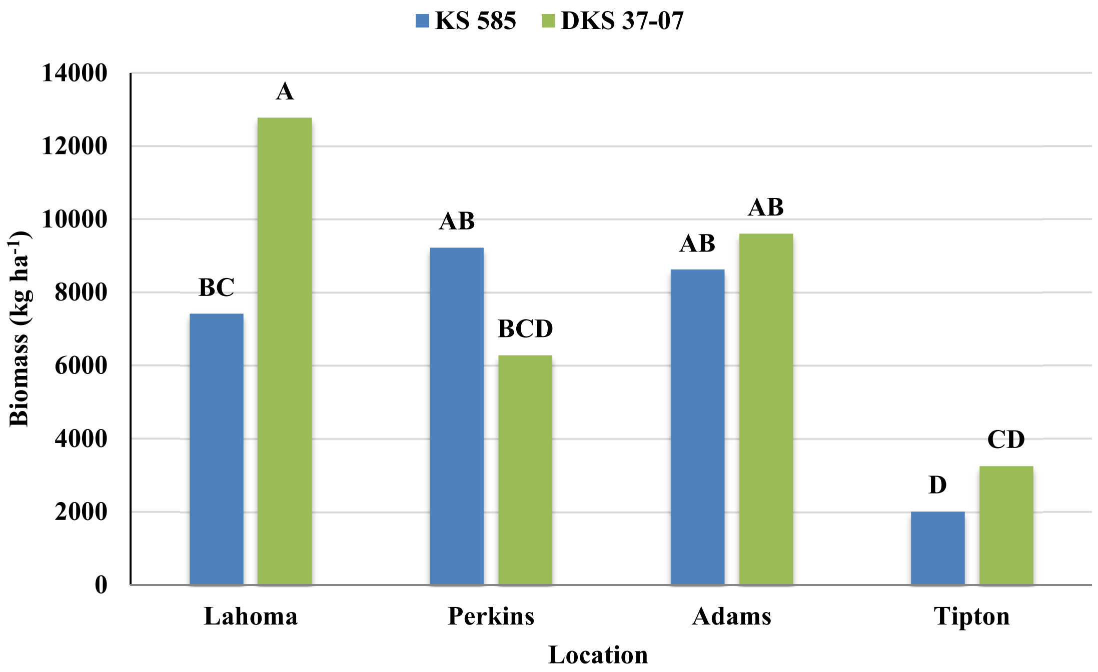

Figure 35. Biomass amounts (kg ha^{-1}) in terms of location and hybrid. Letters denote significant differences in biomass as a result of a two-way interaction between locations and hybrids ($\alpha = 0.10$).

NITRATE (NO_3^-) CONTENT

Species within the sorghum genus are prone to NO_3^- accumulations. Consumption of high amounts of NO_3^- cause NO_2^- poisoning in animals resulting in suffocation due to blood becoming unable to carry oxygen, often leading to death. Testing forages, particularly sorghums, for NO_3^- contents is imperative when considering grazing.

2016

There were no significant differences in NO_3^- concentrations between hybrids at Tipton in 2016 (Figure 36). The DKS 37-07 hybrid had an NO_3^- content of 1478 ppm while the KS 585 hybrid had a concentration of 1951 ppm. Variability in NO_3^-

concentrations within a single hybrid was high at Tipton with standard deviations of 1153 ppm and 1376 ppm for DKS 37-07 and KS 585, respectively. This could be the reason for the lack of significance even with nearly a 473 ppm difference in NO_3^- concentrations.

