**Evaluation of Warm-Season Annuals for Livestock Production**

By

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Abstract

Warm-season forages are high yielding and can have high nutritive value, providing producers with an ideal option during the months in which cool-season forages are not productive. Two, 2-year small plot studies were completed to evaluate the forage mass and nutritive value of warm-season annual forages. Study 1 evaluated sorghum × sudangrass [(*Sorghum bicolor* L. Moench) × (*Sorghum* × *drummondii*)], cowpea (*Vigna unguiculata* L. Walp), and crabgrass (*Digitaria sanguinalis* L.), in mono-, bi-, and tri-mixtures, as well as sorghum × sudangrass with an insecticide at E.V. Smith Research and Extension Center (Headland, AL). Plots containing sorghum × sudangrass were also evaluated for sugarcane aphid [SCA; *Melanaphis sacchari* (Zehntner)] infestations on a weekly basis. Forage mass (FM) was not different between treatments and ranged from 1038 to 2358 kg/ha. Crude protein (CP) concentration in both years was greater ($P \leq$ 0.02) in cowpea than all treatments except sorghum × sudangrass + cowpea ($P = 0.06$) in year 2 and cowpea + crabgrass ($P \geq 0.24$) in both years. Concentrations of CP ranged from 6.6 to 16.6%. Neutral detergent fiber (NDF) ranged from 47.4 to 67.7%. In year 1, NDF was less ($P = 0.02$) in cowpea and cowpea + crabgrass than sorghum × sudangrass + insecticide and sorghum × sudangrass + crabgrass, and in year 2, cowpea and cowpea + crabgrass were less ($P \leq 0.01$) than all treatments except sorghum × sudangrass + cowpea ($P \geq 0.16$). Acid detergent fiber (ADF) was not different between treatments and ranged from 16.5 to 39.6%. Mixing sorghum × sudangrass with other forage species increased incidence of SCA per leaf. The warm-season annual forages used in this study showed promise for use as forage; however, insecticide use may be recommended when using sorghum × sudangrass. Study 2 evaluated FM, nutritive value and persistence of 5 soybean cultivars (‘Stonewall’, ‘Laredo’, ‘Tower of Leaves’, Asgrow® ‘AG64X8’, and Asgrow® ‘AG79X9’) at two locations in two growing seasons under two management strategies (row spacing and stubble height). Years and location did vary, but overall Stonewall consistently had the highest FM with high nutritive value. Tower of Leaves had high FM but had lower nutritive value the Stonewall. The grain cultivars (AG64X8 and AG79X9) had high crude protein, but otherwise were inconsistent in nutritive value and had moderate FM. Laredo consistently had the lowest FM. Lower stubble heights resulted in increased FM but decreased nutritive value. Row spacing did not consistently influence either FM or nutritive values. Due to the high nutritive value and FM, Stonewall should be evaluated alone and in mixtures with other summer annual forages for inclusion in livestock diets.

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| | |
|---|---|
| ADF | Acid Detergent Fiber |
| COW | Cowpea |
| CP | Crude Protein |
| COW + CRAB | Cowpea + crabgrass |
| DE | Digestible Energy |
| EVSREC | E.V. Smith Research and Extension Center |
| FM | Forage Mass |
| IVDMD | In Vitro Dry Matter Digestibility |
| K | Potassium |
| N | Nitrogen |
| NDF | Neutral Detergent Fiber |
| P | Phosphorus |
| CRAB | Crabgrass |
| RP | Rhizoma Perennial Peanut |
| SSG | Sorghum × Sudangrass |
| SSG + COW | Sorghum × Sudangrass + cowpea |
| SCA | Sugarcane aphid |
| SSG + COW + CRAB | Sorghum × Sudangrass + cowpea + crabgrass |
| SSGI | Sorghum × Sudangrass + insecticide |
| SSG + CRAB | Sorghum × Sudangrass + crabgrass |
| TDN | Horse Total Digestible Nutrients |
| WREC | Wiregrass Research and Extension Center |

# I. Review of Literature

## Forage Responses and Livestock Production

Forage species which produce high yields and nutritive values are ideal for producers due to high fixed costs and time inputs associated with hay and forage production [1]. Important nutritive value responses which can be measured include crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, *in vitro* dry matter digestibility (IVDMD), digestible energy (DE), and total digestible nutrients.

