GENOTYPE AND HERBICIDE AFFECT HYBRID SWEETGUM GROWTH AND DEVELOPMENT ON TWO UPLAND SITES IN NORTH LOUISIANA

by

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ABSTRACT

American Sweetgum (*Liquidambar styraciflua*) was hybridized by ArborGen and the University of Georgia with Formosan Gum (*Liquidambar formosana*) to create a faster growing hardwood variety that can produce greater volumes of pulpwood on shorter rotations. In this study growth rate and physiological factors of five clonal hybrid varieties were tested against a native half-sib family to determine if the hybrid gum varieties were superior. All hybrid varieties grew significantly taller and larger at ground line than the native family. Indeed, the largest hybrid variety in both height and ground line diameter was 94.7 cm taller and 13.9 mm wider than the native family after two growing seasons. Another test was conducted within this study to determine how herbicide application timing affected the growth and survival of the hybrid gum varieties, as they break dormancy earlier than native sweetgum, and it has been documented that mortality can occur when herbicide is applied over actively growing sweetgum. Each of these tests were carried out at two locations, Louisiana Tech in Ruston, Louisiana, and LSU AgCenter's Hill Farm Research Station in Homer, Louisiana. Over 99% of the sample trees at Louisiana Tech survived for the duration of the study across all herbicide treatments. At Hill Farm over 90% of the sample trees survived the two year duration of the study.

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CHAPTER 1

INTRODUCTION

1.1 Objectives

The goal of this project is (1) to determine hybrid sweetgum growth relative to native sweetgum on two upland sites in North Louisiana, and (2) to test the industry-standard herbaceous weed control timing for these new hybrid sweetgum varieties. Neither formal testing to compare growth rates of these hybrids with native sweetgum growth nor testing of herbicides for herbaceous weed control have been conducted for these hybrid sweetgums. Seedlings were provided by Arborgen Corporation for testing of new commercial hybrid sweetgum varieties in response to the treatments associated with the goals of this project at two sites in Louisiana.

1.2 Literature Review

Hardwood trees are economically important to many states in the United States of America, especially in the eastern half of the country. The eastern United States is home to approximately 90 percent of the nation's hardwood growing stock (Smith, et al. 2001). Hardwood timber production is a large industry in Louisiana; in 2002, 131 million cubic feet of hardwood trees were harvested in Louisiana and 43% of trees harvested in Louisiana were pulpwood or other industrial products like composite panels and mulch (Bentley, Howell and Johnson 2002). The pulpwood industry requires a hardwood

component in many products to create the proper characteristics desired in the final product, such as the softness of tissue paper (Ampulski 1988). A difficulty with using hardwood trees as feedstock is that many southern hardwood trees are located in bottomland areas. Harvesting these sites is challenging because bottomland soils are often inoperable by modern heavy logging equipment as the sites may have soil too soft or too prone to rutting, limiting when these sites can be harvested to just 2-3 months a year in some bottomland flats. Another challenge for growing hardwood trees in the Southeast is the intense amount of interspecific competition for sunlight and nutrients, especially in regards to young seedlings that are vulnerable to stunting or death by being overtopped by other trees, shrubs, or vines (Seifert, Selig and Morrissey 2007).

Because of its broad presence among important hardwood forest types and its growth potential, a major component I the suite of hardwood species in the southeastern United States is sweetgum (*Liquidambar styraciflua*). Sweetgum is a fast growing hardwood species native to much of the eastern United States, along with scattered populations throughout Mexico and Central America (Martin and Harrell 1957). The species spans from Texas and Missouri in the west along the gulf coast of the U.S. and as far north as southern Illinois and New Jersey (Burns and Honkala 1990).

Sweetgum is one of only four species in the *Liquidambar* genus; the other three, *L. formosana*, *L. orientalis*, and *L. acalysina* are dispersed across Asia, from the Island of Taiwan, to the eastern Mediterranean region in Turkey. *L. formosana*, native to Taiwan, increased overall stand production of Masson Pine (*Pinus massonianai*) plantations by as much as 72.5% in 12 years when the two species were planted together compared to monoculture plantations of Masson Pine (Xiaoniu and Hongkai 1997). Besides American

Sweetgum (*L. styraciflua*), *L. formosana* is the tallest member of the *Liquidambar* genus. The chemical compounds produced by *L. acalycina*, whose range extends across much of southeast Asia, have been studied to identify several chemical compounds the tree produces in search of new ways to retard fungal growth (HaiShan, et al. 2009). Research has also been done with *L. orientalis*, native to the Mediterranean region of Asia, concerning chemical compounds produced within the plant for use as a fumigant to combat fungal growth.

Sweetgum has evolved traits that facilitate fast colonization in forests after disturbances like fires or tornados. The seeds of a sweetgum tree are very small and housed in seed pods that are shaped like a spiked ball, giving rise to its common name "gumball tree". Individual seeds are released in the fall and dispersed by the wind, allowing seedlings to germinate as much as 700 feet away from the parent tree (Nuttle and Haefner 2005). The seeds of a sweetgum tree germinate best on bare mineral soil but can compete with a vegetative layer, i.e. grass, to reach mineral soil. Young seedlings cannot tolerate being overtopped by floodwaters. Maturing seedlings also need an uninhibited root zone to allow roots to spread freely in search of water and nutrients, especially in areas where water has the potential to become a limiting factor to plant growth (Schenk and Jackson 2002). Sweetgum is commonly found on upland sites alongside pine in full sunlight but grows fastest on bottomland sites (Koch 1985).

Sweetgum has wood characteristics that can be used in pulpwood manufacturing, or it can be converted into biofuel (Bentley, Howell and Johnson 2005). The wood characteristics of sweetgum lend themselves well to biofuel products (Alig, Adams and McCarl 2000). A relatively new forestry practice becoming more commonplace within

the forest industry is called Short Rotation Woody Crop (SRWC) forestry- where the goal is to cultivate a crop of trees as rapidly as possible using intensive silviculture to improve the growth rates of the trees (Kaczmarek, et al. 2012). The objectives for SRWC stands are to provide material for pulpwood mills or to be chipped and processed into biofuels. A few hardwood genera have been selected for testing in this new system including sycamore, poplar/cottonwood, eucalyptus, and sweetgum. Genetic improvements have been made in the last few decades within these genera through hybridization within genus, genetic selection, and clonal replication to create faster-growing individuals capable of rapidly responding to fertilizer or release treatments to capitalize on monetary inputs to the stand (Scott, Burger, et al. 2004). Each of these improved crops has varying attributes in regards to cold tolerance, drought tolerance, resistance to disease and fertilization requirements that must be considered before selecting a planting stock when establishing a SRWC plantation (Kline and Coleman 2010).

Timing of water availability impacts hardwood tree growth and survivorship; trees benefit less from abundant water during the winter when many tree species are dormant, than water availability in the summer during the active growing season. Water accessibility is in part dependent on the water holding capacity of soil. Sandy soils do not maintain as much water as soils containing a higher percentage of silt or clay (Brady and Weil, 2008) or soil with just a lower percentage of sand (Franzmeier, et al. 2016). Water-holding capacity and the timing of water availability are two important variables along with nutrient availability and sun exposure that play a crucial part of growing seedlings. Indeed, sweetgum growth performs best on moist alluvial clay and loam soils near river bottoms. Still, sweetgum is arguably the most widely adaptable hardwood species and

can grow in upland areas of the Coastal Plain and Piedmont, though with considerably less growth (Burns and Honkala 1990). As such, sweetgum is one of the most common hardwood species associated with upland sites that are typically managed for pine. Pines generally inhabit lower-quality sites that have lower water availability than needed by many hardwood species to grow to their fullest potential. Sweetgum can take advantage of a wide range of soil conditions, although they still grow best in moderately well drained bottomland areas that have a low percentage of clay in the soil (Koch 1985).

In commercial operations, such as SRWC, a common practice is to alleviate herbaceous competition by using herbicide application during early development to give the seedlings a strong head start before they have to compete with weeds for nutrients, water, and light. Herbaceous vegetation control is hard to maintain within a young hardwood stand because many of the herbicides designed to kill undesirable species are also lethal to hardwood crop trees. Herbicides must be registered for use at specific application rates and for use under specific conditions. Herbicides are broken down into classes depending on their chemical properties and modes of action. Some herbicides move readily through the soil, sometimes leaving the target area and killing vegetation away from the target area. In the same way, other herbicides are easily washed away from the target area with water (Kushla and Self 2013). The process whereby an herbicide enters a plant and causes mortality is called the mode of action of the herbicide. Mode of action often describes how a chemical interacts with the metabolic pathways required for proper plant function. The risks and dangers of herbicide application are dependent on herbicide class, e.g. sulfonylurea herbicides degrade markedly slower in alkaline pH soils than in acidic soil conditions (Robertson and Davis 2010). The

sulfonylurea herbicides are a single herbicide class because they all have a similar chemical makeup; sulfometuron methyl is one herbicide within the sulfonylurea class of herbicides frequently used in the forest industry to reduce herbaceous competition (Robertson and Davis 2010). When sulfometuron methyl (Oust XP [Dupont; Wilmington, DE]) is used, it prevents the production of an enzyme called acetolactate synthase (ALS) that controls root growth, and without this enzyme affected plants stop producing roots and slowly succumb to starvation (Klotzbach and Durkin 2004). One consideration when deciding to use sulfometuron methyl over sweetgum or other hardwood species is that the crop trees must be dormant when applying the herbicide (while the roots are not actively growing) to prevent damage to the crop trees from the herbicide. Sulfometuron methyl can be used bot as a pre-emergent (prevents weeds from sprouting) and post-emergent (kills weeds currently on site) herbicide to control undesirable vegetation that is already growing and prevent new vegetation from sprouting (Klotzbach and Durkin 2004).

Hybrid sweetgum varieties may be able to produce more biomass than native sweetgums efficiently on upland sites, which can be harvested year-round as it can maintain superior growth on upland sites (S. Martin 2016). These new genotypes could open up a new sphere of possibilities for land managers and timber companies (S. Martin 2016). If hybrid sweetgum varieties are adaptable to diverse soil and water conditions, they can readily and rapidly produce biomass under traditionally adverse soil conditions. Two potential reasons for hybrid sweetgum's ability to produce large quantities of biomass in a short span of time are: (1) native sweetgum was hybridized with a tropical Asian species called Formosan Gum (*Liquidambar formosana*) that has a shorter period of dormancy, and (2) many hybrids including hybrid sweetgum display "hybrid vigor";

the trees grow exceptionally well because of the new genetic diversity introduced (S. Martin 2016). If these claims can be quantified and silvicultural regimes (i.e. herbicide prescription) can be deduced to maximize the growth of hybrid varieties it could provide a year-round hardwood feedstock supply for the pulpwood industry.

1.3 Research Need

Currently we do not know if new hybrid sweetgum genotypes will outperform native sweetgum in regards to growth traits or if the standard herbicide recommendation should remain the same. This study also tests the physiological traits exhibited by both hybrid and native varieties of sweetgum including water use efficiency and photosynthetic capacity of each variety. Physiological information may not only provide a link for the mechanism underlying improved growth but may also give insights into site requirements of hybrid varieties. With this information land managers will be better equipped to determine what seedlings to plant on their land and silvicultural recommendations to maximize seedling growth rate. Herbicides play a vital role in hardwood plantation management; therefore, herbicide timing was also tested. Herbicides such as sulfometuron methyl, may cause damage to sweetgum and other hardwood tree species when applied over the seedlings while they are not dormant (Cox 2002). Hybrid sweetgum may take advantage of a longer growing period, becoming dormant later in the year, and they often maintain some leaves through the winter until the seedling is ready to produce a new flush of leaves in the spring. Therefore, research needs to be conducted to better describe when hybrid sweetgum varieties are least susceptible to herbicide damage. This study at Louisiana Tech University in Ruston, Louisiana and Hill Farm Research

Station in Homer, Louisiana tests the performance of hybrid sweetgum varieties against native sweetgum on two upland sites that can be harvested year-round.

CHAPTER 2

METHODOLOGY

2.1 Site Descriptions

Two trials were conducted as part of this thesis project; common characteristics between the two trials are discussed first, followed by specifics of each trial individually. These two trials include a genotype trial, which was designed to assess hybrid and native sweetgum growth, survival, and physiology. A second trial (i.e. herbicide trial) tested herbicide application timing efficacy and effects on growth and survival of hybrid sweetgum varieties.

Both trials were replicated simultaneously between October 2015 and December 2017 at two sites: Louisiana Tech South Campus in Ruston, Louisiana (32º 30’ 42” N, 92º 39’ 10” W), and LSU Ag Center’s Hill Farm Research Station in Homer, Louisiana (32º 44’ 52” N, 93º 03’ 11” W). The Louisiana Tech study site was largely on an Angie fine sandy loam soil, with a small portion on a Sacul very fine sandy loam, while the Hill Farm site was located on a Darley-Sacul complex, with Darley being on the ridgetop and down the hillside and Sacul being predominant in the bottom below the hill (NRCS WebSoilSurvey). Available nutrients from each site were analyzed, and pH was tested to ensure Oust XP (Bayer Crop Sciences; Research Triangle Park, NC) could be safely used (Appendix C-22). Site index was estimated for each site using Baker Broadfoot

estimation as there was no web soil survey reported site index for sweetgum. Sweetgum site index at Louisiana Tech was predicted to be 69ft (24m) of height after 50 years of growth, while the Hill Farm location was predicted to obtain 62ft (18.9m) of height after 50 years of growth. The limiting factor at both sites was the presence of a hardpan; Louisiana Tech's was caused by cow and tractor traffic, Hill Farm's was caused by the presence of ironstone in the subsoil. The Louisiana Tech site was used for grazing and hay production since 1990. During this time horse manure was spread over the field occasionally as fertilizer. Prior to 1990, this site was the interior of a racetrack which was actively used back into the late 1970's, during which time Christmas trees were periodically grown on the site. The Hill Farm study site was mulched in 2014 to remove vegetation and lain fallow until the installation of the current study after having two failed loblolly pine (*Pinus taeda* L.) plantings in 2009 and 2010. Prior to these failed plantings, the site was used for loblolly pine research since the 1960's. In the summer of 2015, the Hill Farm site was fertilized with 150 lbs/acre (168 kg/ha) of diammonium phosphate (DAP). The Louisiana Tech study location did not receive any fertilizer treatment prior to planting due to the site's history of manure fertilization (Scott, Burger, et al. 2004). In preparation for planting, both sites were subsoiled (ripped) to a 24-inch (0.6m) depth in late summer prior to planting. One week before planting 3 quarts/acre (7 L/ha) of glyphosate was applied (Accord XRTII ® [Dow; Indianapolis, IN]) via ATV-mounted sprayer to remove any herbaceous vegetation present. Prior to planting, containerized seedlings were left outside under a covered awning and watered daily to prevent soil from drying out. Seedlings were planted in late October 2015 by hand on the upslope side of the rip when slope was present. The Hill Farm site had significant slope

while none was present at the Louisiana Tech site. After planting, height (cm) and ground line diameter (GLD) (mm) were measured with a meter stick and caliper, respectively. Measurement took place in November before seedlings initiated growth after planting to establish a baseline for comparison of future growth.

2.2 Genotype Trial

The genotype trial was laid out in a randomized complete block design at both locations. For the trial we used 1,200 containerized (1-0) seedlings between the two sites. There were four replications of each genotype. Each of the genotypes formed a plot consisting of five rows of five trees each. Six genotypes were compared in the study, including four hybrid varieties: “AGHS1”, “AGHS2”, “AGHS3”, “AGHS4”, alongside two native half-sibling families: “AGH2”, and “AGH25”. The study was designed to have the nine internal trees (3 tree x 3 tree) within each 5 tree x 5 tree plot analyzed. At both sites, rows were spaced ten feet apart, and seedlings were planted every eight feet along the row. The total area of each plot was 40 feet x 40 feet, with the interior study plot being 24 feet x 24 feet; no gaps between plots was created because of the inclusion of buffer trees around each study plot.

Each row of the study at both sites received 2 oz/acre (146 mL/ha) of sulfometuron methyl (Oust XP) to reduce herbaceous competition with seedlings on February 5, 2016. Rotary mowing was conducted between rows at the Hill Farm site twice per year in 2016 and 2017; brush trimmers were used to reduce vegetation within rows in mid-summer during the same years at that site. After one full growing season post planting (November 2016), the seedlings were re-measured, and again in December (2017) after two full growing seasons. At each measurement time, a survival tally was

kept to determine genotype effects on survival rate. Prior to the 2017 growing season (i.e. second growing season) 2 oz/acre (146 mL/ha) of imazapic herbicide (Plateau® BASF; Iselin, NJ) was applied to both sites in an attempt to control morning glory (*Jacquemontia tamnifolia*) that overtook a portion of the study late in the summer of 2016.

During the second growing season (i.e., 2017) physiological characteristics (water potential, and photosynthetic capacity) were sampled. A Model 615 Pressure Chamber Instrument [PMS Instrument Company; Albany, OR] with attached nitrogen tank was used to measure water potential. Sampling was done pre-dawn, beginning 1.5 hours before sunrise, with the excision of the mature leaf closest to the tip of the dominant stem. This leaf was placed in the chamber with the petiole protruding through a sealed gasket in the lid. The chamber was then pressurized until exudate was observed. At observation of exudate, the chamber pressure was recorded in BARs. Photosynthesis measurements were taken the same day as water potential. After sunrise, trees were given an hour to acclimate to ambient light conditions. Light-saturated photosynthetic rate (mol CO_2 $m^{-2}s^{-1}$) was measured using a LI-6400XT Portable Photosynthesis System [LICOR; Lincoln, NE] with a leaf chamber fluorometer (Model 6400-40) attachment. The leaf chamber was set to emit 1400 PAR of light in the sample chamber and maintain a constant flow of 400 ppm of CO_2 into the chamber. Photosynthetic rate of the leaves in µmol per $m^{-2}sec^{-1}$ was observed until the values stabilized, at which point the value was recorded. While photosynthesis was being measured, another member of the sampling team measured soil moisture as percent volumetric water content. Water content was measured with a Field Scout TDR 300 soil moisture meter (10 cm probe depth). The

seedling's height and ground line diameter (GLD) were measured at the same time. One tree was selected from each plot to be sampled for these parameters. The tree was selected by determining the individual tree within the plot that was closest to the combined average height and GLD for that specific plot. The sampling of these individual trees was repeated three times during the 2017 growing season, including June, August and September. These three times were expected to represent various levels of water availability through seasonal changes as rainfall normally decreased through the summer and early fall in Louisiana.