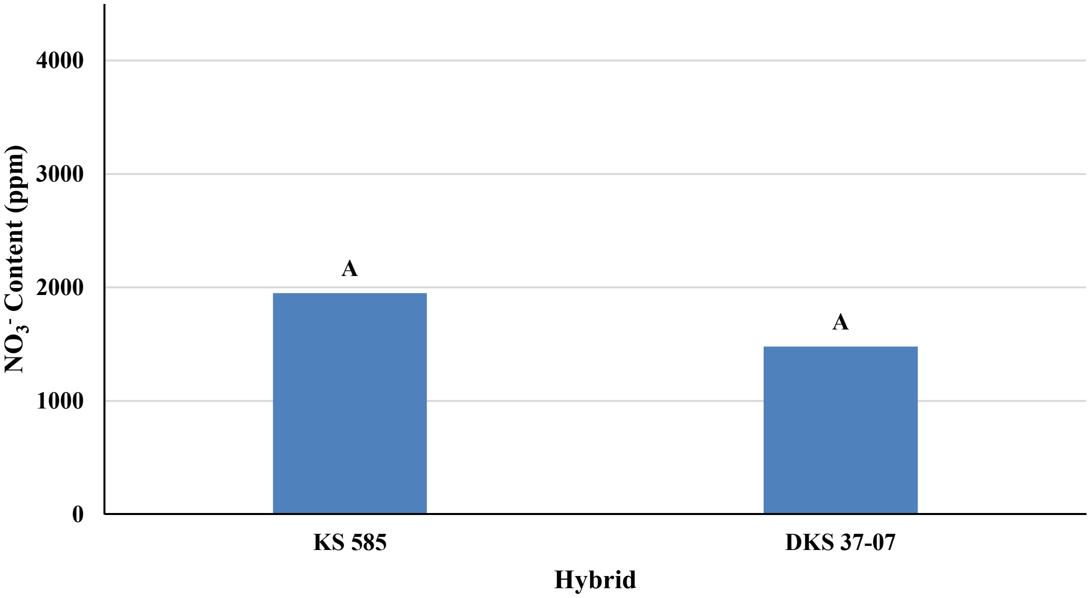

Figure 36. NO_3^- amounts (ppm) at Tipton in 2016 in terms of hybrid.

2017

No significant differences were noted for NO_3^- concentrations between hybrids or locations in 2017 (Figure 37). Nitrate contents were 2110 ppm, 2149 ppm, and 3819 ppm for Dacoma, Lahoma, and Tipton respectively. Similar to 2016, the high variability within locations could account for the lack of significant differences between locations. The standard deviation for NO_3^- at Lahoma was 1143 ppm, 1504 ppm at Dacoma, and 3471 ppm at Tipton (CV = 111.5%).

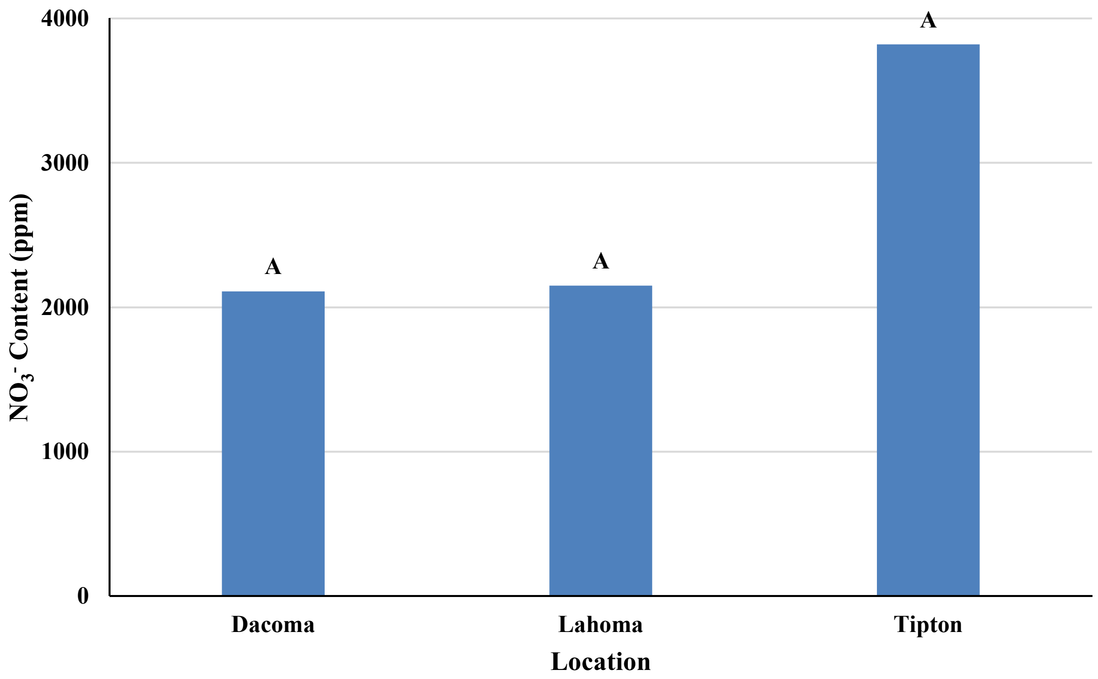

Figure 37. NO_3^- concentrations (ppm) in terms of location with values averaged across hybrid as no significant differences between hybrids were present.