Protein is made up of amino acids, which livestock require as a part of their diet [2]. Protein content in forages is usually analyzed as CP [1]. This method of analysis gives the N content of the forage, which is then extrapolated to CP using the equation N × 6.25. Due to this method of analysis, some CP may not be available to livestock, especially equine species because they digest protein before microbial fermentation takes place and are not able to utilize microbial protein in the same manner as ruminants [1-3].

Neutral detergent fiber is a measure of total cell wall contents of the plant, and includes hemicellulose, cellulose, and lignin; ADF is a measure of the mostly indigestible portions of the plant cell wall, including cellulose and lignin [1,4]. Using these two methods and lignin analysis the concentration of each of these structural carbohydrates in the plant can be determined. Hemicellulose and cellulose are partially digestible by equids and ruminants; however, lignin is indigestible and high lignin concentrations may affect the digestibility of hemicellulose and cellulose [1]. The concentration of NDF is inversely correlated to voluntary intake of the animal, while ADF concentration is inversely correlated to digestibility [1].

*In vitro* fermentation techniques, including IVDMD, may be used to simulate the digestion process of the animal, and allow for a reasonable approximation of the digestibility of a feedstuff [1]. Inoculation sources for IVDMD may include, but are not limited to, equine feces or rumen fluid depending on the species of interest [1,5]. Digestible energy (DE) and total digestible nutrients (TDN) are estimates of energy availability using equations based on the carbohydrate and fiber concentrations of a feedstuff [1].

**Warm-Season Annual Forages**

Warm-season annual forages are high yielding and generally have a higher nutritive value than warm-season perennial forages. Due to these qualities, they are useful forages for animals with higher energy needs and are often used to fill in the gap during the hot summer months when cool-season forages are not as productive. These forages often exhibit an upright growth pattern and grow rapidly during the summer months; however, they typically have a shorter growing season and require annual reestablishment, which makes them more costly to maintain than perennial forages [6]. Warm-season annual forages may also be useful during drought periods, when warm-season perennial forages may not produce much biomass [7]. The forages evaluated in this study were sorghum × sudangrass [(*Sorghum bicolor* L. Moench) × (*Sorghum* × *drummondii*)], cowpea [*Vigna unguiculata* (L.) Walp.], and large crabgrass [*Digitaria sanguinalis*].

**Sorghum × Sudangrass**

Sorghum × sudangrass is a hybrid grass species that is well adapted across a wide variety of geographic regions and often used for silage production. It is a warm-season annual forage species, which makes it a good option during the summer period when cool-season forages have poor production. Sorghum (*Sorghum bicolor*) is a tropical grass species that is grown for forage and grain production, as well as showing promise as a biofuel. Because it is a tropical grass species, it is best adapted to semiarid and drier areas of the world [9]. As a result, sorghum × sudangrass is heat and drought tolerant and valuable in livestock production for its rapid growth and high yield [8]. In 2018 there were 60 million megagrams (Mg) of grain sorghum harvested on 42 million ha worldwide [10]. Sudangrass (*Sorghum sudanese*) is often used during the summer months in the Midwestern U.S. It is of a moderate to high quality [11]. However, the growth pattern exhibited by sorghum × sudangrass can present management challenges when grazing, including highly variable stocking rates throughout the growing season [6].

***Forage yield***

Studies evaluating forage yield in sorghum × sudangrass have reported a wide range of yields ranging from 1.12 to 28 Mg/ha [6,8,12-15]. The lowest yields were recorded by Fontaneli et al. [6] and Beck et al. [15] when time from planting until harvest was decreased. Fontaneli et al. [6] evaluated a range of planting dates for sorghum × sudangrass, with yields greatly reduced for a late planting date of July 1 compared to an early planting date of March 20. The results from this study showed a reduction in yield of 23 to 36 kg/ha for each day that planting was delayed.  Beck et al. [15] also assessed a range of growing periods, however, differences in time from planting until harvest were due to harvest date, not planting date. Weekly harvests occurred from 34 to 63 days, with greatly reduced yields seen from plots harvested at 34 days compared to those harvested at 63 days.