Plot growth and survial analyses for this project were conducted using the internal plot trees only (i.e., the border trees were removed from the data set). All analysis was conducted using SAS version 9.4 [Carey, NC]. Average of height, diameter, and survival percentage was calculated for each plot. A generalized linear mixed model (GLMM) accounting for repeated measurements of each sample was used to test for significance of the randomized complete block design over two locations and three time points (Table 2-1). In the analysis, both genotype and location factors were considered fixed effects. In instances where global significant differences (α=0.05) were found among the treatments, an F-protected Fisher's least-significant differences (LSD) test was performed to identify where the differences occurred among the treatments. To determine effects on sweetgum physiological data, a repeated measures GLMM was used to test for significance of fixed effects of location and genotype on the individual tree photosynthetic rate, leaf water potential, and spatially close volumetric water content.

Table 2-1: Expected mean square table for Genotype Trial. Location and Genotype were treated as fixed effects in our analysis using the GLIMMIX package of SAS.

Source of Variation	*d.f.*	MS#	Expected Mean Square	F-Test (MS#/MS #)
Time (T)	2	8	$\sigma^2+LGn\sigma^2_T$	8/1
Location (L)	1	7	$\sigma^2+TGn\frac{\sum(L)_l^2}{(l-1)}$	7/1
Genotype (G)	5	6	$\sigma^2+TLn\frac{\sum(H)_h^2}{(h-1)}$	6/1
T x L	2	5	$\sigma^2+Gn\sigma^2_{TL}$	5/1
T x G	10	4	$\sigma^2+Ln\sigma^2_{TG}$	4/1
L x G	5	3	$\sigma^2+Tn\frac{\sum(LG)_{lg}^2}{(l-1)(g-1)}+n\sigma^2_{TL}$ G	3/2
T x L x G	10	2	$\sigma^2+n\sigma^2_{TLG}$	2/1
Error		1	σ^2	
Total	35			

2.3 Herbicide Trial

The herbicide tested in this study was sulfometuron methyl (Oust XP®). Oust XP® was applied in a 36-inch (91.4 cm) wide band using a boom sprayer attached to a tractor at 2 quarts/acre (4.7L/ha) directly over the seedlings. This rate of Oust XP® was selected in accordance with recommendations for sweetgum based on prior studies

(Kushla and Self 2013). Each row was placed into one of four herbicide treatments groups. Bud condition was used to separate the treatments as a visual cue that the tree was preparing to break dormancy and begin growing in the spring (Figure 2-1). A control treatment that received no herbaceous weed control was one of the four treatments. In the earliest herbicide application (winter treatment) on January 29, buds were completely dormant. The second application (recommended treatment) was applied on February 17 as the buds began to show the first signs of swell due to the unusually warm winter northern Louisiana experienced early in 2016. This middle treatment was recommended by the label of Oust XP® as the best time to apply herbicide to prevent tree damage or mortality while still achieving adequate herbaceous weed control. The final treatment group (late treatment) received herbicide on March 5 after many of the buds had already broken dormancy and the trees began leafing out, marking the beginning of the growing season.

Figure 2-1: Three stages of bud swell observed at each herbicide application timing. (A) At the early herbicide application timing all buds were completely dormant. (B) At the recommended herbicide application timing buds had begun to turn green, especially the lateral buds along the stem. (C) At the late herbicide application timing buds were open, and some leaves were present along the stem. All pictures were taken at Louisiana Tech South Campus study site by Robert Hane in 2015-2016.

The treatment structure for the study was a split-plot design, with herbicide timing as the whole-plot treatment and variety as the subplot treatment. Subplots were 3ft (0.9m) by 40ft (12.2m) in size. Each row was treated as a separate plot and contained all genotypes; each genotype had an eight-tree subplot randomly placed within the row's 200 foot (61m) length. Within each row there were buffer trees separating the study trees of each genotype from other groups. The first and last tree of each genotype was considered a buffer tree and was removed from the data set before statistical analyses were conducted. A total of four herbicide treatments and five hybrid sweetgum varieties were tested in this study. Hybrids tested in the study were "AGHS1", "AGHS2", "AGHS3", "AGHS4", and "AGHS8". The varieties available commercially during this study were

"AGHS1", "AGHS2", "AGHS3", and "AGHS4" in our study; also included in our study was one non-commercial hybrid "AGHS8". Five replications of each main plot were installed at Louisiana Tech University, and three replications were installed at the Hill Farm Research Station. A total of 1,280 seedlings were planted for this study between the two study sites. The seedlings were planted five feet (1.6m) apart along the row, while the rows were ten feet (3.3m) apart. Both sites were hand planted in November 2015 with 1-0 hybrid sweetgum (*Liquidambar formosana x styraciflua*) varieties provided by ArborGen Corporation, from their nursery located in Shellman, Georgia.

Height, ground-line diameter (GLD), and survival were measured in December 2015. Survival was again measured in July, September, and October of 2016. Height was measured again in July and October of 2016, while GLD was only measured in October of 2016. Height (cm) was measured using a meter stick from the ground level to the highest living bud present on the seedling. Ground-line diameter (mm) was measured with a caliper held at ground level unless roots were exposed above the ground, in which case GLD was take at the root collar. The growth of individual trees was determined as the difference in height and GLD between December 2015 and all subsequent measurement periods.

During every sampling period each tree was given a damage score from "1" being undamaged and "9" being dead. Many trees also showed signs of being browsed by deer, so the number "10" was added to denote browse damage (Blazier et al. 2011) (Table 2-2). The damage score was used to assess the tolerance level of each genotype and herbicide timing. Late in the first growing season, portions of the study were overtaken by small-flower morning glory, and a separate tally was taken to determine the number of trees

morning glory affected. Morning glory is an annual climbing vine that rapidly grows up and around seedlings. This vine was a concern as it can bend seedlings over and bind them horizontal to the ground. Potentially when the vines become large enough, they could almost completely shade the seedlings. Girdling, however, was not a major concern during the first growing season, because the vines died during the winter and were removed from the seedlings.

To determine the impacts of herbicide application and application timing on weeds, percent ground cover, the height of the tallest weed, and average vegetative height were measured along with the measurements take of the crop trees within each plot. This was accomplished using three 1-square meter samples per plot. Within the sample plot a 1/20-meter grid was formed to improve the estimation accuracy of the samples. These samples were combined to create an average vegetation estimate for each plot. The vegetative plots were located after the first seedling in the row, in the middle of the plot, land before the last seedling of the plot to maintain an unbiased sample. Percent ground cover surveys occurred twice during the first growing season (2016), the first sample period was in late May, and the second was the beginning of September. Alongside the September ground cover survey the average height of vegetation was measured (cm), and height of the tallest non-crop stem (cm) was also recorded. Percent ground cover was sampled twice to determine if the various herbicide timings differed in their ability to control herbaceous competition through the course of a growing season. Average vegetation height and height of the tallest non-crop stem were recorded to give a better picture of the interspecific competition intensity after one growing season under various herbicide regimes.

Table 2-2: Scoring chart used to score the magnitude of damage to seedlings after herbicide treatment.

Seedling Damage Score	Score Description
1	No Damage
2	Chlorotic Leaves
3	Dead Leaves, Upper Stem
4	Dead Leaves, Lower Stem
5	Tip Dieback, Second Flush
6	Tip Dieback
7	Dieback to bottom, Resprout
8	Dieback to bottom, No Resprout
9	Dead
10	Browse Damage

Plot means of height and GLD growth were analyzed independently as a split-plot of genotype within herbicide treatment using a general linear mixed model (GLMM) (Table 2-3). For both dependent variables, samples were taken three times, the initial measurements and after the two successive growing seasons, creating the need to treat this data with a procedure that could handle repeated measures. Before any analysis began, border trees were removed from the data set and were not included in the analysis. Plot means were used in the analysis for significance using independent fixed-variables of location, genotype, and herbicide treatment and all possible interactions between these factors. When significance ($P<0.05$) terms were found, an F-protected Fisher's least-significant difference (LSD) method was used for means separation. Vegetative samples were also analyzed using a GLMM. Percent ground cover was a repeated measurement,

but tallest weed height and average weed height were both collected at only one time point near the end of the first growing season.

Table 2-3: Expected mean square table for Herbicide Trial. Location, Herbicide, and Genotype were treated as fixed effects in our analysis using the GLIMMIX package of SAS.

Source of Variation	*d.f.*	MS#	Expected Mean Square	F-test (MS#/MS#)
Time (T)	2	12	$\sigma^2+LGHn\sigma^2_T$	12/1
Location (L)	1	11	$\sigma^2+HGn\sigma^2_{TL}+THGn\frac{\sum(L)_l^2}{(l-1)}$	11/9
Herbicide (H)	3	10	$\sigma^2+LGn\sigma^2_{TH}+TLGn\frac{\sum(H)_h^2}{(h-1)}$	10/8
T x L	2	9	$\sigma^2+HGn\sigma^2_{TL}$	9/1
T x H	6	8	$\sigma^2+LGn\sigma^2_{TH}$	8/1
L x H	3	7	$\sigma^2+TGn\frac{\sum(LH)_{lh}^2}{(l-1)(h-1)}$	7/6
T x L x H	6	6	$\sigma^2+Gn\sigma^2_{TLH}$	6/1
Genotype within H{G(H)	12	5	$\sigma^2+TLn\frac{\sum(HG)_{hg}^2}{(h-1)(g-1)}+Ln\sigma^2_{TGH}$	5/4
T x G(H)	24	4	$\sigma^2+Ln\sigma^2_{TGH}$	4/1
L x G(H)	12	3	$\sigma^2+Tn\frac{\sum(LHG)_{lhg}^2}{(l-1)(h-1)(g-1)}+n\sigma^2_{TLHG}$	3/2
T x L x G(H)	24	2	$\sigma^2+n\sigma^2_{TLHG}$	2/1
Error		1	σ^2	
Total	89			

CHAPTER 3

RESULTS

3.1 Climate

Climate conditions during the study, and more broadly over the last 30 years, were derived from National Oceanic and Atmospheric Administration (NOAA) data collected at the closest weather stations to each study site within the NOAA network (SCIPP 2019). There is a NOAA weather station located at and another near Hill Farm, there were also four weather stations around Ruston for the Louisiana Tech study site (NOAA 2019). The weather stations all had gaps in their data from station malfunctions, so to reduce the size of these gaps the two stations in proximity to Hill Farm were averaged together and the four stations close to Louisiana Tech were averaged together. The observed weather data was then used to gain monthly and yearly averages for each study site. Few departures from the average temperature and rainfall recorded across the past 30 years occurred during the trial period. Over the three-year duration of the study the monthly average temperature never departed more than 5 ºF from the 30-year average temperature, but in several months there was drastically more rainfall than the 30-year average rainfall. During the summer of the second study year (2017), from May through August 6.53 inches of rainfall above the 30-year average fell at the study sites, which was nearly double the 30-year average (Appendix C-23).

3.2 Genotype Trial

3.2.1 Growth and Development

Overall, survival at both sites among all sweetgum hybrid genotypes was high (91%). At the end of the second growing season, the seedlings at the Louisiana Tech study site grew to an average of 219.23 cm (+/- 42.46) and were significantly taller than the seedlings at the Hill Farm study site which averaged 195.10 cm (+/- 37.45) in total height. Because there were no differences in genotypes at the initial measurement period ($p>0.05$), all genotypes were roughly the same height at the time of planting (Figure 3-1). Height of sweetgum hybrids were significantly affected by the factors tested in this study ($p<0.01$). There were two significant interactions of factors from the repeated measures GLM affecting total sweetgum height. The interactions of Location by Time, and Genotype by Time were both highly significant ($p\leq0.0001$). The Location by Time interaction was only significant at the end of the second growing season whereas the initial measurements and the measurements taken at the end of the first growing season were not significantly separated within the time point by Location. In the second growing season, seedlings at Louisiana Tech were taller than those at Hill Farm.

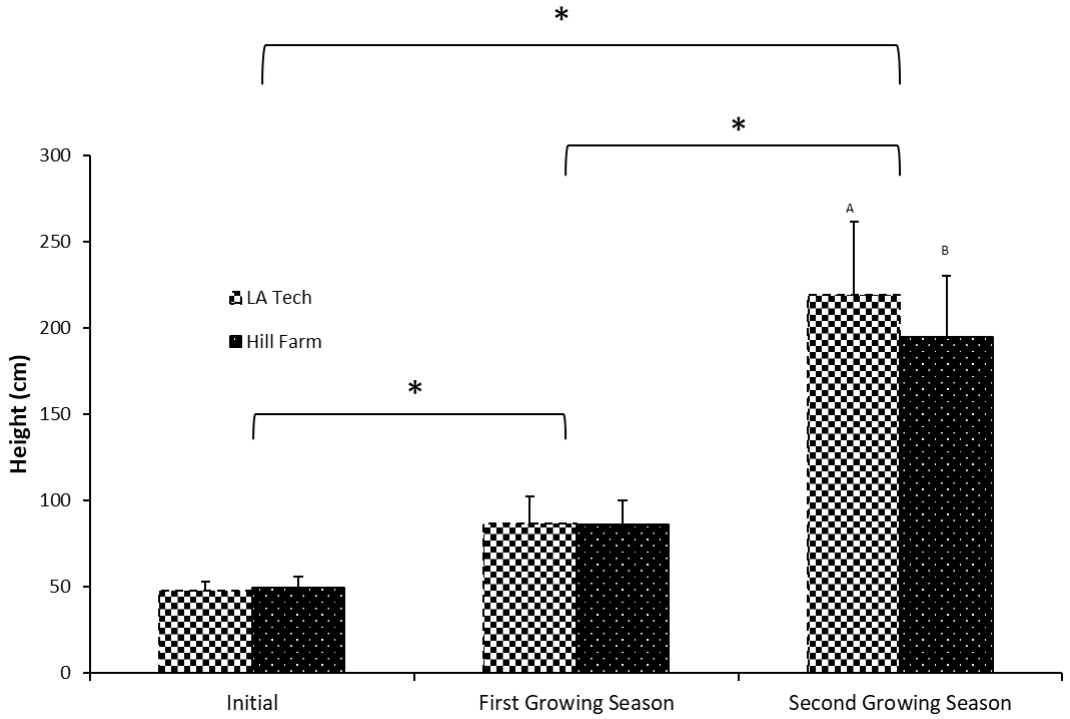

Figure 3-1: Time and Location variables significantly interacted to affect mean height in the Genotype Study (p=<0.0001). The Time variable represented the three times data was collected: "Initial" was at planting, "First Growing Season" was after the first growing season and "Second Growing Season" was after the second growing season. The Location variable consisted of the two study sites included in the study: Louisiana Tech and Hill Farm. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-7.

Initially, all genotypes were similar in height (p>0.05). However, after the first growing season, three of the four hybrid varieties, which included AGHS1 (96.60 +/- 9.38 cm), AGHS2 (96.06 +/- 14.23 cm), and AGHS4 (94.33 +/- 9.62 cm) were significantly taller than either of the native half-sib families (AGH2 72.52 +/- 8.40 cm; AGH25 69.87 +/- 8.75 cm) (p=0.023). The remaining hybrid, AGHS3 (88.95 +/- 4.34 cm) was not significantly different from the native family AGH2 (72.52 +/- 8.40 cm) but was significantly from the other native family AGH25 (69.87 +/- 8.75 cm). Both native

families were similar to each other in height after the first growing season. After the second growing season, all of the hybrid varieties were significantly taller than the native families, with AGHS2 (244.45 +/- 42.83 cm) and AGHS1 (232.26 +/- 26.48 cm) being the tallest, but AGHS1 was not significantly separated from AGHS4 (219.58 +/- 28.19 cm) in the analysis (Figure 3-2). A full list of significant separations can be found in Appendix B-8.

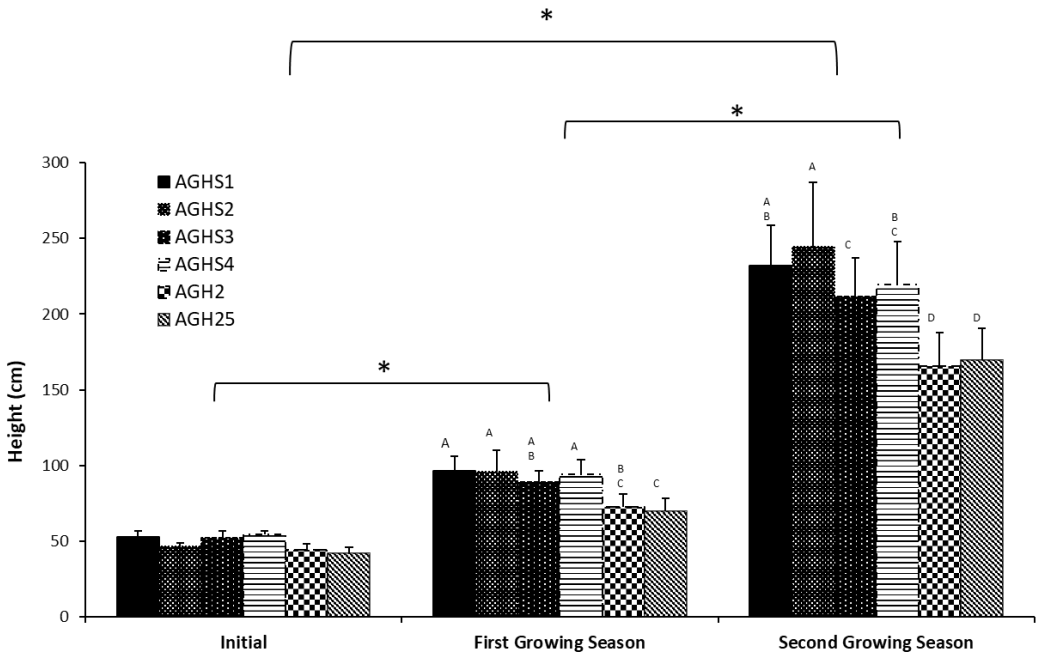

Figure 3-2: The Time and Genotype variables significantly interacted to affect mean height in the Genotype Study (p=0.0001). The Time variable represented the three times data was collected: "Initial" was at planting, "First Growing Season" was after the first growing season and "Second Growing Season" was after the second growing season. The Genotype variable consisted of the four hybrid clones and two native half-sibling native families being tested. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-8.