2018

No significant interaction was found between hybrid and location for NO_3^- in 2018. When evaluating the main effects, the only significant effect was location (Figure 38). For this analysis, NO_3^- concentrations were averaged across hybrid at each location. Nitrate concentrations varied throughout locations ranging from an average of 310 ppm in Lahoma to an average of 3727 ppm in Adams. Adams and Tipton both had significantly higher amounts of NO_3^- than Lahoma by 3416 ppm and 3255 ppm respectively. No other significant differences were present. Variability between NO_3^- content within a location was high. Meaning that the NO_3^- concentrations were different from one replication to the next; showing that NO_3^- concentrations are not always similar across a single field. The standard deviations of NO_3^- content were 328 ppm at Lahoma, 1888 ppm at Perkins, 1268 ppm at Adams, and 2558 at Tipton.

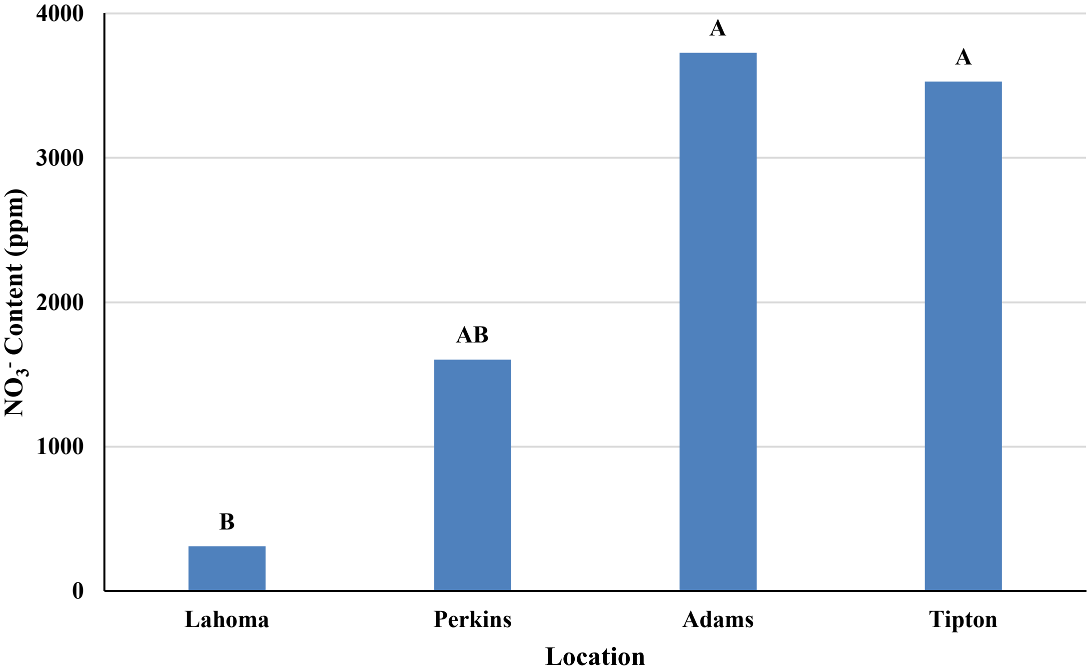

Figure 38. NO_3^- concentrations (ppm) in terms of location averaged across hybrids.

QUALITY PARAMETERS

2016

There were no significant differences in CP, ADF, or TDN contents between hybrids at Tipton in 2016 as variability was low. The average CP was 6.75%, ADF was 41.6%, and TDN was 56.4% for the location. (Appendix B).