Venuto and Kindiger [14] and McLaughlin et al. [12] reported the greatest yields of sorghum × sudangrass in the literature. McLaughlin et al. [12] grew sorghum × sudangrass under swine effluent irrigation and harvested plots when the sorghum × sudangrass was 0.8 to 1.8 m tall. Venuto and Kindiger [14] observed greater yields in plots that were harvested once compared to those that were harvested twice.

***Nutritive value***

Previous studies in sorghum × sudangrass have reported CP concentrations of 2.9 to 20.7% [6,8,13,15,16], NDF concentrations ranging from 55.5 to 72.2% [10-12], and concentrations of ADF ranging from 33.2 to 43.3% [15-17]. Studies by Clark et al. [13], Pedersen and Toy [8], and Beck et al. [15] have found CP concentrations decreasing as time until harvest increased. The greatest CP concentrations were seen by Clark et al. [13] at early harvests, whereas Beck et al. [15] found the lowest CP concentrations from plots harvested at 63 days. However, concentrations of NDF and ADF were seen to be increased at later harvest dates compared to earlier harvest dates by Beck et al. [15] and Gelley et al. [17]. Concentrations of CP, NDF, and ADF were also shown to vary due to differing broiler litter fertilization programs in a study by Sleugh et al. [16].

Pedersen and Toy [8] observed IVDMD of 63.2 to 64.1% in the first cutting and 59.2% to 61.8% in the second cutting, while Fontaneli et al. [6] reported slightly higher in vitro organic matter digestion of 66.8 to 71.2% in their varieties tested. Gelley at al. [17] reported NDF disappearance of 50.9 to 59.7%.

Kiesling and Swartz [11] compared lambs grazing cowpea, sudangrass, and 2 feedlot diets consisting of corn (*Zea mays*)/soybean (*Glycine max*) meal and corn/whole cottonseed (*Gossypium*). The authors results noted that lambs grazing sudangrass had the lowest gains and carcass qualities of any of the treatments. These carcass qualities included backfat, kidney-pelvic fat percentage, retail cuts, and yield grade.

### *Sugarcane Aphid*

Sugarcane aphids [*Melanaphis sacchari*] are a pest that appears in regions where sorghum and sugarcane are cultivated. In many of these regions, it has a negative impact on the economy [18]. As a result, much of the research on the sugarcane aphid has occurred in areas of high grain sorghum and sugarcane production. In recent yr, the sugarcane aphid has become an emerging issue for forage producers establishing sorghum, sudangrass, and sorghum × sudangrass hybrids in the Southeast US. Sugarcane aphids were first identified in sorghum in the U.S. along the Texas Gulf Coast in 2013. By 2015, the sugarcane aphid could be found in 17 states and over 400 counties in the US [19-21]. This quick geographic spread may have been aided by aphids in the alate form being carried by the wind, which may distribute aphids both locally and over long distances, and the aphid's ability to overwinter on living hosts, such as Johsongrass (*Sorghum halepense* L.), in the southern areas of the region [20,21].

Aphid infestations can reach up to 30,000 insects on a single plant, causing decreased yield and forage quality [22] and leading to economic losses for producers. High aphid infestations can cause a rapid decline in the host plant quality as well as reducing yields by as much as 447 kg/ha in forage sorghum and a loss of up to $1,067 per ha in grain sorghum. These losses can occur at populations as low as 250 aphids per leaf [21]. High aphid populations may also allow an increase in alate production and dispersion of alate aphids, as well as an increase in aphid predator populations [21,23]. Due to the possibility of economic losses, aphids should be scouted for on a regular basis to ensure that populations are staying at an acceptable level of 250 aphids/leaf or lower [21].