Similar to height, the analysis of GLD found two significant interactions within the model. The interactions of Location by Time, and Genotype by Time were both significant ($p<0.01$ and $p<0.01$, respectively). The Location by Time interaction significantly affected differences between the two locations after both the first and second growing season; no differences were detected at the initial measurement of GLD. By the end of the second growing season the tree at the Louisiana Tech study site (45.34 +/- 6.20 mm) were significantly larger than those at the Hill Farm study site (37.45 +/- 6.88 mm) (Figure 3-3).

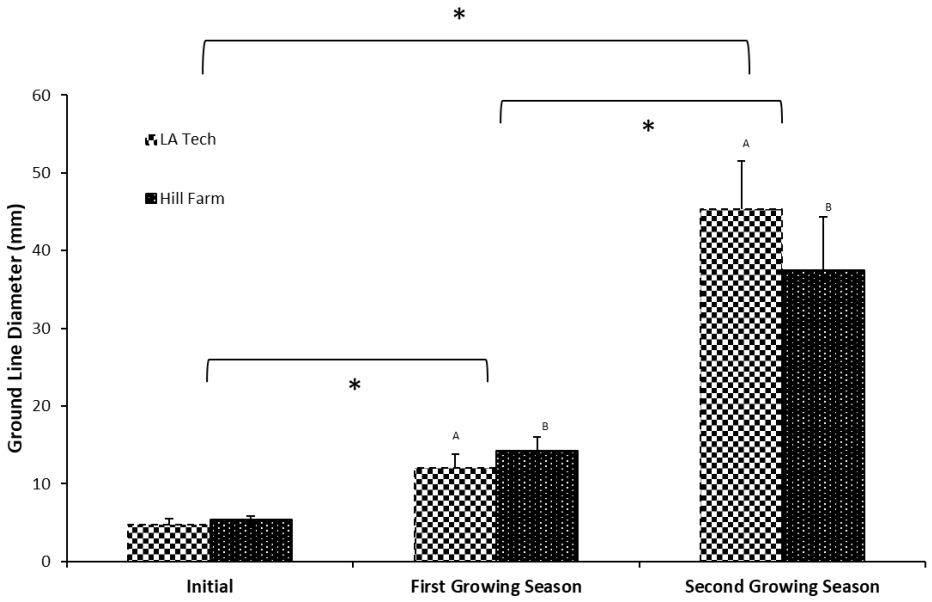

Figure 3-3: The Time and Location variables significantly interacted to affect mean ground line diameter in the Genotype Study ($p<0.0001$). The Time variable represented the three times data was collected: "Initial" was at planting, "First Growing Season" was after the first growing season and "Second Growing Season" was after the second growing season. The Location variable consisted of the two sites included in the study: Louisiana Tech and Hill Farm. Significant differences detected using Least Significant Difference mean separation test ($\alpha=0.05$) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-7.

The Genotype by Time interaction was only found to be significant after the second growing season for GLD. At this point, all of the hybrid varieties were statistically similar, and both native families were statistically similar; the only significance found was when comparing hybrid varieties to the native families. The four hybrid varieties averaged together grew to 43.69 +/- 6.20 mm in diameter while the native families averaged a GLD of 36.80 +/- 5.61 mm after the second growing season (Figure 3-4).

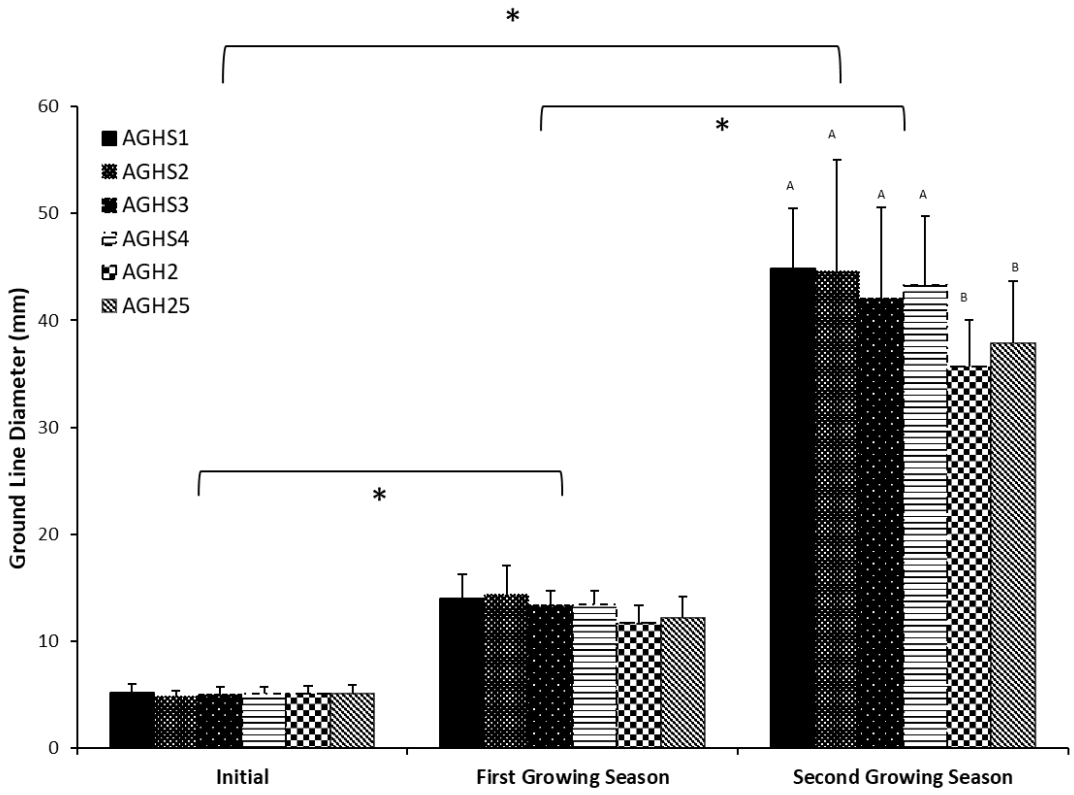

Figure 3-4: The Time and Genotype variables significantly interacted to affect mean ground line diameter in the Genotype Study (p=0.0046). The Time variable represented the three times data was collected: "Initial" was at planting, "First Growing Season" was after the first growing season and "Second Growing Season" was after the second growing season. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-8.

3.2.2 Physiology

Leaf water potential differed by sampling period (p<=0.001) and Genotype (p<=0.001). The first sampling period (conducted in May of 2017) was excluded from analysis due to many of the sampled being significantly outside a plausible range for living plants. Among the two remaining time points the final sample (conducted in

August 2017) was the highest at 0.47 +/- 0.24 psi, and the middle sample period (conducted in June 2017) was the lowest at 0.24 +/- 0.13 psi (Figure 3-5).

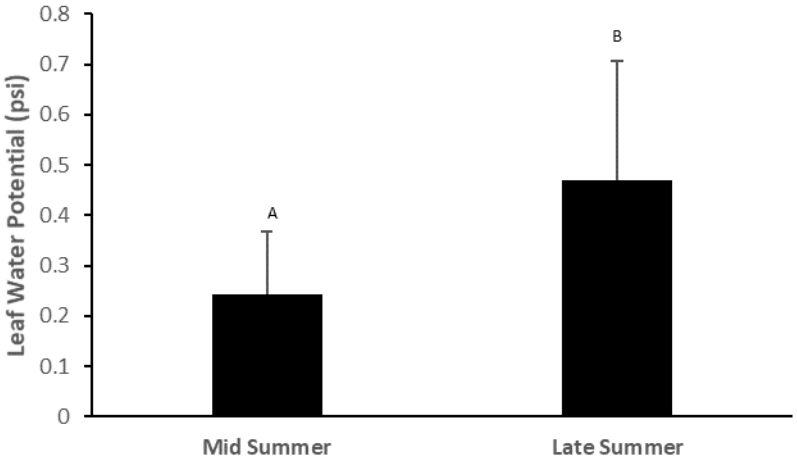

Figure 3-5: Mean leaf water potential was significantly different between the two sample points during the summer ($p<0.0001$) that could be analyzed. Grouping of significant differences detected using Least Significant Difference mean separation test ($\alpha=0.05$) displayed above each bar. Error bars represent one standard deviation.

When leaf water potential was averaged by genotype, across the two time points analyzed the genotypes with the highest water potential were AGHS2 and AGHS3 at 4.24 +/- 2.3 psi and 4.62 +/- 3.2 psi respectively (Figure 3-6). These two genotypes were significantly higher than AGHS4 (2.9 +/- 1.69 psi) and AGH25 (2.8 +/- 1.54 psi), but not significantly higher than AGHS1 (3.38 +/- 1.7 psi) or AGH2 (3.44 +/- 2.07 psi). AGHS1 and AGH2 were not significantly separated from any genotype in the leaf water potential analysis.

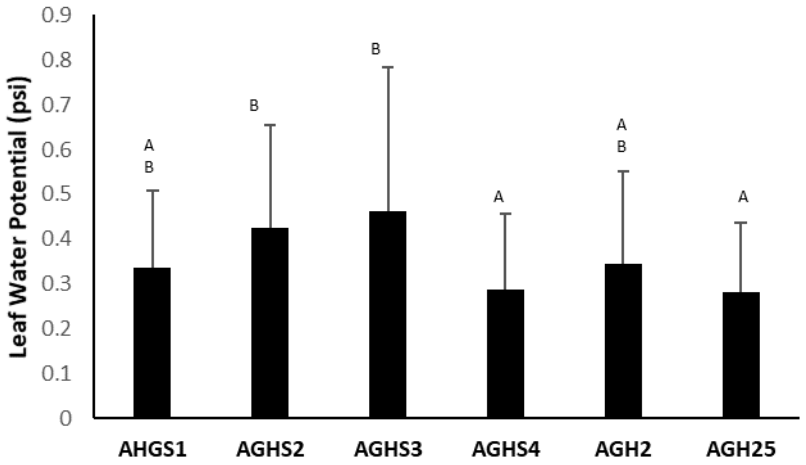

Figure 3-6: Mean leaf water potential was significantly affected by genotype ($p<0.0001$). Grouping of significant differences detected using Least Significant Difference mean separation test ($\alpha=0.05$) are displayed above each bar. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-9.

A significant three-way interaction was observed between the variables of Location, Herbicide, and Sample Time in analyses of soil moisture ($p=0.013$). At the first sample time, which was conducted early in the summer (May), all of the genotypes except AGHS2 at the Louisiana Tech study site (8.83% +/- 2.58) were growing in significantly more moist soil condition than any genotype at the Hill Farm study site (5.64% +/- 1.49). AGHS2 at the Louisiana Tech study site was not significantly different from AGHS1 or AGHS2 at the Hill Farm study site. At the second sample period, conducted during midsummer (July), there were many statistical differences among genotypes at both locations. The Hill Farm study site had a broader separation among genotypes than the Louisiana Tech study site but also had more genotypes with the highest statistical ranking of soil moisture than the Louisiana Tech site. No statistical differences were detected from the late summer (August) sample period due to the lack of rain during the summer of 2017 (second growing season) in the region. All of the soil

moisture measurements taken in the August sample period had less than 5% soil moisture, with the vast majority recording 0% soil moisture within the first 10 cm of soil (Figure 3-7).

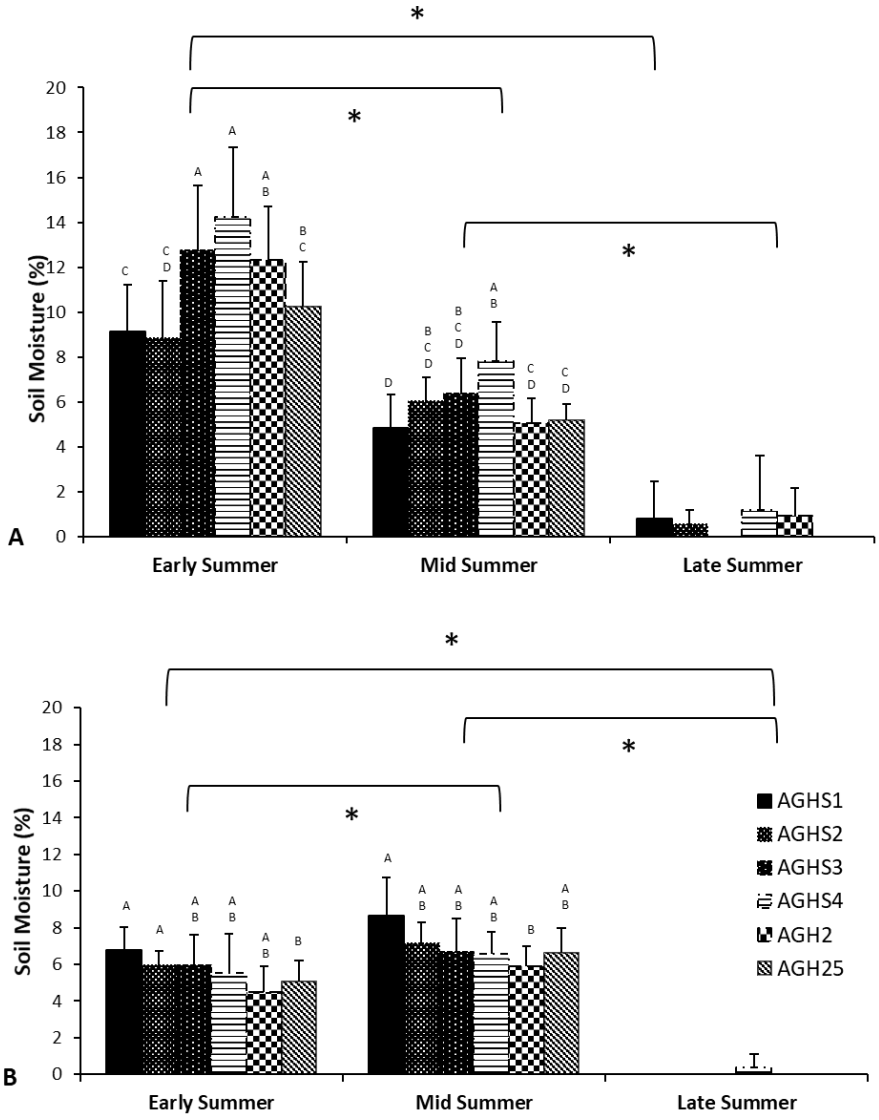

Figure 3-7: The Time, Location and Genotype variables significantly interacted to affect mean soil moisture in the Genotype Study (p=0.0172). The Time variable represented the three times data was collected: "Early Summer" (May), "Mid Summer" (July), "Late Summer" (August). The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Genotype variable consisted of the four hybrid clones and two native half-sibling native families being tested. Significant differences detected using Least Significant Difference mean separation test (a=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-10.

A significant interaction was found between Location and Sample Time when photosynthesis measurements were analyzed ($p=0.02$). At the first sample time the Hill Farm study site had significantly higher average photosynthetic rates (μmol CO_2 m^{-2} s^{-1}) than the Louisiana Tech Study site (14.67 +/- 3.80 μmol CO_2 m^{-2} s^{-1} and 10.83 +/- 3.94 μmol CO_2 m^{-2} s^{-1}, respectively), these differences became insignificant over the course of the summer, as neither the midsummer (June) or late summer (August) sample times resulted in any detectable significant differences between the two study sites. The Hill Farm site remained higher than the Louisiana Tech site at the midsummer (June) sample period, although not significantly (9.93 +/- 3.68 μmol CO_2 m^{-2} s^{-1} and 8.18 +/- 3.97 μmol CO_2 m^{-2} s^{-1}, respectively). Trees at the Hill Farm study site did not maintain the rapid rate of photosynthesis found at the beginning of the summer (May) (Figure 3-8).

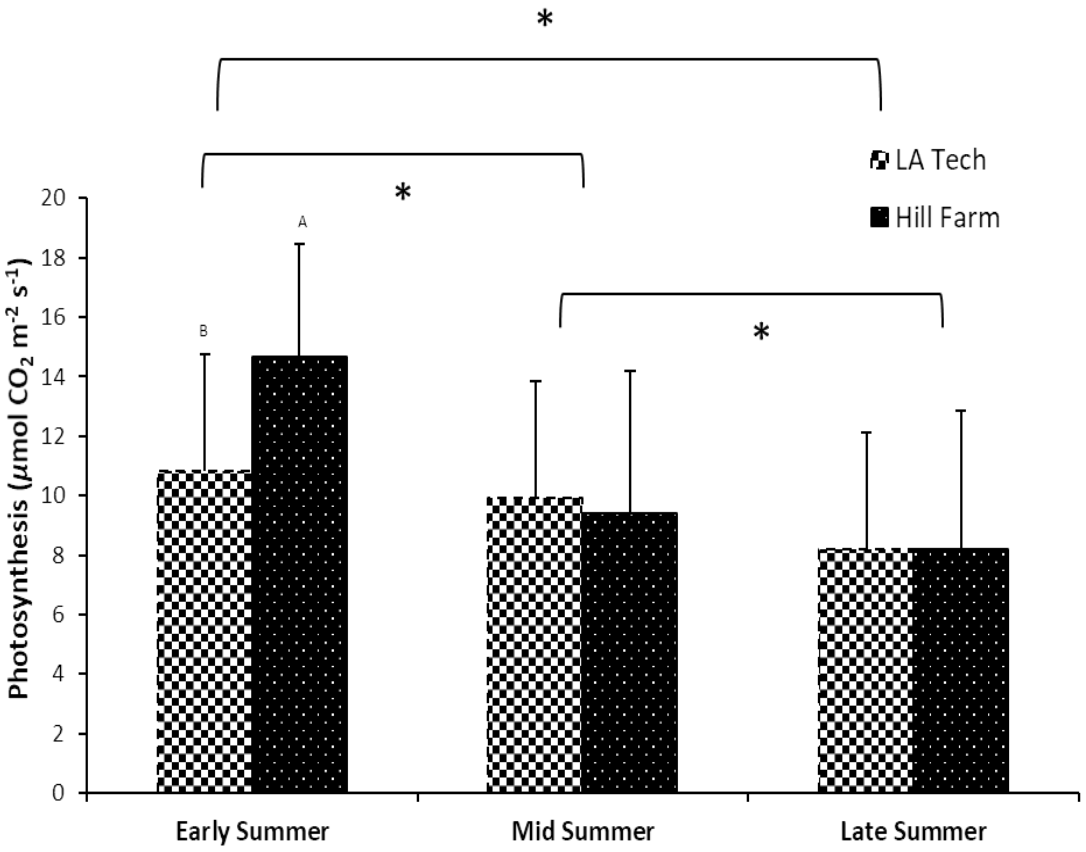

Figure 3-8: The Time and Location variables significantly interacted to affect mean photosynthesis in the Genotype Study (p=0.214). The Time variable represented the three times data was collected: : "Early Summer" (May), "Mid Summer" (July), "Late Summer" (August). The Location variable consisted of the two study sites included in the study: Louisiana Tech and Hill Farm. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-11.