2017

A two-way interaction between hybrid and location influenced TDN concentrations in 2017 with concentrations in the hybrid DKS 37-07 at Lahoma and Tipton significantly exceeding concentrations in the same hybrid at Dacoma by 13.1(%) and 13.2(%) respectively. There were no other significant differences in TDN concentrations as well has no significant differences in CP or ADF content. (Appendix B)

2018

Similar to the effects on NO_3^- contents in 2018, location had a significant effect on the protein, ADF, and TDN contents, while hybrid did not (Table 7). Therefore, all quality parameters have been averaged across hybrids for each location. Crude protein (CP) ranged from 6.1% at Perkins to 13.6% at Tipton. Crude protein content at Tipton was significantly higher than all other locations, with no other differences between site locations. Unlike with NO_3^- content, the quality parameters had lower standard deviations. For CP, the standard deviation at Lahoma was 1.58, at Perkins it was 1.68 with a CP average of 6.1%, at Adams it was 0.56 with a CP average of 6.2%, and at Tipton is was 2.05. The ADF values ranged from the lowest of 34.5% in Tipton to the highest of 51.4% in Perkins. Both locations were significantly different than Lahoma and Adams. Standard deviations were below 3.25 for all locations. Conversely, Perkins had the lowest average TDN value of 48.8% while Tipton had the highest of 62.1%, both significantly different than Lahoma and Adams. All standard deviations were below 2.6.

Table 7. Forage quality parameters for all locations in 2018 averaged across hybrids. Letters denote significant differences between locations for each quality parameter.

Location	**CP (%)**	**ADF (%)**	**TDN (%)**
Lahoma	7.5 B	40.2 B	57.6 B
Perkins	6.1 B	51.4 A	48.8 C
Adams	6.2 B	39.2 B	58.3 B
Tipton	13.6 A	34.5 C	62.1 A

DISCUSSION

The use of crop residue as an alternative to high quality pastures may not seem logical; however, in the lag time between high quality summer pastures and winter wheat pastures, crop residue could prove beneficial. Corn residue is commonly utilized in the U.S. corn belt and northern Great Plains as a winter forage (Sletmoen-Olson et al., 2000; Warner et al., 2011) and grain sorghum residue is commonly used in parts of Australia (Radford et al., 2008). Ward (1978) suggests that year round grazing is possible with the utilization of corn and sorghum residues from October through March.

The amount of biomass produced by a sorghum crop after harvest or following a failed crop makes it a viable forage option for grazing livestock. Average forage yields from this study ranged from 4291 kg ha^{-1} to 10129 kg ha^{-1}, showing the abundance of forage available for grazing. According to Lalman and Richards (2016) for growing steer and heifer calves at a current weight of 226.8 kg and a finishing weight of 544.2 kg, for an average daily gain (ADG) of 0.7 kg they would have a dry matter (DM) intake of 5.7 kg d^{-1}. Considering a field with residue amounts of 8000 kg ha^{-1}, mid-range for our study, growing steer or heifer calves as described above at a stocking rate of 20 head ha^{-1} could graze one hectare for 70 days. It is important to note that this stocking rate, although higher than traditional stocking rates, could still be supported by the amount of biomass that remained in the field. A growing yearling at a current weight of 353.7 kg and a finishing weight of 544.2 kg, for an ADG of 1.4 kg they would have a DM intake of 9.3 kg d^{-1} (Lalman and Richards, 2016). Considering the same field with residue amounts of 8000 kg ha^{-1} but now for the growing yearling described above, at a stocking rate of 20 head ha^{-1}, forage would last for 43 days.

Although plenty of material remains after harvest in a grain sorghum crop, there are issues that may arise with grazing crop residue, particularly of the sorghum genus. Low forage quality and the potential of toxic compounds residing in the residue are valid concerns and are worth discussing. Similar to values observed in grain sorghum residues at some locations in this study, corn stalks have a relatively low CP content of 6.5% and a TDN of 65.9% (NRC, 2000). Ward (1978) warns that corn and grain sorghum residue may not be adequate for supporting gestating and lactating cows due to low protein as well as energy and that supplementation may be necessary. However, Adams et al. (1996) reason that with properly managed grazing, grain sorghum or corn residues can provide a good quality feed source force for cows during the fall and winter months.

Looking at the range of CP contents of grain sorghum residue found in this study (ranging from 6.1% through 13.6%), the potential need for supplementation widely varies and is highly dependent upon location and type of animal being grazed. The lowest CP content of 6.1% was observed at Lahoma in 2018; this residue, considered right between low and moderate quality, meets requirements for a dry cow mid-pregnancy during the fall and winter months (Adams et al., 1996). However, according to Kellems and Church (1998) forages with crude protein less than 7.0% might not be adequate for cattle and supplemental protein should be provided as low protein contents of forages limits dry matter intake. Warner et al. (2011) found that in gestating cows grazing corn residue in their last trimester, supplementation with cubes had no effect on performance during reproduction or of the calf. Although the corn stalk residue is typically low in CP, they attribute the lack of effect of supplementation to selective grazing (Warner et al., 2011). Livestock tend to eat the higher quality portions of the residue, the grain and leaves, first leaving the lower quality stalks for last (Rasby et al., 2014). If grazing for a relatively short amount of time, such as the time in between a high quality summer forage and high quality winter wheat pasture, cattle may not need supplementation. Forage testing is a necessary practice to understand the potential needs for the grazing animals, as well as the risks associated with that particular field.