*Habits and damage to plants*

The amount of damage to the crops from aphid infestations depends greatly on the crop stage when first infested and the density and duration of infestations. The range of yield losses varies, with some estimates reaching as high as 39% in forage sorghum [24]. Losses in plant quality may also occur, with decreases in leaf N documented [22]. Aphids suck sap out of the xylem of older leaves which removes plant nutrients and sugar [18]. The aphids then release a honeydew which causes a black sooty mold to grow on the leaves below it, causing a reduction in photosynthesis (Figure 1) [18,21]. This can cause damage to the plants which results in yield loss, and a disruption in crop harvest [21]. Harvest disruption may occur due to honeydew secretion, causing the plants to become sticky, which may lead to plant material building up in the separator. This causes a reduction in harvest yield in grain harvests and mechanical issues during cutting and baling of forage sorghum [21,25]. Damaged forage sorghum may also have reduced quality, be moldy, and potentially have increased drying time [21]. Some articles report that aphids can also cause reduced yields through the transmission of Sugarcane Yellow Leaf Virus [26] and Sugarcane Mosaic Virus [18], while others report that there is no indication of plant pathogen transmission [21].

Figure 1. Sooty mold caused by sugarcane aphids. Photo retrieved from: https://entomology.k-state.edu/extension/insect-information/crop-pests/sorghum/sugarcane%20aphid.html

Symptoms of aphid damage on sorghum include purpling of leaves on young plants; as the plant matures, this can lead to stunting, chlorosis, and necrosis [18]. Plant symptoms of aphid infestations may not be visible when aphid colonies are first detectable but become apparent as aphid populations and plant damage increase [21].

Aphid colonies first begin to appear on plants during the early growth stage of the plant. Following the first appearance, the colonies will begin to grow exponentially [27]. Aphid colonies will reach their peak levels when the plants enter their flowering stage when they provide the most nutrition for the aphids [27]. After peak infestation levels, the aphids undergo a heavy dispersal in the mid-season, aphid populations are then kept in check by natural enemies during the late summer season [28]. Environmental factors such as rainfall and ambient temperature appear to influence the population density of aphids on their summer host plants, as well as their dispersal from their summer hosts [18,29]. Warm, dry conditions may lead to faster population growth in aphid colonies [27].