3.3 Herbicide Trial

3.3.1 Growth and Development

In the herbicide study, height was significantly affected by interacting factors. The first interaction was Location by Herbicide by Genotype (p=0.03). While not always

significant, AGHS8 was the smallest clonal variety under all herbicide treatment regimes at both locations at the end of the two-year study (165.44 +/- 36.85 cm). The next smallest genotype was AGHS3 growing to 180.38 +/- 40.05 cm after two growing seasons. At the Louisiana Tech study site, AGHS2 grew the tallest after the first two growing seasons in each of the three herbicide application timing treatments (250.17 +/- 22.99 cm); within the recommended herbicide timing application AGHS2 grew to be 15.9% taller than the next tallest genotype, and over 17% taller than the average of all other genotypes within that herbicide treatment group at Louisiana Tech. Within the no-herbicide control at Louisiana Tech, AGHS4 surpassed AGHS2 in height growth, but the difference was not significant (210.65 +/- 27.77 cm and 198.90 +/- 24.66 cm respectively). Still, the control at Louisiana Tech was 17% shorter than the average height of trees. These trends were not necessarily reflected at the Hill Farm site. Individual genotype ranks were different at Hill Farm, with AGHS1 being the tallest hybrid variety under both the control and recommended herbicide treatments (163.29 +/- 33.82 cm and 201.49 +/- 40.04 cm, respectively). Within the early herbicide treatment at Louisiana Tech AGHS2 was the tallest at 250.18 +/- 22.99 cm in height after two growing seasons. AGHS4 grew taller than the other hybrid varieties within the late herbicide treatment, growing to 176.37 +/- 31.76 cm in height after two growing seasons (Figure 3-9).

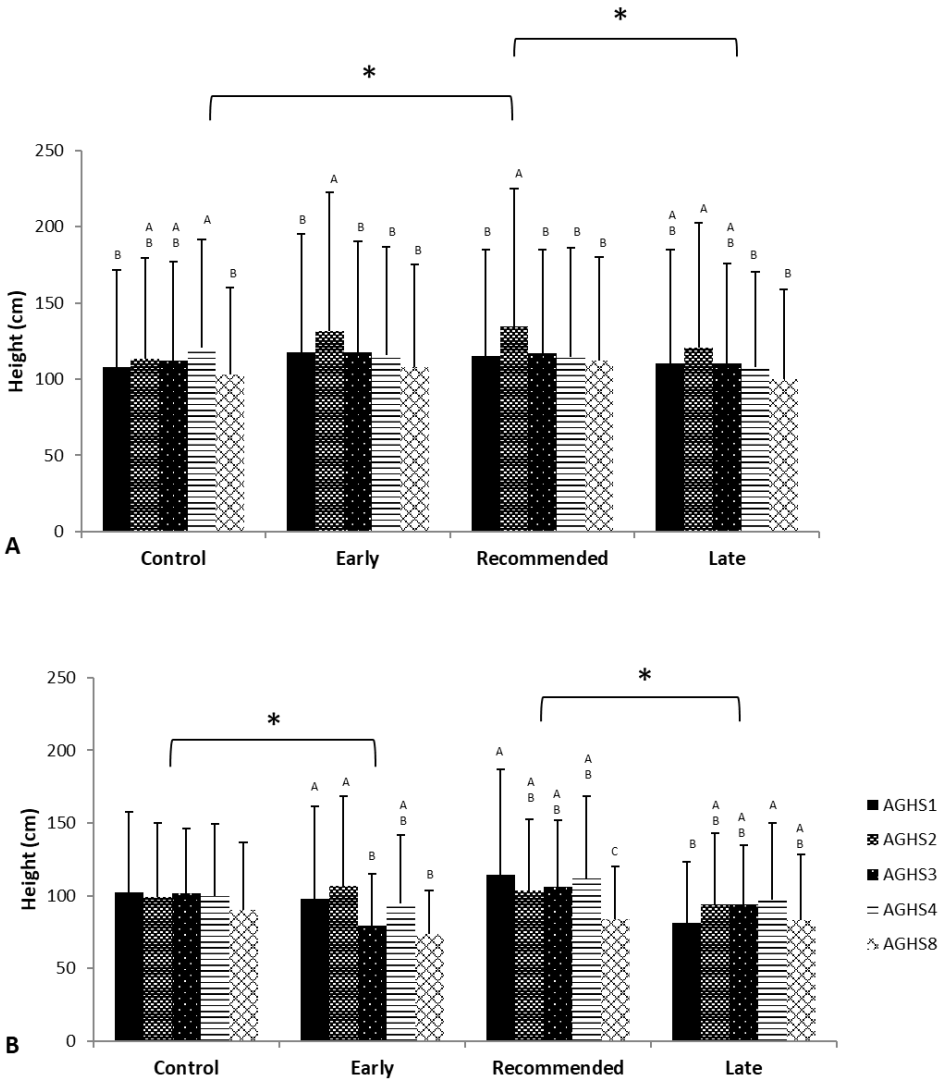

Figure 3-9: The Location, Herbicide and Genotype variables significantly interacted to affect mean height in the Herbicide Study when all measurements were analyzed together (p=0.0310). The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Herbicide variable had four possible treatments: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-12.

The second interaction that affected height was Year by Herbicide by Genotype ($p<0.01$). During the initial survey, no significant differences were observed among the Herbicide and Genotype combinations, but after both the first and second growing seasons many differences were apparent, most notably that AGHS2 was among the top performing genotypes across herbicide treatments. This was especially true in the Early Herbicide treatment group after the second growing season in which AGSH2 was 22.0 cm greater than the next tallest genotype and 63.5 cm from the shortest genotype (Figure 3-10).

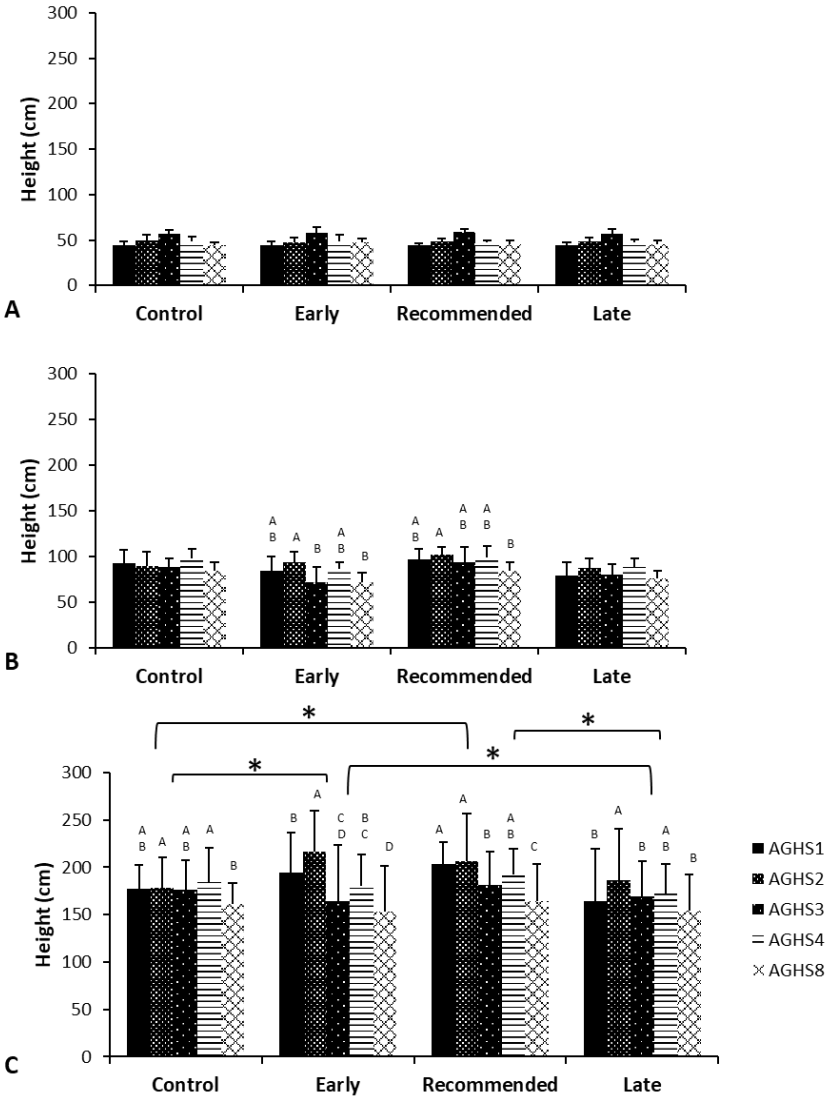

Figure 3-10: The Time, Herbicide and Genotype variables significantly interacted to affect mean height in the Herbicide Study ($p<0.0001$). The Time variable represented the three times data was collected: (A) the initial measurements at planting, (B) height measurements taken after the first growing season after planting, (C) height measurements taken after the second growing season after planting. The Herbicide variable had four possible treatments: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences were detected using Least Significant Difference mean separation test ($\alpha=0.05$) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-13.

The final three-way interaction that was observed within the Height data was that of Time, Location and Herbicide (p=0.04). No significant differences were detected during the initial inventory measurements. After the first growing season, the Early herbicide treatment at the Hill Farm study site (76.1 +/- 15.61 cm) was significantly lower than all of the other Herbicide by Location interactions except for the Late herbicide treatments at both sites, both of which were still over 5 cm taller than Hill Farm's Early herbicide treatment. The highest performing herbicide application timing for height growth was the recommended treatment at both sites (LT: 98.59 +/- 13.72 cm; and HF: 92.4 +/- 11.71 cm); these two Herbicide by Location combinations were only significantly separated from the three lowest performing combinations of Herbicide by Location mentioned previously (Figure 3-11). After the second growing season, all four herbicide application timings at Louisiana Tech had become significantly taller than any herbicide treatment at Hill Farm, with Early (217.69 +/- 26.29 cm) and Recommended (214.06 +/- 28.22 cm) treatments being the tallest.

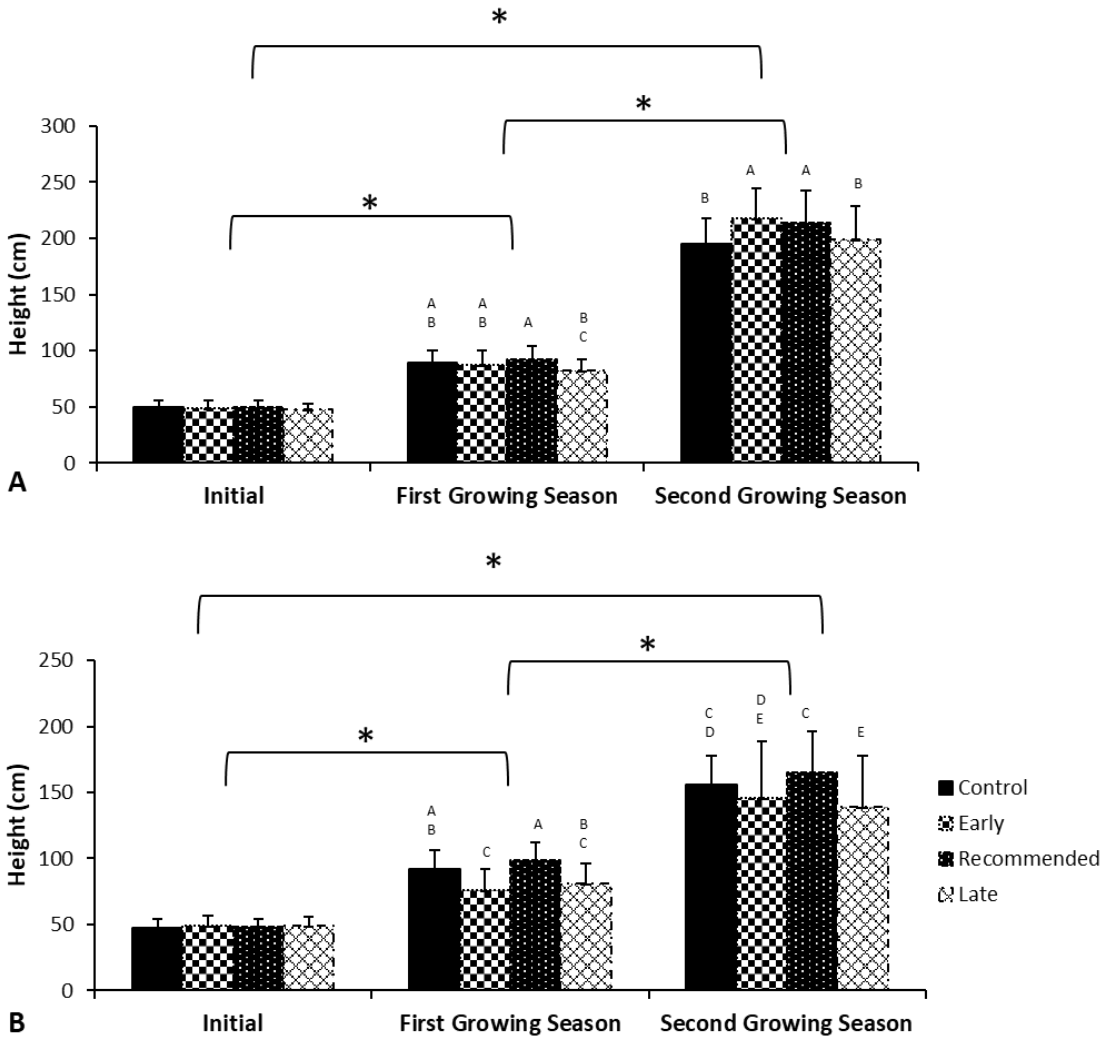

Figure 3-11: The Time, Location, and Herbicide variables significantly interacted to affect mean height (p=0.0369). The Time variable represented the three times data was collected: "Initial" was at planting, "First Growing Season" was after the first growing season and "Second Growing Season" was after the second growing season. The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). Significant differences were detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-14.

Like in the height analysis, the analysis of Ground Line Diameter (GLD) contained multiple three-way interactions. The first is the interaction among the variables: Location, Herbicide and Genotype. At Louisiana Tech, the smallest Herbicide and Genotype combinations came from the Control (AGHS3: 32.31 +/- 4.75 mm) and Late (AGHS8: 33.13 +/- 4.86 mm) Herbicide treatment groups, while at Hill Farm the smallest combination of Genotype and Herbicide came from the Early Herbicide treatment group (AGHS8: 12.72 +/- 2.77 mm). The largest trees found at the Hill Farm site (Rec/AGHS3: 26.97 +/- 1.76 mm) were comparable in GLD with the smallest trees found at the Louisiana Tech study site (Control/AGHS3: 32.31 +/- 4.75 mm) (Figure 3-12).