Nitrate accumulations are common within the sorghum genus, particularly in stressed conditions, and when overly consumed can cause death in livestock. Toxic levels of NO_3^- vary depending on the animal consuming the forage as well as the amount of forage consumed. According to Strickland et al (2017), 3000 ppm of NO_3^- can be harmful for pregnant cattle while 5000 ppm of NO_3^- can be risky for all cattle. Kellems and Church (1998) however, states that forages with NO_3^- contents of above about 4300 ppm should be limited to 50% of total ration for pregnant beef cattle and above about 6500 ppm should be limited to 50% of total dry matter intake for non-pregnant cattle.

Nitrate concentrations found in this study were highly variable between locations. Site year averages ranged from 310 ppm to 3727 ppm, of NO_3^-. Two locations in 2018, Tipton and Dacoma, had average NO_3^- contents above the conservative threshold of 3000 ppm given by Strickland et al. (2017) for pregnant cattle; however, they were well below the 5000 ppm threshold given for non-pregnant cattle. All averages were well below the critical levels given by Kellems and Church (1998). Most locations through the years averaged below 3000 ppm and would be considered safe for all cattle, even according to the conservative critical level. Location did play a significant role in NO_3^- concentrations due to varying climatic conditions.

Tipton and Adams, the locations with the highest NO_3^- levels, are located in two areas of the state that are prone to drought and water stress, the Southwest and the panhandle respectively. Crop failure occurred at Tipton due to extremely low rainfall, far below average from two months before planting throughout all of the season with the critical month of June receiving 104 mm or 92% less rain than average for that month and location. Due to the varying climatic regions throughout the state of Oklahoma, high NO_3^- concentrations within a field are more probable in some areas than others and this should be taken into consideration when considering to graze sorghum residue.

Not only are NO_3^- values inconsistent across locations, but also within a single field. The high variation seen through the standard deviations within locations signifies that there are likely pockets within the field that have spiked levels of NO_3^- while others have lower levels. This was particularly seen at the Lahoma and Perkins locations in 2018 locations which had standard deviations of 328 ppm and 1888 ppm respectively (equivalent to over coefficients of variation over 100% for both); however, these locations did not have significant amounts of NO_3^- present as a whole. The Tipton and Adams locations were less variable while having significantly higher NO_3^- levels. Several things such as a high spot that lacks water, an area that received higher amounts of nitrogen fertilizer, or areas with heavy weed pressure could cause variability within a field. It would be beneficial to test residue from areas such as these in a field.

Another source of variation could be caused by sample bias. All residue was collected from above the surface of the soil within the m^2 and partitioning of leaves and stalks into sample bags for testing was random. Nitrates typically accumulate in lower portions of the stalk (Kellems and Church, 1998). Therefore, if higher amounts of leaves were placed in the bag, nitrate content may be lower than if mostly stalks were placed in the bag. This bias accounts for the uncertainty of available forage for the animal and their selectivity. The high variation within a field could potentially cause issues with grazing if high amounts of residue in an area of spiked NO_3^- concentrations were consumed. However, the mixture of residue with low nitrate concentrations, such as leaves, can buffer the high concentrated residue allowing for safe grazing. As stated earlier, cattle often select leaves first and stalks last.

Quantity of forage, quality of forage, and time frame of availability are all important factors of a potential grazing system (Ward, 1978). Grain sorghum residues offer high amounts of forage of decent quality at an opportune time for fall season grazing in Oklahoma. Sampling grain sorghum residue prior to releasing cattle for grazing is imperative. It is particularly important to test for nitrate concentrations in locations prone to drought and other stresses. If aware of particularly stressed spots within a field, or an area that received high amounts of N fertilizer, take separate samples from that area.