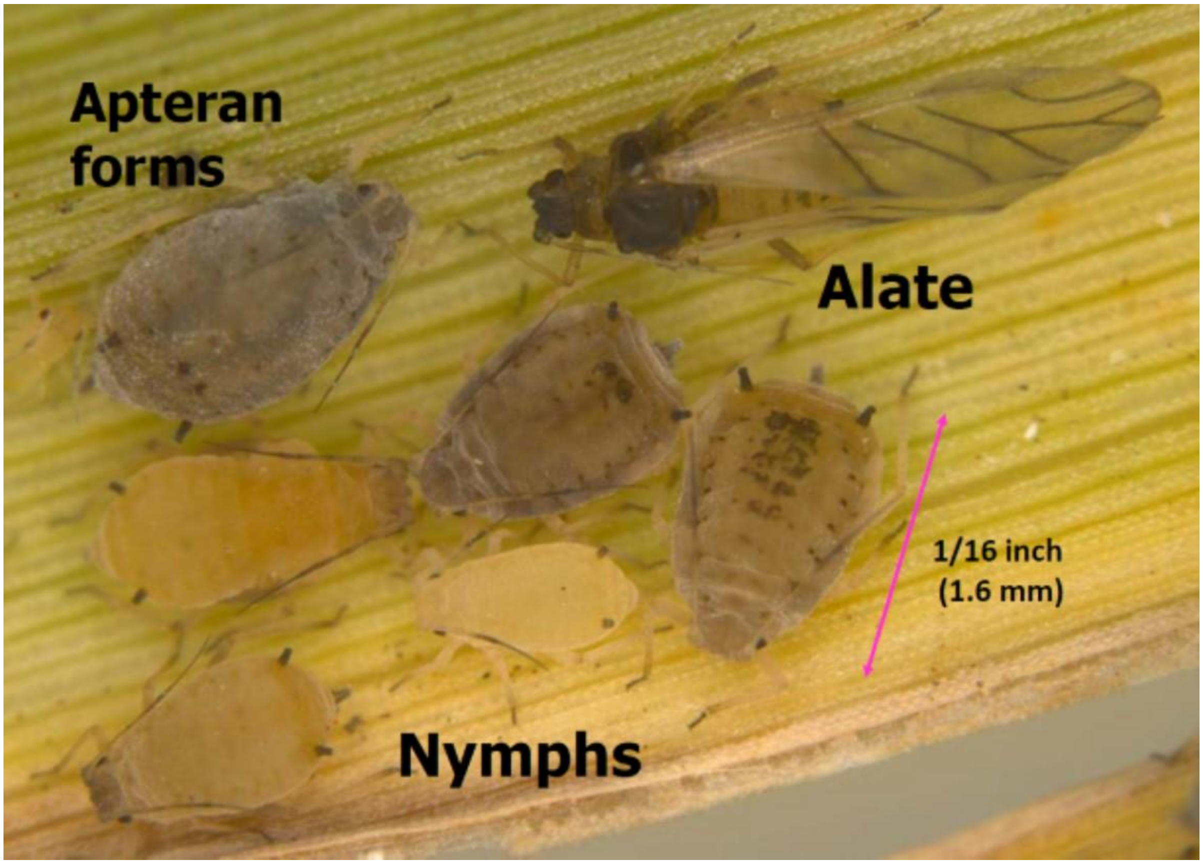


Figure 2. Sugarcane aphid life cycle forms. Photo retrieved from: http://blog.umd.edu/agronomynews/2017/08/01/pests-of-sorghum-sugarcane-aphid/

*Life cycle*

A study by van Rensberg [27] showed that sugarcane aphid aptera live 28 d and produced an average of 85.6 larvae on young sorghum plants; on mature sorghum plants, they live 28.1 d, producing an average of 96.2 larvae. The immature sugarcane aphid morphs will go through a series of 4 stages lasting 5 and 5.2 d on immature and mature sorghum, respectively. Other reports show the adult stage, either in aptera or alate form, lasts 10 to 37 d and produces 34 to 96 nymphs per female [29,30]. The variation in nymphs produced may be due to temperature, rainfall, and nutritional factors [21,29]. Aphids have 51 to 61 generations on an annual basis, with longer lifespans in the winter months [29]. Changes in temperature appear to cause a variation from 4 to 12 d in the time it takes the sugarcane aphid to develop from birth to adulthood [29]. Sugarcane aphids in the U.S. appear to be solely females which reproduce live young asexually, with the exception of a single egg which was found in Mexico [21]. Sexual sugarcane aphid forms have been reported in other countries, including 1 report from Mexico [21,31].

Sugarcane aphids feed on an annual host, such as sorghum through the spring and summer months [28]. Due to varying environmental signals, the aphids will begin to leave their sorghum host plants in the early fall to find a winter host plant, such as Johnsongrass or remnant sorghum, where they overwinter parthenogenetically [28,34]. Mild winters in the southern areas of sorghum production give the sugarcane aphid a long-term option for overwintering, while overwintering in more northern locations may depend on the availability of living vegetation [28].

**Cowpea**

Cowpea is an annual legume mainly used for human grain consumption; however, it shows promise as a forage crop. It is a tropical and subtropical species [32], growing well in warmer regions of the world. Cowpea was most likely domesticated in Africa and introduced into India in the Neolithic period. It is now grown around the world, including areas of Africa, Asia, and the Americas, with most of the worldwide cowpea production in sub-Saharan Africa [33]. As a forage, cowpea has been shown to be a very diverse, versatile species, growing well in various climates and soils, as well as being stress tolerant, allowing it to withstand high temperatures and droughts [33,34].