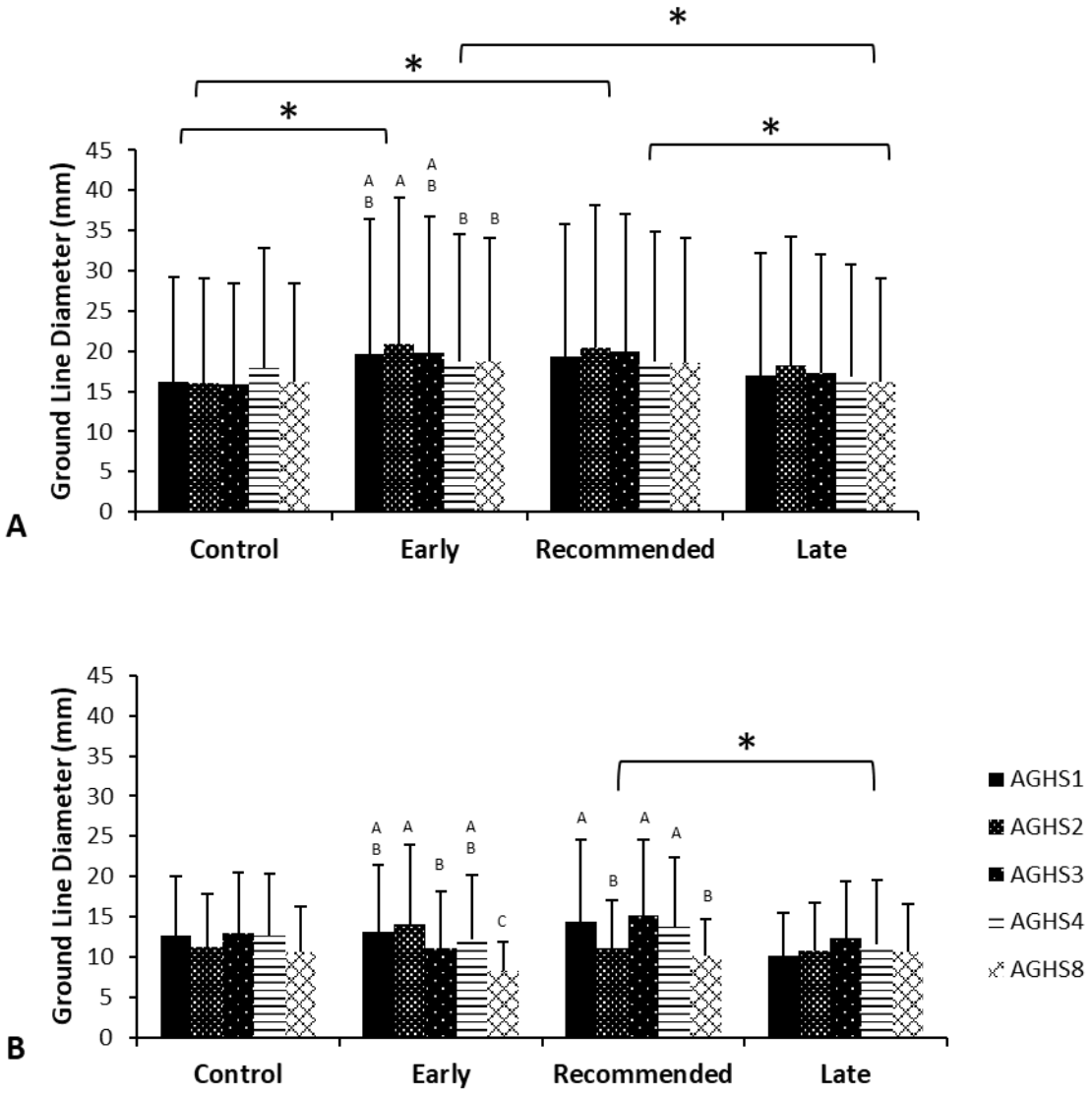

Figure 3-12: The Location, Herbicide and Genotype variables significantly interacted to affect mean ground line diameter in the Herbicide Study. The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-15.

The second three-way interaction within the GLD analysis was between the variables of Time, Herbicide and Genotype; trends found in this interaction closely resemble the trends displayed within the first three-way interaction of Location, Herbicide and Genotype. During the initial measurement time, no significant differences were observed, and after the first growing season the only significant differences were between AGHS2 within the Control Herbicide treatment (9.387 +/- 1.06 mm) and both AGHS2 within the Early Herbicide treatment (12.64 +/- 2.02 mm) and AGHS3 within the Recommended Herbicide treatment (12.3 +/- 1.86 mm), with the Control Herbicide AGSH2 being shorter by 3.9 mm from the average GLD of 12.4 mm for the other two. After the second growing season, three interactions of Herbicide and Genotype grew larger than the other interactions. Within the Recommended Herbicide treatment, AGHS1 (35.81 +/- 8.72 mm) and AGHS3 (36.67 +/- 9.51 mm) were the tallest two families but were not significantly separated from other smaller combinations. These aforementioned interactions were the only test combinations not significantly smaller than AGHS2 within the Early Herbicide treatment (37.7 +/- 11.14 mm). The combination of the Early Herbicide treatment and the AGHS2 variety had the highest GLD of any Genotype by Herbicide combination (Figure 3-13).

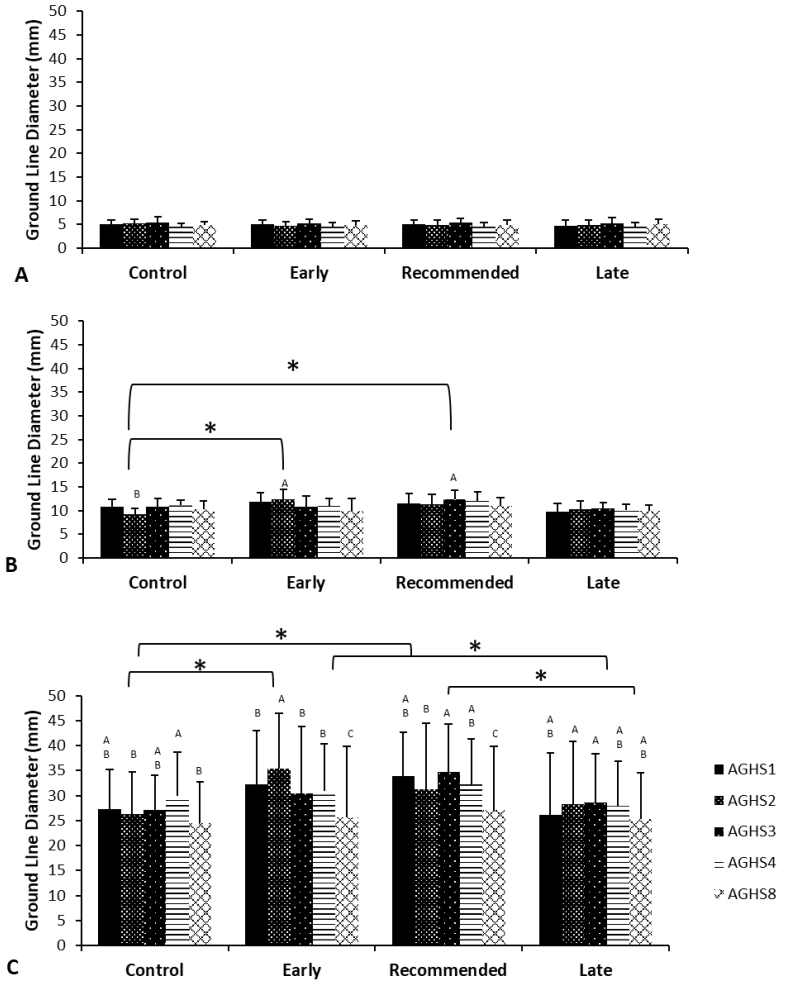

Figure 3-13: The Time, Herbicide and Genotype variables significantly interacted to affect mean ground line diameter in the Herbicide Study. The Time variable represented the three times data was collected: (A) the initial measurements at planting, (B) measurements taken after the first growing season after planting, (C) measurements taken after the second growing season after planting. The Herbicide variable had four possible treatments: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences were detected using Least Significant Difference mean separation test (α=0.05), the only significant separations presented on graph B are directly pointed to by bracket, with lettered significance rankings above the individual bars, on graph C significant differences are denoted within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in the Appendix B-16.

The final significant three-way interaction affecting GLD was among the variables Time, Location, and Herbicide. At the Initial Time measurement, no significant differences were detected, but after the first growing season, the Control Herbicide treatment at Louisiana Tech (10.39 +/- 1.48mm) was significantly smaller in diameter than all but the Late Herbicide treatment at that site (10.67 +/- 1.1 mm). No significant differences were detected at the Hill Farm site at that time. After the second growing season, the Louisiana Tech site continued to have more variation than the Hill Farm site (31.2 +/- 9.65 mm), with the Early (41.56 +/- 4.23 mm) and Recommended (41.39 +/- 4.4 mm) herbicide treatments having larger GLD than either of the other two treatments, with the Late (36.16 +/- 5.59 mm) herbicide treatment also being significantly larger than the Control (33.71 +/- 4.71 mm) herbicide treatment at Louisiana Tech (Figure 3-14). This Control Herbicide treatment at Louisiana Tech was more than 10 mm wider at the ground line than any herbicide treatment at the Hill Farm study site.

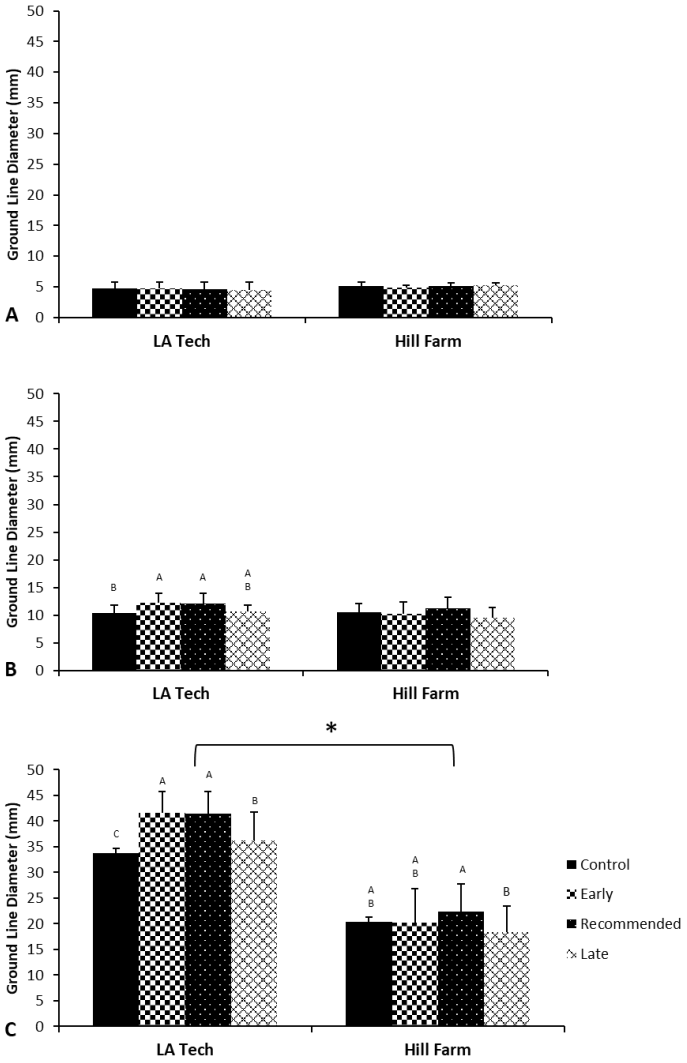

Figure 3-14: The Time, Location and Herbicide variables significantly interacted to affect mean ground line diameter in the Herbicide Study (p=0.0045). The Time variable represented the three times data was collected: (A) the initial measurements at planting, (B) measurements taken after the first growing season after planting, (C) measurements taken after the second growing season after planting. The Location variable consisted of the two study sites included in the study: Louisiana Tech and Hill Farm. The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix B-17.

Survival was significantly affected by a three-way interaction of Location, Herbicide, and Genotype significantly affected percent survival of the sweetgum ($p=0.005$). At the Louisiana Tech study site, no significant differences were found; only two combinations of Herbicide and Genotype (AGHS3, Early: 0.124 +/- 0.065 mortality; AGHS3, Recommended: 0.084 +/- 0.11 mortality) had less than 95% survival during the first two years after planting. The Hill Farm study site also had exceptional survival, with more than half of the Herbicide and Genotype combinations having better than 95% survival and all combinations having over 80% survival in the first two growing seasons after planting (Figure 3-15).

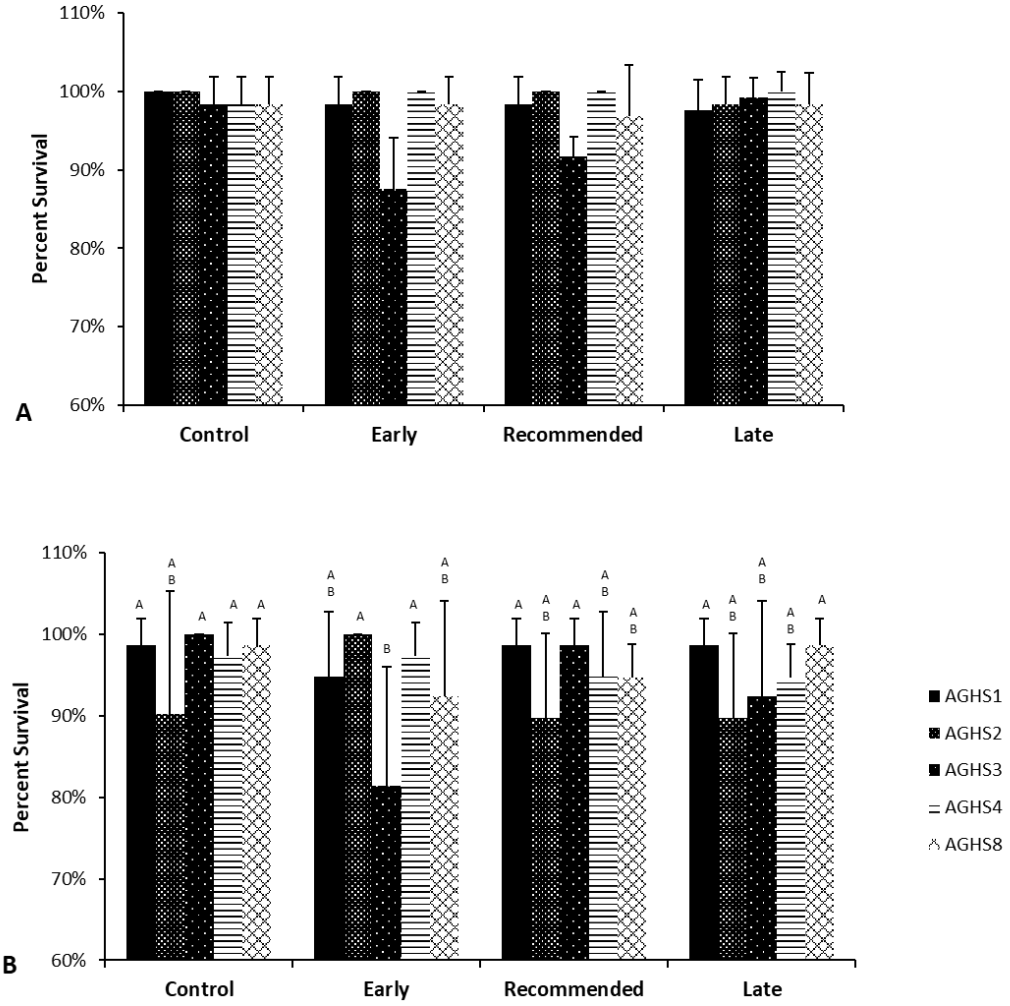

Figure 3-15: The Location, Herbicide and Genotype variables significantly interacted to affect mean percent survival in the Herbicide Study (p=0.005). The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings. Error bars represent one standard deviation. A full list of significant separations can be found in the Appendix B-18.

3.3.2 Competing Vegetation

A significant three-way interaction among Time, Location, and Herbicide was found in analysis of percent groundcover ($p=0.002$). During the middle of the summer of 2016 (First Growing Season), percent ground cover was observed at both sites, during this time the Hill Farm study site was 100% covered in various grasses across all herbicide treatments (Figure 3-16). During the same time interval, the Louisiana Tech study site only had 100% ground coverage in the control plots where herbicide was not applied; all of the treatment plots had less than 70% ground cover from volunteer plant species. Coverage at Louisiana Tech differed among herbicide timing treatments as control > recommended > late > early. Later in the summer (July), the survey was retaken and the Louisiana Tech study site had become 100% covered in weedy vegetation, while the Hill Farm study site experienced a modest reduction in interspecies competition at the same time, as determined by the average percent ground cover present on each site.

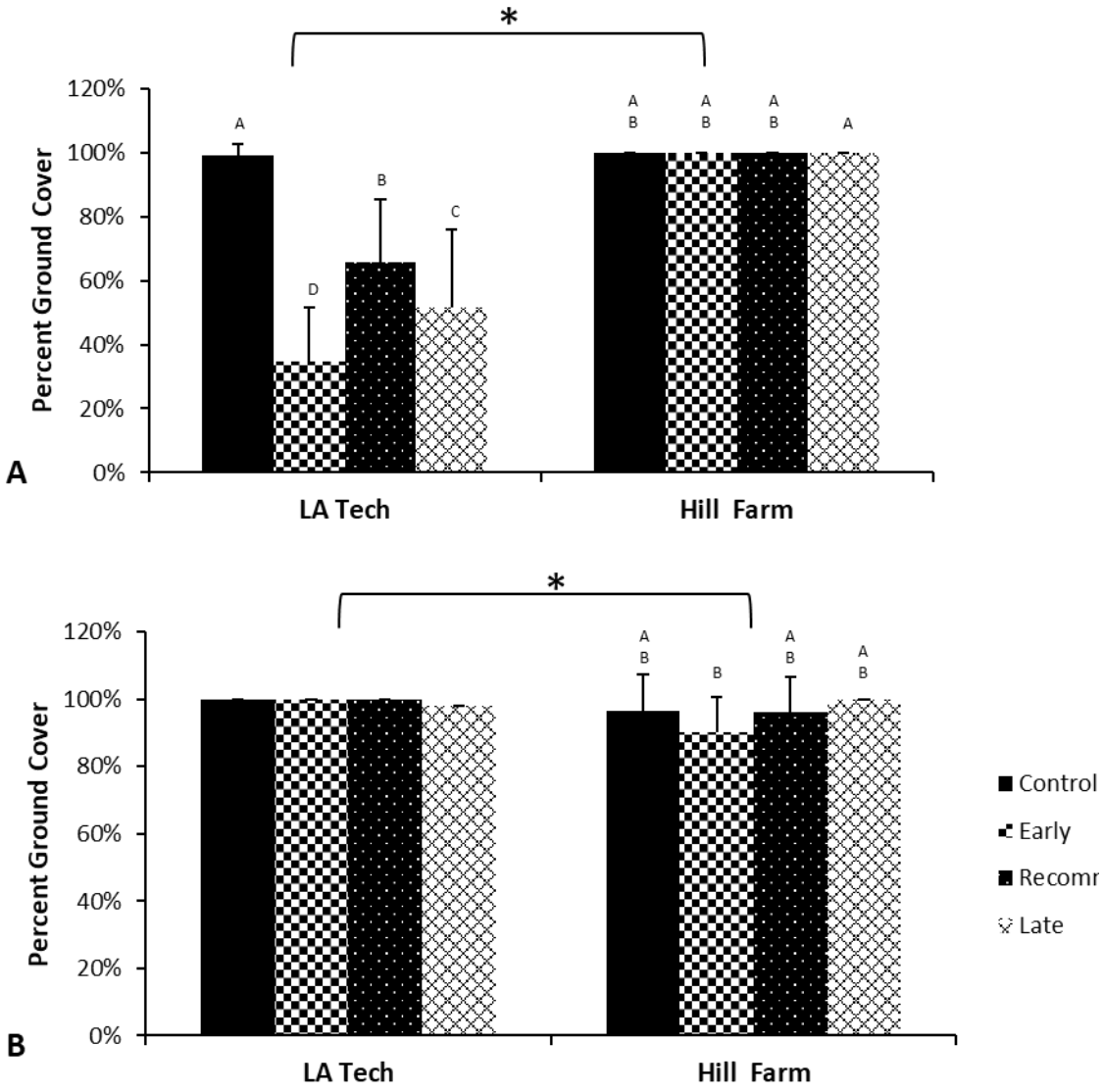

Figure 3-16: The Sample, Location and Herbicide variables significantly interacted to affect mean percent ground cover in the Herbicide Study (p=<0.0001). The Sample variable consisted of two sample times: (A) early summer (May), and (B) late summer (July). The Location variable consisted of the two study sites included in the study: Louisiana Tech and Hill Farm. The Herbicide variable had four possible treatments: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). Significant differences were detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in the Appendix B-19.