CONCLUSIONS

Results of this study suggest that grazing of grain sorghum residues after harvest or a failed crop may be a viable option in areas of Oklahoma. Average biomass throughout site years was 7087 kg ha^{-1}, CP was 8.5%, ADF was 40.0%, TDN was 56.0%, and NO_3^- was 2311 ppm. While quality was marginal, it could still be utilized for animals with lower nutritional needs or with an addition of supplementation. Nitrate toxicity is a continued risk with grazing sorghum. This study found that, on average,

NO_3^- contents of hybrids were lower than the conservative threshold denoting danger to grazing pregnant cattle. However, high variation was found between replications, which suggests that there may be areas within the field that have spiked NO_3^- concentrations. At Tipton in 2017 average NO_3^- content was 3819 ppm with a standard deviation of 3848 ppm, meaning NO_3^- levels could reach approximately 7500 ppm in places. This should be considered when testing crop residue prior to grazing. It is likely that these areas with high NO_3^- concentrations fall within more stressed areas of a field such as areas with more weed pressure, a high area with low water, and area where extra nitrogen fertilizer was applied. It is important to test areas that meet those criteria separately to see if high levels of NO_3^- exist, making sure to collect stalks down to the soil surface as most NO_3^- is found in lower portions of plant.

Grain sorghum production is often centered in semi-arid regions that are prone to drought stresses, which are an inherent production risk. Another challenge associated with grain sorghum production in Oklahoma is low profitability margins due to low grain prices. A potential practice to offset this issue is to utilize the residue that remains after harvest as a forage for livestock. Grain sorghum in Oklahoma is typically harvested from late September through October. This occurs around the time high quality summer forages are dwindling and the winter wheat pastures are being planted. This timing makes it a prime candidate for a grazing system.

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APPENDIX

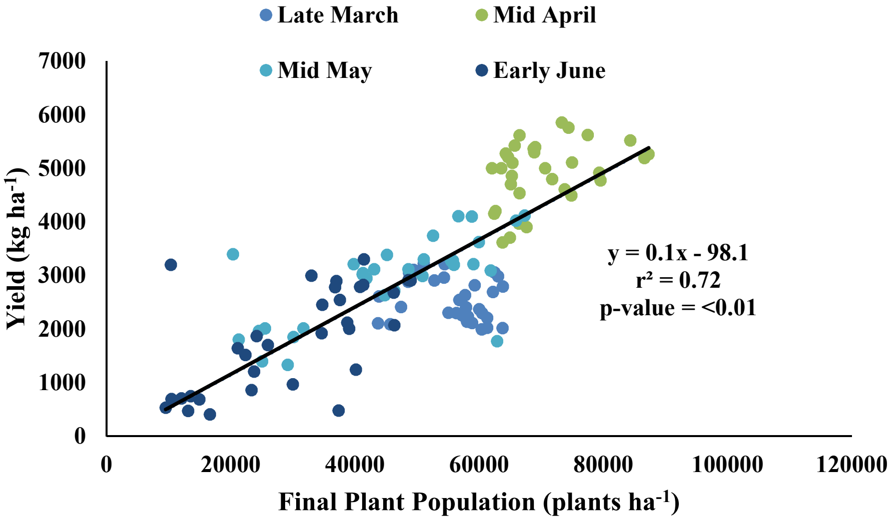

Figure 1. Correlation between final plant populations and yield at EFAW in 2016 separated into planting dates.