While cowpea can be used as the sole crop, it is often used in intercropping schemes for human food production. It can be intercropped with sorghum, pearl millet (*Pennisetum glaucum*), maize, cassava (*Manihot esculenta*), or cotton. In the US, cowpea is also often planted in the rows between fruit and nut trees in orchards [33]. As a result of cowpea's adaptability and ability to withstand high temperatures and low rainfall, it is well adapted to the Southeastern and Southwestern U.S. and has been grown successfully during experimental trials as far north as Minnesota [33]. It is able to withstand the hot summer seasons in these areas while also still producing during drought periods. As a result, cowpea can provide a high-quality forage opportunity for the late summer months when cool-season forages undergo their summer slump. Interestingly, due to its adaptability and nutritive qualities, cowpea was chosen by NASA as one of the few crop species to study for cultivation in space stations [33].

Cowpea grows best in sandy loam soils, and it is drought tolerant [32], making it a good forage possibility for central and south Alabama. Due to its ability to continue to grow during dry periods, it may help to reduce forage shortages during poor production years. Intercropping with other forage species has been shown to help increase forage yields from cowpea and may help diversify forage mixtures and extend forage production window relative to monocultures alone [32].

The ‘Iron clay’ variety is currently the most commonly grown forage variety of cowpea in the U.S. [35]. Iron clay cowpea is a photosensitive variety of cowpea, which allows it to produce large amounts of biomass when planted early in the season. It rapidly regrows following grazing or cutting and does not produce seed until very late in the season when daylength gets short enough to signal seed production. [36].

***Forage yield***

Dry matter forage yield in cowpea has been reported to range from 5.3 to 21.8 Mg/ha. These studies have taken place in locations across the world, from the deserts of the United Arab Emirates to the Northern Great Plains of the U.S. [18,34]. The lowest yields were seen from a study by Boe et al. [34]. Yields in this study decreased with shorter planting to harvest time periods and increased with a greater time until harvest. Management in row spacing also resulted in variations in yields, with yields significantly decreased when row spacing was increased (25- vs. 50-cm) [34].

Rao and Shahid [18] observed far greater yields than either Boe et al. [34] or Ayan et al [32]. The study by Rao and Shahid [18] was located in the deserts of the UAE and was evaluating cowpea as an alternative forage to alfalfa, which has greater water requirements. Plots in this study were planted in February, and allowed to grow for 118 to 120 days, which may contribute to the greater yields found by the authors.

Cowpea is known to grow best at low altitudes and with low variations in daily temperatures [32]. Results from a study by Ayan et al. [32] were in agreement with this theory. The authors in this study tested cowpea at two locations in Turkey and found that the coastal location, which had a lower altitude and less variations in daily temperature, produced the greater yields.

***Nutritive value***

Ayan et al. [32] reported cowpea to have CP concentrations of 17 to 18.5%, NDF concentrations of 33.1 to 36.8%, and concentrations of ADF of 26.6 to 28.9%. The authors found no differences from genotypes, but differences were seen due to location. Nutritive value, like forage mass, was higher at the location with better growing conditions. Other sources report CP concentration of 21 to 30%, and TDN of 68% [11,38,39].

Kiesling and Swartz [11] conducted a study in the Midwestern U.S. to determine if cowpea was a viable alternative to concentrate feedlot diets for lambs during the summer period when cool-season forage production is low. This study reported lambs grazing cowpea had higher gains than three other diets, including grazing sudangrass, and two feedlot diets [corn/soybean (*Glycine max*) meal and corn/whole cottonseed (*Gossypium*)]. Lambs grazing sudangrass, a common summer forage in the U.S., had the lowest levels of gains, while cowpea had the greatest. Two feedlot diets were not fed *ad libitum*, which may have resulted in those diets producing lower gains than grazing cowpea. Carcass qualities, which included backfat, kidney-pelvic fat percentage, and retail cuts and yield grade, were similar or better for lambs on the forage cowpea diet compared with those fed drylot diets.