While Ground Cover was being surveyed, the tallest stem within the survey area was found and measured. At Louisiana Tech the weeds averaged almost 30 cm taller than the weeds at Hill Farm, this difference is most likely due to the different species present at either site (Figure 3-17).

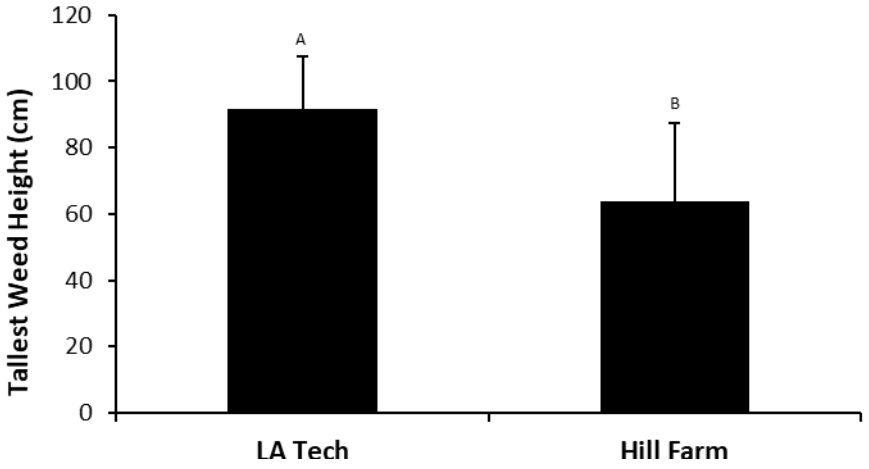

Figure 3-17: Location was a significant source of variation for mean tallest weed height (p=<0.0001). Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph by lettered significance rankings. Error bars represent one standard deviation.

Herbicide treatment had a significant effect on weed height as the Early Herbicide treatment had the average shortest weed height (69.71 +/- 22.04 cm) and the no-herbicide Control treatment had the tallest average weed height (92.33 +/- 23.15 cm). The herbicide with the lowest weed height was the early herbicide treatment, followed by the recommended and late herbicide treatments (78.96 +/- 22.33 cm and 83.68 +/- 20.55cm, respectively). The tallest weeds were produced by the control herbicide treatment; this was not significantly separated from the late herbicide treatment (Figure 3-18).

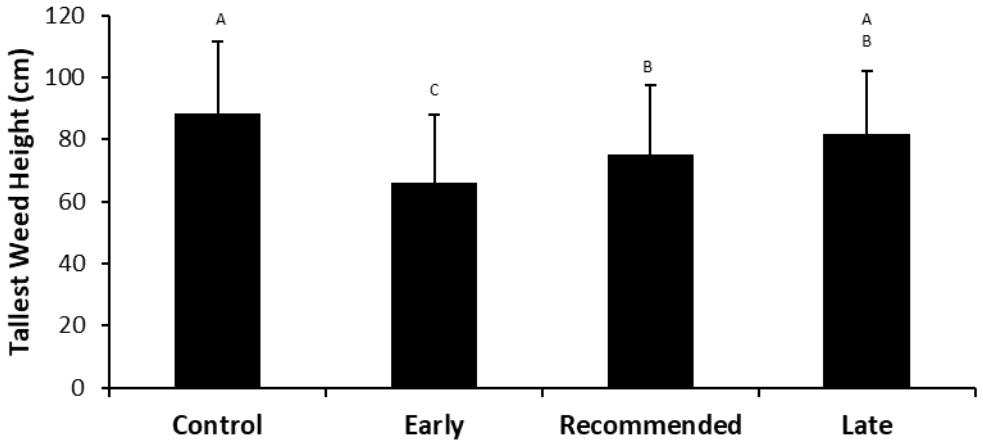

Figure 3-18: Herbicide was a significant source of variation that affected the mean tallest weed height ($p=<0.0001$). The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). Significant differences were detected using Least Significant Difference mean separation test ($\alpha=0.05$) and are denoted on the graph by lettered significance rankings. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix A-20.

When average weed height was analyzed a three-way interaction between Location, Herbicide, and Genotype was found ($p\leq0.01$). At Louisiana Tech the tallest average weed height was 103.33 +/- 9.45 cm (Control, AGHS2); this was similar to the shortest average weed height from Hill Farm (94.11 +/- 22.35 cm; Early, AGHS2). The only significant differences among herbicide and genotype combinations at Louisiana Tech were between AGHS8 under the Early herbicide regime (26.13 +/- 2.01 cm) and both AGHS8 and AGHS2 under the Control herbicide regime (47.07 +/- 7.91 cm and 103.33 +/- 9.45 cm respectively). At the Hill Farm study site, the herbicide treatment that produced the tallest average weeds in our study was the late herbicide treatment (143.49 +/- 20.12 cm) followed by the control treatment (137.11 +/- 24.46 cm). The genotypes within each herbicide treatment produced quite variable heights, most notably within the

early herbicide treatment AGHS8 had an average weed height of 154.94 +/- 26.16 cm while AGHS2 had an average weed height of 94.11 +/- 22.35 cm; this was the largest separation of any two genotypes within the same herbicide treatment group (Figure 3-19).

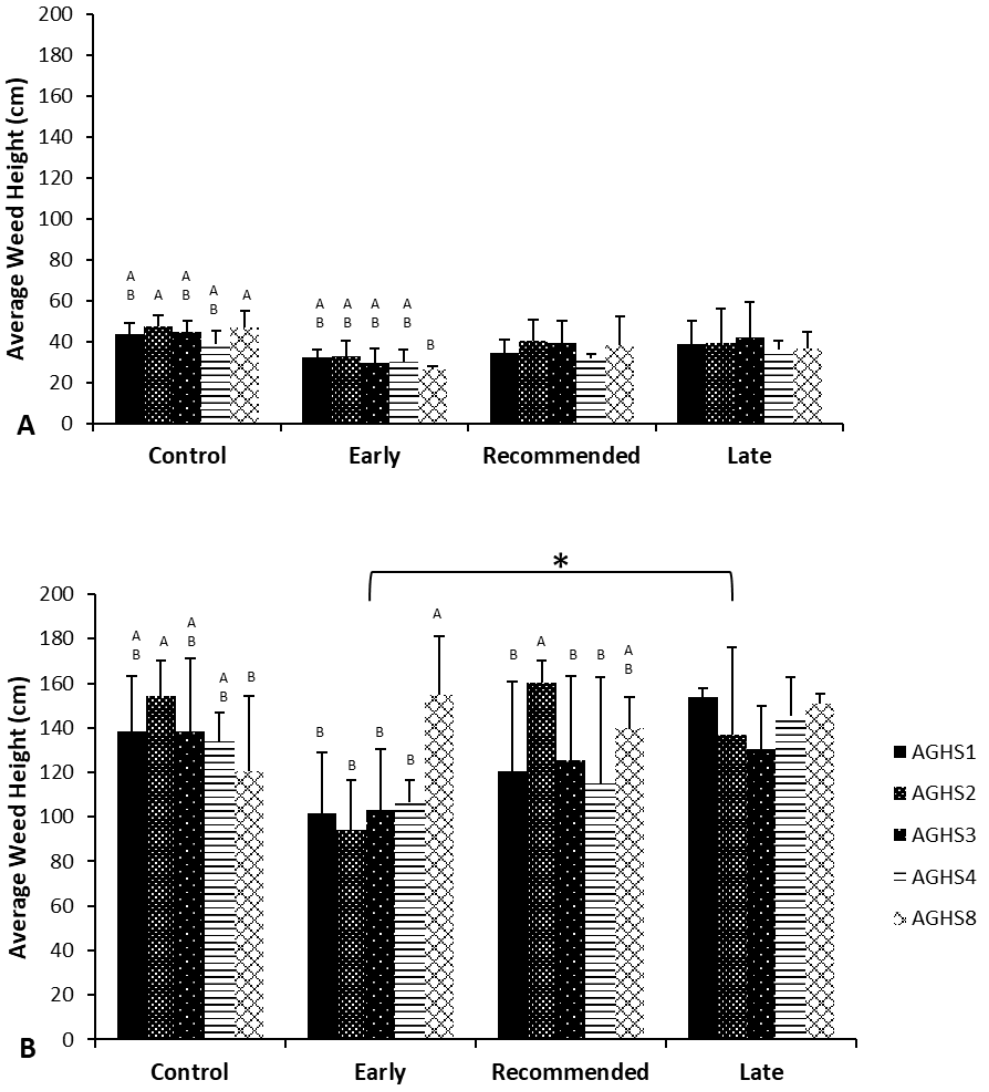

Figure 3-19: The Location, Herbicide and Genotype variables significantly interacted to affect the mean of average weed height, as defined by the tallest point at which a solid layer of vegetation was present in the Herbicide Study. The Location variable consisted of the two study sites included in the study: Louisiana Tech (A) and Hill Farm (B). The Herbicide variable had four possible treatments: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break). The Genotype variable consisted of the five hybrid clones being tested. Significant differences detected using Least Significant Difference mean separation test (α=0.05) and are denoted on the graph within groups by lettered significance rankings, and among groups using brackets and asterisks. Error bars represent one standard deviation. A full list of significant separations can be found in Appendix A-24.

During the first growing season, a side-study was conducted after morning glory overtopped a significant portion of the study; this study was conducted to determine possible causes of the morning glory invasion, as well as to determine if any negative side effects accompanied the invasion. The side study determined that the early herbicide treatment contained the most instances of morning glory climbing seedlings (8% of the study seedlings) followed by both other herbicide treatments (Mid, and Late) with 6% of the study seedlings being affected by morning glory. None of the three herbicide treatments were significantly separated from each other, but the control treatment which received no herbicide was significantly different ($p=0.03$) and had fewer than 1% of the study seedlings within this group being bound by morning glory (Figure 3-20).

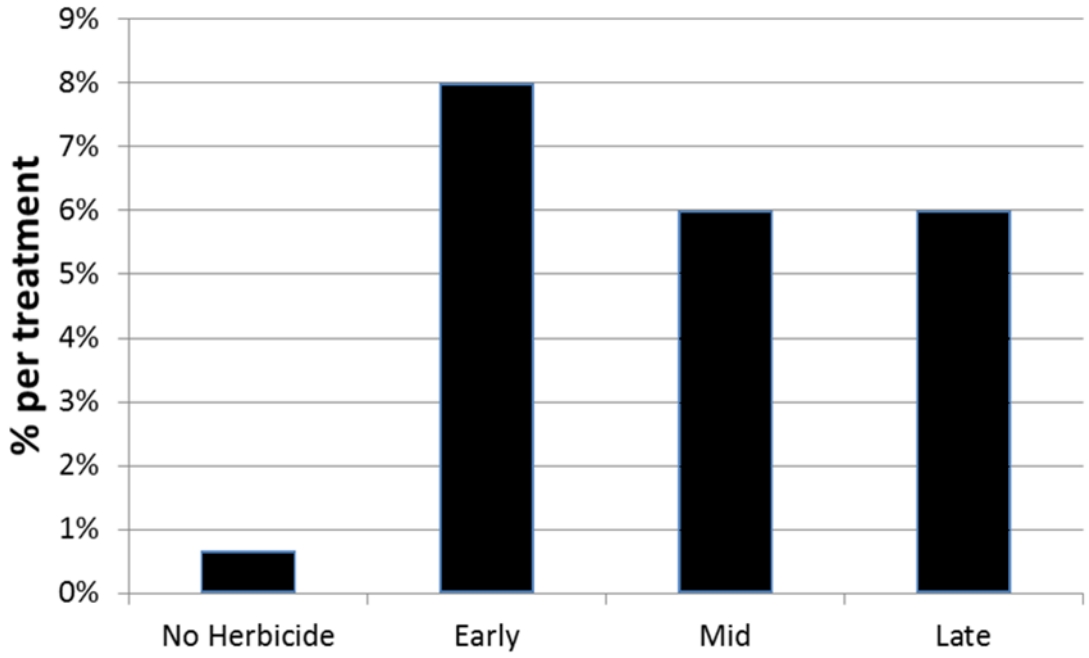

Figure 3-20: Percent of seedlings affected by morning glory within each Herbicide treatment. The Herbicide variable had four possible treatment: Control (no herbicide), Early (dormant herbicide application), Recommended (herbicide application at the beginning of bud swell), and Late (herbicide application after bud break).

In total, when all herbicide treatments were combined to obtain the overall average percentage of morning glory interaction with seedlings between groups that received herbicide or not was significant ($p<0.01$). Seedlings that received herbicide were approximately 10 times more likely to become tangled with morning glory than those seedlings that did not receive any herbicide treatment (Figure 3-21).

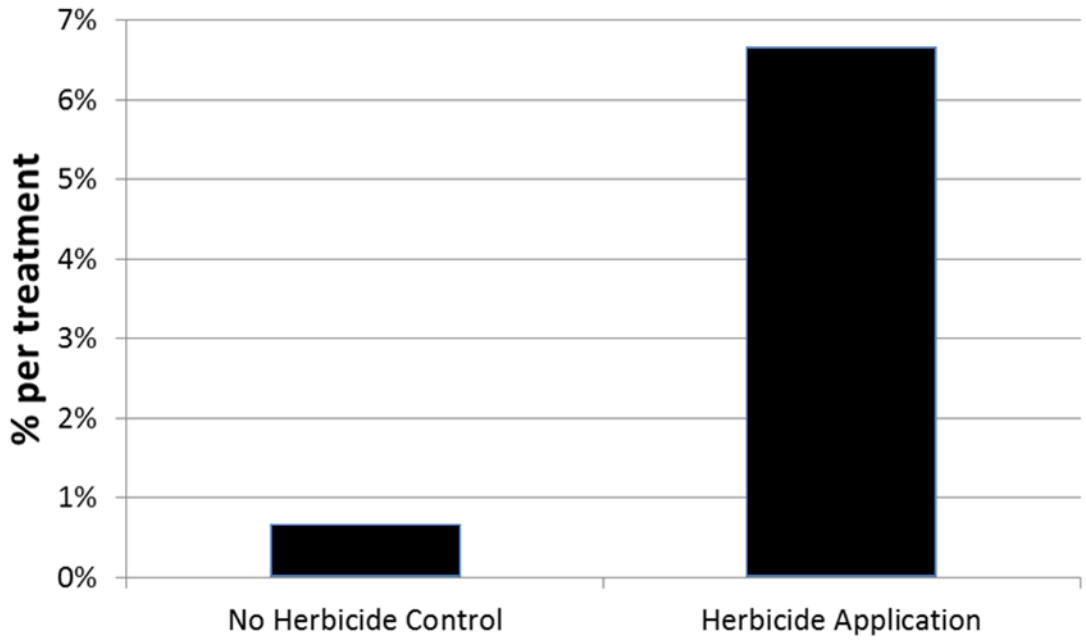

Figure 3-21: Percent of seedlings affected by morning glory, all herbicide treatments were averaged together to form the combined "Herbicide Application".

CHAPTER 4

DISCUSSION

4.1 Genotype Trial

All sweetgums planted in this study had over 90% survival and fast growth rates relative to the other studies. Indeed, all of the genotypes tested in this study were larger than the seedlings in a study by Davis and Trettin (2006), which compared growth rates of sweetgum and sycamore (*Plantanus occidentalis* L.) on an abandoned agricultural field in South Carolina. Their site closely resembles the Louisiana Tech study site. The trees at Louisiana Tech grew taller and larger at the ground line diameter than a the Hill Farm study site, where more aggressive herbaceous competition and less fertile soil (primarily differing between the sited due to the Tech site having an agricultural history and the Hill Farm site having a non-fertilized loblolly pine plantation history prior to study establishment) could have limited their growth. In the Davis and Trettin (2006) study after two growing seasons, sweetgum seedlings (presumably native families) had grown to a height of 1.1m. this is compared to the current study where the shortest genotype across both study sites was the native family AGH2, which grew to a height of 1.7m tall after two growing seasons. The hybrid varieties tested in this study out-performed the native families at both testing locations, leading us to the conclusion that

the hybrid varieties that were tested are capable of out-performing the native families across a broad land base in the southeastern United States.