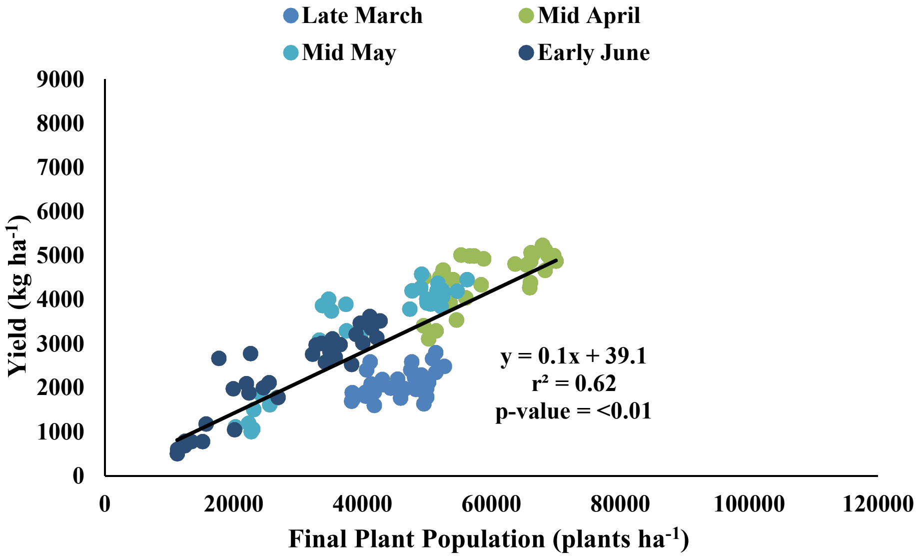

Figure 2. Correlation between final plant populations and yield at Lahoma in 2016 separated into planting dates.

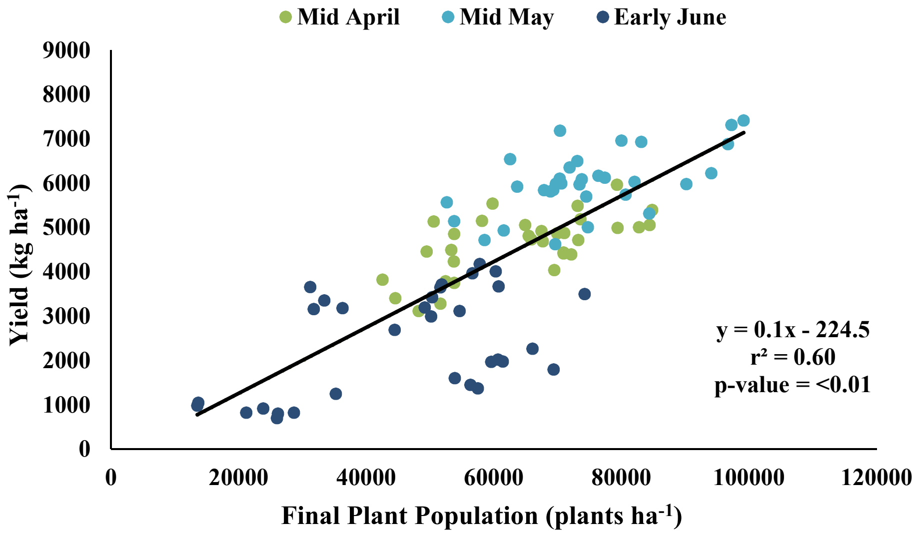

Figure 3. Correlation between final plant populations and yield at EFAW in 2017 separated into planting dates.

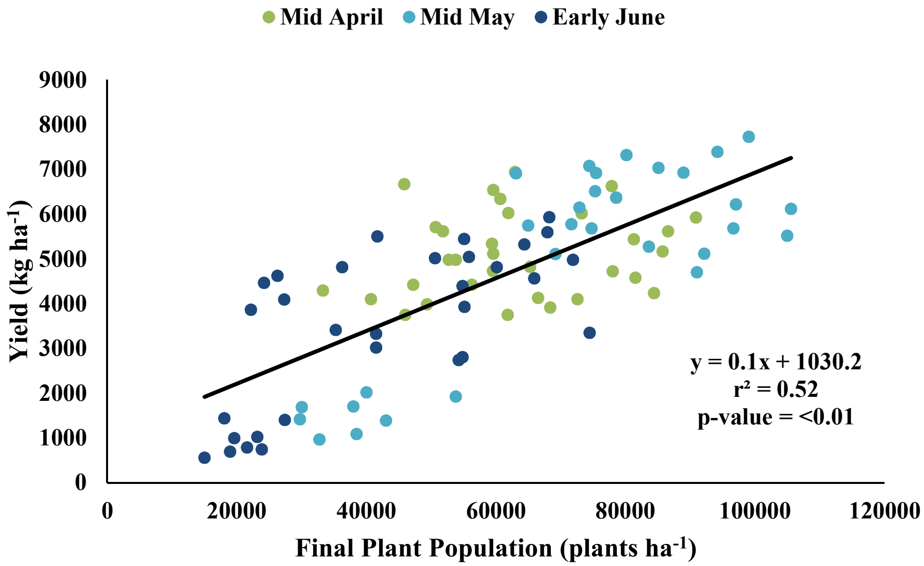

Figure 4. Correlation between final plant populations and yield at Lahoma in 2017 separated into planting dates.