Our study did not find a link between physiological and soil factors (i.e., photosynthetic rate, soil moisture, and leaf water potential) and growth rates. Lockaby (1997) found that irrigation and fertilization could increase diameter growth of sweetgum, but the diameter was not significantly increased with irrigation alone, without fertilization, under normal climatic conditions. This supports our findings that sweetgum (including hybrids) did not have their growth limited by the availability of water in the soil under normal climatic conditions. Lockaby (1997) also found that fertilization and soil moisture availability could affect pre-dawn moisture potential of sweetgum. However, the present study did not detect a close link of soil moisture and pre-dawn water potential, though the initial sampling period was null due to human error. Fang (1996) found that as long as the leaves of the seedlings did not wilt, growth was not retarded. This supports the decoupling of the present studies' results in which growth traits did not necessarily correspond to observed differences among genotypes in water stress or soil moisture. Fang (1996) found that sweetgum has many natural defenses to aid in the retention of water to prevent desiccation from drought, including: osmotic adjustment, mid-day stomatal closure, vertical leaf presentation, reducing leaf area, and lowering transpiration rates. The trees that were the most efficient at obtaining water from the soil had a higher leaf water potential, presumably because the trees did not engage these defense mechanisms. Perhaps the rainfall amounts experienced during the study were sufficient to prevent enough drought in the sweetgum stands to detect a corresponding slowdown of growth. The monthly averages of rainfall during the second

growing season (2017) may be misleading about how much water was available to the plants during this time. Almost double the 30-year average rainfall was recorded in May and June of that year, and nearly triple the 30-year average rainfall was recorded in the month of August 2017. However, in August there were also recordings of near 0% soil moisture in the top 10 cm of the soil. Upon closer inspection, this low soil moisture measurement could be possible with above average rainfall, almost all of the rainfall in North Central Louisiana during the month of August that hear happened on the days of 8/5 and 8/28, whereas sampling was conducted on 8/15. On both rainfall dates, severe storms passed through the region accompanied by many flash flood warnings. Ziadat and Taimeh (2013) found that even small increases in rainfall intensity can significantly increase runoff and erosion of cultivated and rangeland soils in the country of Jordan. When runoff or erosion rates are increased, less water remains in the soil left around the plants, reducing the benefit of the rainfall event on soil moisture. Therefore, with the intense heat experienced during Louisiana Summers and the water demands of the plants it is not surprising to find low soil moisture in the top 10 cm of soil within the same month as two severe rainfall events. With a decrease of soil moisture, photosynthetic rates tend to decrease. An extended period of reduced photosynthetic rate was observed by Fang (1996) following a drought even in sweetgum. The smaller Hill Farm trees averaged a higher photosynthetic rate per leaf while water was available, but no significant difference could be detected between the study sites after became limited in August. An important distinction between photosynthetic rate of an individual leaf and photosynthetic capacity of an entire tree was found by Hollinger (1992) when comparing two species of oaks in northern California. Hollinger (1992) found that *Quercus lobata*

had a higher annual photosynthate production, when factoring the cost of foliage production, compared to *Quercus agrifolia*, even though *Q. agrifolia* had a higher Leaf Area Index (LAI) than *Q. lobata*. Whole tree photosynthate production was not tested in our study, but this highlights the possibility that leaf-level leaf level samples from Hill being significantly higher in photosynthetic rates than leaf-level LA Tech samples does not mean that whole-tree levels at Hill Farm are guaranteed to be higher because of the tree size differences.

4.2 Herbicide Trial

This study demonstrated the superior growth rate of hybrid sweetgum over native sweetgum genetic material at two different study sites. The relative ranking among genotypes were the same at both study sites, leading to the conclusion that there is a low genotype-specific interaction with the environment concerning the growth rate of the genotypes tested. None of the physiological or soil parameters tested in this study showed a clear relationship with measured growth dimensions, but in the future an effort should be made to test crown-level physiological parameters to better qualify the capabilities and limitations of these genotypes.

The timing of herbicide treatment proved to be a leading factor on the productivity of hybrid sweetgum varieties in the first two growing seasons, as found in prior studies conducted with native sweetgum families. The appropriate use of herbicide, fertilizer, and irrigation significantly increased sweetgum height growth by almost double over no silvicultural control treatments (9.5m to 5.0m respectively) after 6 growing seasons (Williams and Gresham 2006). Survivability of hybrid sweetgum varieties was a concern leading up to this study. Past studies have shown native sweetgum to be resilient

to herbicide application, but the same has not been proven for the hybrid varieties tested in this study. Williams and Krajicek (1976) tested sweetgum and other species against three herbicides (dichlobenil, atrazine-simazine, and amitrole-simazine) at various application rates (and timings) and found that sweetgum and Black Walnut (*Juglans nigra*) were the only two species tested that showed minimal negative side effects from the herbicide applications. Some of the negative side effects of the herbicide treatments among the other genotypes tested were an increased mortality rate, and a sharp reduction in growth. The present study also showed no observable mortality differences among herbicide treatments including the late treatment that was applied beyond the labeled timing period. Williams and Krajicek (1976) did however find height differences among the seedlings of the various herbicide treatments similar to our own study, which could point to various hardwood species having varied response to herbicide timing. The same theory could be applied to the varied reactions of each genotype within this herbicide application timing study to explain why the different clonal varieties exceled under various herbicide application timings. Each clonal variety paired with the herbicide timing that individual variety grows best within could extend the efficacy of an herbicide application by creating a larger shade zone under the tree making a less favorable environment for weeds to compete against the crop trees. Further complicating the relationship of genotype and herbicide timing is the variations of the species composition found depending upon the timing of herbicide application. It is unclear what produced the variability of average weed height at Hill Farm, but the biggest difference between the Hill Farm and Louisiana Tech study sites was the species composition found at each site. Average weed height was defined as the height at which a complete layer of vegetation

was present within the sample area. At Hill Farm, hay grasses were the primary vegetative competition to the hybrid sweetgum seedlings creating an almost uniform layer of vegetation. During the same time period the Louisiana Tech study site saw many tall single-stemmed weeds develop, with a much shorter underlying layer of grasses that formed the complete cover define by the sampling parameters. Besides herbicide timing, many other factors could have affected the variability of weed species composition seen within the study, such as: soil composition, slope, water availability, previous uses of the stand, and aspect (which direction the slope of a hill faces).

Devine (2006) found that sweetgum had a consistent diameter growth rate when planted on a bottomland site in Tennessee alongside sycamore and green ash (*Fraxinus pennsylvanica*). The steady growth pattern of the sweetgum seedlings planted surpassed the growth rate of either other species in the study significantly after 18 years. At the end of the study the sweetgum trees sampled averaged 144 mm in diameter at breast height and would be assumed to have an even larger average ground line diameter. The average DBH growth per year of their study was 8 mm, while in the two years of this study all tested genotypes together averaged 20 mm per year of growth. This previous study was conducted with a native sweetgum family and did not consider hybrid varieties in the testing, which have proven superior to the native parent in the current study.

Comparing the survival rating seen in this study to that of other herbicide studies planted on an upland site shows the hybrid sweetgum varieties have exceptional survivability. When Wendel (1980) planted a variety of red oak species on an upland site in West Virginia, planning 2 to 3.3 seedlings were needed for each tree surviving to harvest. Davis and Trettin (2006) reported that most sweetgum mortality in a plantation

setting occurred in the first two growing seasons and was frequently increased by the presence of intense competition from woody vines. In our studies during this crucial period of time in the life of a plantation an average survival of over 90% was observed even with the invasion of woody vines (Morning Glory) into the study.

An extreme example of ground cover is the cover crop, when a grass species is seeded into a site along with sweetgum. Malik (2001) found that cover crops could significantly reduce sweetgum biomass production by as much as 41%, depending on the species of grass selected as the cover crop. This significant reduction in growth is the reason vegetative control is so important during the establishment phase of a sweetgum plantation to allow seedlings to reach their full growth potential. Broadcast application of herbicides are when the entire field has chemical applied to it, whereas banded applications apply herbicide only to narrow strips across a field. In our study banded herbicide techniques were utilized to reduce the volume of chemical needed; but it meant untreated areas between the rows were left as they were, with an unaltered species composition. These areas were controlled through mowing but could have played a role in the recolonization of the treated areas as the herbicide lost its potency in the soil. Johnson and others (1995) observed that 70% of the area between banded rows remained free of grass weeds, and 94% of the sprayed area remained clear for the duration of one growing season when a pre-emergent herbicide was applied. These results are significantly better than the weed control we saw in our study using a pre-emergent banded herbicide application, this is because the entire field was void of weeds prior to the herbicide application, and subsequent planting of crops in the field. In our study the

weeds were left alive between the rows to which herbicide was applied, increasing the speed to which these areas could be re-colonized by undesired vegetation.

Several advantages of hybrid sweetgum were displayed in this study, high survival rate, predictable growth rate across a variety of locations, and confidence in a well-proven application timing of herbicide. Across all herbicide application timings and all hybrid varieties over 90% of the hybrid individuals tested survived to the end of the second growing season. As discussed on the Oust XP label, this study displayed the need to apply herbicide as early as possible in the growing season. The seedlings in the late herbicide group, although not substantially damaged by the late application, were not significantly larger than the non-treated control group. No evidence was found in this study to alter the label of Oust XP for hybrid sweetgum varieties to be different that the recommendation for native sweetgum families. The consistency in responses of genotypes at both study sites suggest that herbicide protocols should be consistent across both site types. At both sites, non-crop vegetation coverage was comparable to that of the control by late summer. This finding highlights that measures beyond a single application of sulfometuron methyl would be necessary for sustained vegetation suppression in hybrid sweetgum plantations.

APPENDIX A MEASUREMENTS AND AVERAGES

Table A-1: Means Table of Genotype Study including the variables of Height, GLD, and Percent Mortality at each measurement time averaged by Location and Genotype, and the Location average for each variable.

		Average Height (cm)			Average Ground Line Diameter (mm)			Average Mortality (%)		
Location	**Genotype**	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2
LA Tech	AGHS1	49.83	92.17	240.97	4.63	12.16	46.94	0.00	0.00	0.00
	AGHS2	45.59	99.16	267.78	4.62	13.43	50.92	0.00	0.00	0.00
	AGHS3	50.17	90.17	223.03	4.74	12.38	47.66	0.00	8.33	5.56
	AGHS4	54.61	97.43	236.33	4.73	13.14	48.05	0.00	0.00	0.00
	AGH2	45.01	72.04	173.11	4.72	10.65	36.95	0.00	16.67	22.22
	AGH25	42.26	68.87	178.97	4.93	10.81	41.76	0.00	8.33	8.33
Location Average		47.91	86.64	220.03	4.73	12.09	45.38	0.00	6.00	6.00
Hill Farm	AGHS1	55.37	100.65	223.06	5.69	15.66	42.52	2.78	8.33	8.33
	AGHS2	47.30	93.84	221.97	5.00	15.34	39.01	2.78	5.56	8.33
	AGHS3	54.48	87.68	197.19	5.30	14.37	35.66	0.00	8.33	11.11
	AGHS4	54.21	91.21	204.24	5.49	13.67	38.65	8.33	5.56	5.56
	AGH2	44.11	73.06	161.85	5.47	13.07	34.30	2.78	16.67	25.00
	AGH25	41.78	70.42	159.12	5.18	13.42	33.45	0.00	13.89	11.11
Location Average		48.38	83.24	188.87	5.24	13.97	35.60	3.00	10.00	12.00

Table A-2: Means Table of Genotype Study including each variable tested at three time points in the second growing season including photosynthesis rate, water potential, and soil moisture averaged by Location and Genotype, and the Location average for each variable.

		Photosynthesis Rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)			Water Potential (BARs)			Soil Moisture (%)		
Location	**Genotype**	May	July	August	May	July	August	May	July	August
LA Tech	AGHS1	12.12	11.60	9.15	10.00	2.50	4.88	9.15	4.85	0.83
	AGHS2	9.52	10.81	8.97	9.52	10.81	8.97	8.83	6.03	0.55
	AGHS3	10.97	7.89	6.78	12.50	3.75	5.25	12.75	6.38	0.00
	AGHS4	12.43	8.88	8.36	7.50	2.50	4.00	14.25	7.80	1.20
	AGH2	11.87	10.00	5.74	17.50	2.75	4.75	12.33	5.08	0.93
	AGH25	8.07	10.37	10.08	11.25	2.25	4.50	10.25	5.20	0.00
Location Average		10.83	9.93	8.18	11.38	4.09	5.39	11.00	6.00	1.00
Hill Farm	AGHS1	15.66	11.74	9.66	17.50	1.75	4.38	6.80	8.68	0.00
	AGHS2	14.73	10.62	6.79	9.75	3.50	5.88	5.98	7.18	0.00
	AGHS3	13.75	6.35	7.17	8.25	2.75	6.75	5.98	6.68	0.00
	AGHS4	14.56	6.87	6.60	12.25	1.50	3.50	5.53	6.58	0.38
	AGH2	14.94	10.54	8.34	14.00	2.00	4.25	4.48	5.88	0.00
	AGH25	14.47	10.35	10.51	7.50	1.25	3.25	5.08	6.65	0.00
Location Average		14.49	8.95	7.88	10.35	2.20	4.73	5.41	6.59	0.08

Table A-3: Means Table of Herbicide Study including variables of Height, GLD, and Survival averaged by each Genotype and Herbicide combination at the LA Tech site.

		Average Height (cm)			Average Ground Line Diameter (mm)			Average Survival (%)		
Herbicide Timing	Genotype	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2
Control	AGHS 1	46.76	85.36	190.67	4.91	10.29	33.21	100	100	100
	AGHS 2	51.08	89.36	198.90	4.88	9.63	33.35	100	100	100
	AGHS 3	55.27	86.24	195.47	4.92	10.36	32.31	100	100	100
	AGHS 4	49.77	101.02	210.65	4.58	11.18	37.72	100	100	100
	AGHS 8	47.04	85.22	177.06	4.77	10.48	31.97	100	100	100
Herbicide Average		49.98	89.44	194.55	4.81	10.39	33.71	100	99.98	99.98
Early	AGHS1	88.56	88.56	218.39	5.07	11.94	42.02	100	100	100
	AGHS 2	99.89	99.89	250.17	4.61	13.27	44.78	100	100	100
	AGHS 3	83.25	83.25	213.72	4.88	12.20	42.16	100	99	99
	AGHS 4	89.33	89.33	208.90	4.48	11.69	39.80	100	100	100
	AGHS 8	78.19	78.19	197.29	4.99	11.93	39.05	100	100	100
Herbicide Average		87.84	87.84	217.69	4.81	12.21	41.56	99.99	99.79	99.76
Recommended	AGHS 1	44.17	96.18	204.55	4.93	11.57	41.32	100	98	98
	AGHS 2	47.72	102.86	252.97	4.42	13.02	44.01	100	100	100
	AGHS 3	60.37	85.40	204.80	5.12	12.05	42.49	100	100	100
	AGHS 4	47.79	89.17	206.57	4.40	11.79	40.00	100	100	100
	AGHS 8	47.09	88.38	201.40	4.48	12.11	39.12	100	100	100
Herbicide Average		49.43	92.40	214.06	4.67	12.11	41.39	100	99.68	99.68
Late	AGHS 1	43.70	79.71	206.89	4.13	10.10	36.70	100	97	96
	AGHS 2	45.58	88.19	228.18	4.52	11.20	39.01	100	100	100
	AGHS 3	55.26	78.47	196.75	4.82	10.49	36.60	100	100	100
	AGHS 4	44.81	88.87	189.07	4.20	10.94	35.35	100	100	100
	AGHS 8	47.99	76.40	176.31	4.89	10.63	33.13	100	99	99
Herbicide Average		47.47	82.33	199.44	4.51	10.67	36.16	99.97	99.22	99.05
Overall Location Average		58.68	88.00	206.43	4.70	11.34	38.20	99.99	99.67	99.62

Table A-4: Means Table of Herbicide Study including variables of Height, GLD, and Survial averaged by each Genotype and Herbicide combination at the Homer site.

		Average Height (cm)			Average Ground Line Diameter (mm)			Average Survival (%)		
Herbicide Timing	Genotype	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2	Year 0	Year 1	Year 2
Control	AGHS 1	41.89	101.02	163.29	5.23	11.33	21.37	100	99	99
	AGHS 2	48.84	90.15	157.54	5.49	8.99	19.26	100	100	100
	AGHS 3	57.44	90.38	157.13	5.88	11.26	21.92	10	100	100
	AGHS 4	46.56	95.43	157.25	4.63	11.11	21.97	100	100	100
	AGHS 8	42.00	83.30	144.45	4.80	10.15	17.05	100	100	100
Herbicide Average		47.35	92.06	155.93	5.21	10.57	20.31	100	100	100
Early	AGHS1	42.61	81.03	170.17	5.00	11.81	22.40	100	100	100
	AGHS 2	49.22	88.63	182.33	4.72	11.58	25.91	100	100	100
	AGHS 3	61.44	60.66	115.23	5.46	9.30	18.59	100	99	99
	AGHS 4	47.13	84.08	152.53	4.51	10.19	22.00	100	100	100
	AGHS 8	46.28	66.09	108.18	4.72	8.02	12.22	100	100	100
Herbicide Average		49.34	76.10	145.69	4.88	10.18	20.22	99.93	99.68	99.65
Recommended	AGHS 1	43.56	97.82	201.49	5.08	11.57	26.61	100	100	100
	AGHS 2	48.77	102.39	159.17	5.23	9.73	18.46	100	100	100
	AGHS 3	57.28	102.42	158.53	5.70	12.72	26.97	100	100	100
	AGHS 4	47.44	109.10	178.16	4.81	12.24	24.37	100	100	100
	AGHS 8	43.39	81.21	126.49	5.13	9.92	15.20	100	100	100
Herbicide Average		48.09	98.59	164.77	5.19	11.24	22.32	100	99.98	99.96
Late	AGHS 1	44.11	78.28	122.02	5.14	9.45	15.62	100	99	99
	AGHS 2	50.44	85.91	145.16	5.10	9.35	17.59	100	100	100
	AGHS 3	59.50	80.99	141.93	5.79	10.33	20.74	100	99	99
	AGHS 4	49.68	87.63	155.22	4.97	9.26	20.50	100	100	100
	AGHS 8	43.17	74.72	132.14	5.08	9.25	17.47	100	100	100
Herbicide Average		49.38	81.51	139.30	5.22	9.53	18.38	99.93	99.62	99.59
Overall Location Average		48.54	87.06	151.42	5.12	10.38	20.31	99.97	99.79	99.75

Table A-5: Ground cover height and percent in the Herbicide Study at LA Tech in mid- and late-summer in the first growing season for each Herbicide and Genotype combiniation.

Herbicide Treatment	Genotype	Ground Cover Height		Percent Ground Cover	
		Tallest Stem	Average Stem	Mid-Summer	Late Summer
Control	AGHS 1	97.10	47.30	100	100
	AGHS 2	101.00	44.40	96	100
	AGHS 3	103.00	41.40	100	100
	AGHS 4	106.10	39.50	100	100
	AGHS 8	115.00	49.50	100	100
Herbicide Average		104.44	44.42	99.20	100
Early	AGHS 1	83.50	28.70	44	100
	AGHS 2	86.60	33.90	26	100
	AGHS 3	70.30	26.30	34	100
	AGHS 4	89.50	29.20	40	100
	AGHS 8	70.30	26.30	34	100
Herbicide Average		80.04	28.88	35.20	100
Recommended	AGHS 1	96.30	37.80	47	100
	AGHS 2	91.10	42.00	65	100
	AGHS 3	83.50	33.30	72	100
	AGHS 4	77.10	42.00	74	100
	AGHS 8	97.40	39.90	66	100
Herbicide Average		89.08	39.00	64.50	100
Late	AGHS 1	105.70	43.90	62	100
	AGHS 2	86.20	38.20	51	100
	AGHS 3	81.90	37.90	62	100
	AGHS 4	85.40	35.30	40	100
	AGHS 8	87.10	35.40	46	100
Herbicide Average		89.26	38.14	52.00	100
Location Average		90.71	37.61	62.73	100

Table A-6: Ground cover height and percent in the Herbicide Study at Hill Farm in mid- and late-summer in the first growing season for each Herbicide and Genotype combination.

Herbicide Treatment	Genotype	Ground Cover Height		Percent Ground Cover	
		Tallest Stem	Average Stem	Mid Summer	Late Summer
Control	AGHS 1	139.00	74.00	100	100
	AGHS 2	157.16	99.33	100	100
	AGHS 3	136.33	51.16	100	100
	AGHS 4	137.83	67.60	100	100
	AGHS 8	124.16	65.50	100	93
Herbicide Average		104.44	138.90	71.52	100
Early	AGHS 1	94.66	43.16	100	97
	AGHS 2	85.50	38.66	100	83
	AGHS 3	106.83	51.66	100	96
	AGHS 4	106.50	53.00	100	92
	AGHS 8	149.50	58.33	100	90
Herbicide Average		80.04	108.60	48.96	100
Recommended	AGHS 1	113.33	50.33	100	100
	AGHS 2	165.50	77.33	100	96
	AGHS 3	129.50	80.66	100	95
	AGHS 4	110.33	40.83	100	89
	AGHS 8	143.16	70.16	100	100
Herbicide Average		89.08	132.36	63.86	100
Late	AGHS 1	129.50	70.50	100	100
	AGHS 2	132.00	81.50	97	100
	AGHS 3	151.66	58.66	97	100
	AGHS 4	134.00	75.33	96	100
	AGHS 8	160.33	71.00	100	100
Herbicide Average		89.26	141.50	71.40	97.85
Location Average		90.71	130.34	63.94	99.46

APPENDIX B MEANS AND STATISTICAL SEPARATIONS

Table B-7: Significant differences in height and GLD found between the two Locations for each growing season within the Genotype study. Means followed by different letters are significantly different at the 0.05 alpha level within each variable and growing season.

	Height (cm)						GLD (mm)					
Location	Year 0		Year 1		Year 2		Year 0		Year 1		Year 2	
LA Tech	47.91	A	86.62	A	219.23	A	4.73	A	12.08	B	45.34	A
Hill Farm	49.54	A	86.16	A	195.10	B	5.36	A	14.27	A	37.45	B

Table B-8: Significant differences in height and GLD found among Genotypes for each growing season within the Genotype Study. Means followed by different letters are significantly different at the 0.05 alpha level within each variable and growing season.

	Height (cm)						GLM (mm)					
Genotype	Year 0		Year 1		Year 2		Year 0		Year 1		Year 2	
AGHS1	52.61	A	96.60	A	232.26	AB	5.16	A	13.99	A	44.88	A
AGHS2	46.47	A	96.06	A	244.45	AB	4.81	A	14.31	A	44.56	A
AGHS3	52.33	A	88.95	AB	211.38	C	5.02	A	13.38	A	42.02	A
AGHS4	54.38	A	94.33	A	219.58	BC	5.11	A	13.41	A	43.31	A
AGH2	44.54	A	72.52	BC	165.88	D	5.10	A	11.76	A	35.72	B
AGH25	42.02	A	69.87	C	169.42	D	5.06	A	12.18	A	37.88	B

Table B-9: Significant differences found among the Genotypes analyzed for leaf water potential in the Genotype study when averaged across the Mid and Late summer measurements. Means followed by different letters are significantly different at the 0.05 alpha level.

Genotype	BARs	
AGSH1	0.34	AB
AGSH2	0.43	B
AGSH3	0.46	B
AGSH4	0.29	AB
AGH2	0.34	AB
AGH25	0.28	A

Table B-10: Significant differences found among the combinations of Location, Time, and Genotype for percent soil moisture within the Genotype Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Location and Time.

	LA Tech						Hill Farm					
Genotype	May		July		August		May		July		August	
AGHS1	9.15	C	4.85	D	0.83	A	6.80	DE	8.68	A	0.00	A
AGHS2	8.83	CD	6.03	BCD	0.55	A	5.98	DE	7.18	AB	0.00	A
AGHS3	12.75	A	6.38	BCD	0.00	A	5.98	DF	6.68	ABCD	0.00	A
AGHS4	14.25	A	7.80	AB	1.20	A	5.53	DF	6.58	ABCD	0.38	A
AGH2	12.33	AB	5.08	CD	0.93	A	4.48	F	5.88	BCD	0.00	A
AGH25	10.25	BC	5.20	CD	0.00	A	5.08	EF	6.65	ABCD	0.00	A

Table B-11: Significant differences found between study sites at each time point sampled for photosynthesis rate (µmol CO_2 m^{-2} s^{-1}) within the Genotype Study. Means followed by different letters are significantly different at the 0.05 alpha level within sampling period.

Location	May		July		August	
LA Tech	10.83	B	9.93	A	8.18	A
Hill Farm	14.67	A	9.41	A	8.18	A

Table B-12: Significant differences found among the combinations of Location, Herbicide, and Genotype for height in the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Location.

Location	Genotype	Control		Early		Recommended		Late	
LA Tech	AGHS1	102.07	DEF	97.94	CD	114.29	CDE	81.47	CDEF
	AGHS2	98.84	CDE	106.73	AB	103.44	ABE	93.84	BC
	AGHS3	101.65	CDEF	79.11	CD	106.08	CDE	94.14	CDEF
	AGHS4	99.74	BC	94.58	CD	111.57	CDE	97.51	DEF
	AGHS8	89.92	EF	73.52	DEF	83.69	CDEF	83.34	F
Hill Farm	AGHS1	107.59	ABCD	117.69	BCDE	114.97	A	110.1	FG
	AGHS2	113.11	ABCDE	131.67	ABC	134.51	ABCD	120.65	CDEF
	AGHS3	112.33	ABCD	117.44	FG	116.85	ABC	110.16	CDEF
	AGHS4	120.48	ABCD	116.01	CDEF	114.51	AB	107.58	BCDE
	AGHS8	103.11	DEF	107.92	G	112.29	EFG	100.24	EFG

Table B-13: Significant differences found among the combinations of Time, Herbicide and Genotype for height within the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Time.

Time	Genotype	Control		Early		Recommended		Late	
Year 0	AGHS1	44.32	A	44.37	A	43.86	A	43.90	A
	AGHS2	49.96	A	47.09	A	48.24	A	48.01	A
	AGHS3	56.36	A	58.41	A	58.82	A	57.38	A
	AGHS4	48.16	A	48.47	A	47.62	A	47.24	A
	AGHS8	44.52	A	47.28	A	45.24	A	45.58	A
Year 1	AGHS1	93.19	ABC	84.80	BCDE	97.00	AB	78.99	CDE
	AGHS2	89.76	ABCD	94.26	ABC	102.62	A	87.00	ABCDE
	AGHS3	88.31	ABCD	71.95	E	93.91	ABC	79.73	CDE
	AGHS4	98.23	AB	86.71	ABCDE	99.13	AB	88.25	ABCDE
	AGHS8	84.26	BCDE	72.14	E	84.79	BCDE	75.56	DE
Year 2	AGHS1	176.98	EFGHI	216.25	E	203.02	ABC	164.45	HIJ
	AGHS2	178.22	DEFGH	194.28	A	206.07	AB	186.67	CDEF
	AGHS3	176.30	EFGHI	180.71	HIJ	181.67	DEFG	169.34	GHIJ
	AGHS4	183.95	DEFG	164.47	DEFGH	192.36	BCDE	172.14	FGHI
	AGHS8	160.76	IJ	152.74	J	163.94	HIJ	154.23	J

Table B-14: Significant differences found among the combinations of Time, Location, and Herbicide for height within the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Time.

Year	Location	Control		Early		Recommended		Late	
Year 0	LA Tech	49.98	A	48.91	A	49.43	A	47.47	A
	Hill Farm	47.35	A	49.34	A	48.09	A	49.38	A
Year 1	LA Tech	89.44	AB	87.84	AB	92.40	A	82.33	BC
	Hill Farm	92.06	AB	76.10	C	98.59	A	81.51	BC
Year 2	LA Tech	194.55	B	217.69	A	214.06	A	199.44	B
	Hill Farm	155.93	CD	145.69	DE	164.77	C	139.30	E

Table B-15: Significant differences found among the combinations of Location, Herbicide, and Genotype for ground line diameter within the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Location.

Location	Genotype	Control		Early		Recommended		Late	
LA Tech	AGHS1	16.14	G	19.67	ABC	19.27	ABCD	16.97	EFG
	AGHS2	15.95	G	20.89	A	20.48	AB	18.24	CDEF
	AGHS3	15.86	G	19.75	ABC	19.88	ABC	17.30	DEFG
	AGHS4	17.83	CDEFG	18.66	BCDE	18.73	BCDE	16.83	EFG
	AGHS8	16.22	G	18.66	BCDE	18.57	BCDE	16.22	FG
Hill Farm	AGHS1	12.64	ABCDEF	13.07	ABCDE	14.42	AB	10.07	FG
	AGHS2	11.25	DEF	14.07	ABC	11.14	DEF	10.68	EFG
	AGHS3	13.02	ABCDE	11.12	DEF	15.13	A	12.28	BCDEF
	AGHS4	12.57	ABCDEF	12.23	BCDEF	13.81	ABC	11.58	CDEF
	AGHS8	10.67	EFG	8.32	G	10.08	EFG	10.60	EFG

Table B-16: Significant differences found among the combinations of Time, Herbicide, and Genotype for ground line diameter within the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Time.

	Genotype	Control		Early		Recommended		Late	
Year 0	AGHS1	5.07	A	5.03	A	5.00	A	4.64	A
	AGHS2	5.19	A	4.67	A	4.83	A	4.81	A
	AGHS3	5.40	A	5.17	A	5.41	A	5.30	A
	AGHS4	4.61	A	4.50	A	4.61	A	4.59	A
	AGHS8	4.79	A	4.85	A	4.81	A	4.99	A
Year 1	AGHS1	10.81	AB	11.88	AB	11.57	AB	9.77	AB
	AGHS2	9.31	B	12.43	A	11.38	AB	10.28	AB
	AGHS3	10.81	AB	10.75	AB	12.38	A	10.41	AB
	AGHS4	11.15	AB	10.94	AB	12.02	AB	10.10	AB
	AGHS8	10.31	AB	9.98	AB	11.01	AB	9.94	AB
Year 2	AGHS1	27.29	GHIJK	32.21	BCD	33.97	ABC	26.16	HIJK
	AGHS2	26.30	HIJK	35.34	A	31.23	CDE	28.30	EFGHI
	AGHS3	27.11	GHIJK	30.37	DEF	34.73	AB	28.67	EFGH
	AGHS4	29.85	DEFG	30.90	DE	32.19	BCD	27.93	EFGHIJ
	AGHS8	24.51	K	25.63	IJK	27.16	GHIJK	25.30	JK

Table B-17: Significant differences found among the combinations of Time, Location, and Herbicide for ground line diameter within the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Time.

Time	Herbicide Timing	LA Tech		Hill Farm	
Year 0	Control	4.81	A	5.21	A
	Early	4.81	A	4.88	A
	Recommended	4.67	A	5.19	A
	Late	4.51	A	5.22	A
Year 1	Control	10.39	B	10.57	A
	Early	12.21	A	10.18	A
	Recommended	12.11	A	11.24	A
	Late	10.67	AB	9.53	A
Year 2	Control	33.71	C	20.31	AB
	Early	41.56	A	20.22	AB
	Recommended	41.39	A	22.30	A
	Late	36.16	B	18.38	B

Table B-18: Significant differences found among the combinations of Location, Herbicide, and Genotype for survival percentage whtih the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Locataion.

Location	Genotype	Control		Early		Recommended		Late	
LA Tech	AGHS1	100.00	A	98.40	A	98.40	A	97.59	A
	AGHS2	100.00	A	100.00	A	100.00	A	98.40	A
	AGHS3	98.40	A	87.57	A	91.65	A	99.20	A
	AGHS4	98.40	A	100.00	A	100.00	A	100.00	A
	AGHS8	98.40	A	98.40	A	96.89	A	98.40	A
Hill Farm	AGHS1	98.66	B	94.82	AB	98.66	B	98.66	B
	AGHS2	90.16	AB	100.00	B	89.77	AB	89.77	AB
	AGHS3	100.00	B	81.46	A	98.66	B	92.44	AB
	AGHS4	97.33	B	97.33	B	94.82	AB	94.65	AB
	AGHS8	98.66	B	92.44	AB	94.65	AB	98.66	B

Table B-19: Significant differences found among the combinations of Measurement Time, Location, and Herbicide for percent ground cover in the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level within each Measurement Time.

Location	Herbicide Timing	Mid-Summer		Late Summer	
LA Tech	Control	99.07	A	100.00	AB
	Early	34.67	D	100.00	AB
	Recommended	65.73	B	100.00	AB
	Late	51.73	C	98.22	B
Hill Farm	Control	100.00	A	96.56	AB
	Early	100.00	A	90.33	B
	Recommended	100.00	A	96.00	AB
	Late	100.00	A	100.00	AB

Table B-20: Significant differences in tallest weed height among Herbicide in the Herbicide Study. Means followed by different letters are significantly different at the 0.05 alpha level.

Herbicide Timing	Height (cm)	
Control	88.28	A
Early	65.88	C
Recommended	75.10	B
Late	81.58	AB

Table B-21: Significant differences of average weed height (cm) in the herbicide study for combinations of Location, Herbicide, and Genotype. Means followed by different letters are significantly different at the 0.05 alpha level within each Location.

Location	Genotype	Control		Early		Recommended		Late	
LA Tech	AGHS1	43.87	AB	32.13	AB	34.73	AB	38.93	AB
	AGHS2	47.67	A	33.00	AB	40.33	AB	39.13	AB
	AGHS3	44.80	AB	29.73	AB	39.60	AB	42.20	AB
	AGHS4	38.67	AB	30.00	AB	31.53	AB	35.87	AB
	AGHS8	47.07	A	26.13	B	38.40	AB	36.87	AB
Hill Farm	AGHS1	138.22	ABCDE	101.67	GH	120.67	DEFGH	154.00	AB
	AGHS2	154.56	AB	94.11	H	160.44	A	136.78	ABVDE
	AGHS3	138.44	ABCDE	103.00	GH	125.67	CDEFG	130.56	BCDEF
	AGHS4	134.00	ABCDE	106.44	FGH	115.00	EFGH	145.33	ABCD
	AGHS8	120.33	DEFGH	154.94	AB	139.89	ABCDE	150.78	ABC

APPENDIX C MISCELLANEOUS

Table C-22: Soil analysis conducted prior to study and analyzed by LSU to determine nutrient levels and pH at each site.

	Ca ppm	Cu ppm	Mg ppm	pH (1:1Water)	P ppm	K ppm	Na ppm	S ppm	Zn ppm
HIll Farm Ridg	511.024	0.49	54.34	4.98	11.74	56.01	5.76	5.67	1.38
HIll Farm Ridg	630.48	0.61	81.92	4.92	17.96	75.63	8.53	9.87	2.43
LA Tech	480.28	0.86	78.07	4.63	107.79	85.41	8.93	14.64	3.64

Note: ppm is equivalent to mg/Kg for soil and plant samples and is equivalent to mg/L for water samples. For a description of methods used, please visit our web site at: http://www.stpal.lsu.edu

Table C-23: Weather data collected from NOAA weather stations nearest to the study sites, and averaged by month.

Year	Month	Precipitation (in)	Temp. Max (ºF)	Temp. Min (ºF)
2015	March	5.44	62.86	42.32
	April	2.95	76.74	54.44
	May	12.62	81.81	60.77
	June	5.47	88.04	67.44
	July	1.2	94.51	73.28
	August	2.22	93.98	67.44
	September	0.87	90.97	62.95
	October	13.65	80.07	51.67
	November	15.02	69.02	46.24
	December	15.09	67.59	39.57
2016	January	7.16	59.64	34.32
	February	5.73	67.32	39.71
	March	38.35	73.02	47.31
	April	25.09	78.03	53.05
	May	3.63	82.54	58.7
	June	5.59	90.26	70.66
	July	6.19	94.26	73.23
	August	11.14	94.66	74.93
	September	1.9	88.13	65.25
	October	2.88	83.08	51.26
	November	7.86	72.83	43.19
	December	8.03	58.85	37.77
2017	January	8.13	63.92	39.85
	February	6.74	69.23	44.9
	March	2.03	75.22	44.3
	April	10.36	79.23	51.49
	May	10.74	80.95	56.98
	June	9.49	86.12	67.66
	July	4.5	91.1	71.25
	August	14.83	86.55	70.79
	September	4.97	87.16	65.61
	October	2.12	79.82	52.12
	November	2.32	69.81	44.32
	December	7.76	56.3	35.2

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