Table 1. Tipton 2016 Forage Data.

Statistic	Yield (kg ha^{-1})	CP (%)	ADF (%)	TDN (%)	NO_3^-
Average	4901.33	6.75	41.64	56.46	1714.25
Standard Deviation	1604.55	0.96	4.63	3.62	1202.07

Coefficient of Variation (%)	32.74	14.28	11.13	6.40	70.12

Table 2. Lahoma 2017 Forage Data.

Statistic	**Yield (kg ha^{-1})**	**CP (%)**	**ADF (%)**	**TDN (%)**	**NO_3^-**
Average	6101.53	9.88	39.72	57.31	2149.08
Standard Deviation	1573.09	2.10	4.24	7.10	1143.21
Coefficient of Variation (%)	25.78	21.20	10.67	12.39	53.20

Table 3. Dacoma 2017 Forage Data.

Statistic	**Yield (kg ha^{-1})**	**CP (%)**	**ADF (%)**	**TDN (%)**	**NO_3^-**
Average	6932.59	10.33	36.81	50.48	2109.92
Standard Deviation	844.02	1.94	5.31	8.86	1504.23
Coefficient of Variation (%)	12.17	18.75	14.44	17.55	71.29

Table 4. Tipton 2017 Forage Data.

Statistic	**Yield (kg ha^{-1})**	**CP (%)**	**ADF (%)**	**TDN (%)**	**NO_3^-**
Average	4291.52	8.29	38.48	58.91	3819.00
Standard Deviation	2065.85	1.20	4.52	3.54	3848.32
Coefficient of Variation (%)	48.14	14.47	11.75	6.00	100.77

Table 5. Perkins 2018 Forage Data.

Statistic	**Yield (kg ha^{-1})**	**CP (%)**	**ADF (%)**	**TDN (%)**	**NO_3^-**
Average	7785.34	6.06	51.43	48.83	1602.58
Standard Deviation	2011.21	1.68	3.24	2.52	1888.09
Coefficient of Variation (%)	25.83	27.74	6.30	5.17	117.82

Table 6. Lahoma 2018 Forage Data.

Statistic	Yield (kg ha^{-1})	CP (%)	ADF (%)	TDN (%)	NO_3^-
Average	10128.50	7.43	40.19	57.59	310.42
Standard Deviation	3700.15	1.58	1.95	1.52	327.58
Coefficient of Variation (%)	36.53	21.24	4.85	2.65	105.53

Table 7. Adams 2018 Forage Data.

Statistic	Yield (kg ha^{-1})	CP (%)	ADF (%)	TDN (%)	NO_3^-
Average	9145.88	6.21	39.23	58.32	3726.92
Standard Deviation	1568.84	0.56	1.78	1.41	1627.21
Coefficient of Variation (%)	17.15	9.07	4.55	2.41	43.66

Table 8. Tipton 2018 Forage Data.

Statistic	Yield (kg ha^{-1})	CP (%)	ADF (%)	TDN (%)	NO_3^-
Average	2642.32	13.08	33.56	62.75	3052.67
Standard Deviation	911.69	1.59	1.81	1.39	2604.19
Coefficient of Variation (%)	34.50	12.21	5.40	2.23	85.30

Table 9. Forage Data by Hybrid.

Year	Location	Hybrid	CP (%)	ADF (%)	TDN (%)
2016	Tipton	KS 585	6.68	44.48	54.25
		DKS 37-07	6.83	38.80	58.68
2017	Lahoma	KS 585	10.12	38.58	53.40
		DKS 37-07	9.65	40.85	61.22
	Dacoma	KS 585	10.93	37.48	52.80
		DKS 37-07	9.73	36.13	48.15
	Tipton	KS 585	8.15	41.68	56.43
		DKS 37-07	8.43	35.28	61.40
2018	Perkins	KS 585	5.22	49.58	50.28
		DKS 37-07	6.90	53.28	47.38
	Lahoma	KS 585	7.05	39.87	57.83
		DKS 37-07	7.82	40.52	57.35
	Adams	KS 585	6.65	39.47	58.13
		DKS 37-07	5.77	39.00	58.50
	Tipton	KS 585	14.05	35.15	61.50
		DKS 37-07	13.15	33.78	62.60

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