**Large Crabgrass**

Large crabgrass is a warm-season annual grass that is often considered a weed. The crabgrass family is another forage family that was originally cultivated for grain; however, it has been shown to make a desirable forage crop [40]. It grows well in temperate and tropical regions of the world, with large crabgrass and smooth crabgrass (*Digitaria ischaemum)* being the 2 crabgrass species most commonly found in the U.S. Large crabgrass was 1st introduced to the U.S. by the U.S. Patent office as a forage crop in 1849 but it obtained little initial interest and was forgotten very quickly due to a lack of promotion [40].

Large crabgrass began gaining interest decades after its initial introduction. This renewed interest was among Southern ranchers who found that it was well suited to the hot, dry conditions of the Southern U.S. and that it was nutritious as a pasture and hay forage crop for their expanding cattle ranches [40]. Large crabgrass also thrives well in acidic soils, which are very common in Alabama and throughout the Southeast. Its prolific seed production allows it to spread quickly [41], and as a result has quickly become a weed throughout the southern U.S. It is classified as one of the major lawn weeds in the U.S. and is a troublesome weed in crops such as peanuts (*Arachis hypogaea*), sugarcane (*Saccharum officinarum*), cotton, and sorghum in U.S. cropping systems. It is also a common weed in orchards and vineyards. This prolific seed production also allows crabgrass to reseed itself annually, acting as a perennial forage [1]. Due to its hardiness, crabgrass is often found growing along roadsides and in ditches [40].

### *Forage yield*

Forage yields for crabgrass in previous studies have ranged from 1.6 to 10 Mg/ha. The lowest yields were seen by McLaughlin et al. [42] during a drought. The greatest yields seen in the previous literature were also from McLaughlin et al. [42], who evaluated the use of swine effluent irrigation on large crabgrass and other warm-season annual plots. Beck et al. [43] analyzed large crabgrass hayfields for forage yield and quality at harvest intervals of 21, 35, and 49 days. Forage yields were lowest at the 21-day harvest, while they were greatest at 49-days.

### *Nutritive value*

Crude protein concentrations have ranged from 7.8 to 16.6% in previous studies, while concentrations of NDF have ranged from 54.4 to 70.6%, with ADF concentrations of 35.7 to 50.1% observed [17, 43]. Beck et al. [43] found that CP decreased, and NDF and ADF increased as harvest intervals increased. Although there were differences in forage quality across harvest intervals in this study, the authors found no differences between harvest intervals in calf gain when the calves were fed mixed diets of 20% crabgrass hay, 33% ground corn, and 32% soybean hulls. Gelley et al. [17] observed no relationship between forage mass and harvest date for CP concentrations in crabgrass, but the authors did report that NDF disappearance was influenced by forage mass and ranged from 38 to 54.2%.

## Soybeans

Soybeans were initially introduced into the U.S. from China in the 1800's when they were brought over as a potential forage crop. Production of soybeans shifted from forage-focused to seed production-focused in the 1940's as the value of their oil seed increased [44]. Recently, there has been a small shift back towards forage production, with producers harvesting or grazing soybeans at immature stages, and several researchers introducing improved forage cultivars [45]. Oftentimes, soybean forage production is only done when the crop has been too damaged to use for grain production or when there is a forage shortage [46]. As an annual leguminous forage, forage soybeans may provide an alternative to planting perennial legumes in crop rotation systems, because of lower establishment costs and producers not having to commit the fields for multiple years [47]. The use of soybeans as a forage crop has become increasingly common in northern parts of the continent, where alfalfa (*Medicago sativa*) often suffers winterkill and shorter crop rotations are preferred. Soybean growth may be influenced by environmental conditions such as excess precipitation, drought, low soil pH, compacted soils, and mineral toxicities [45, 48].

The period of soybean growth may vary slightly by location due to photoperiod (daylength) differences and also by maturity group. Soybeans are classified into 13 maturity groups based on time of flowering and maturity, with different groups being more adapted to different climatic zones. Maturity groups ranged from 00 to VIII. Groups assigned a lower number are better adapted to more northern areas and flower earlier, whereas groups assigned a higher number are better adapted to more southern states and flower later. Photoperiodism appears to be one of the major factors in adaptability of maturity groups to certain areas [49].

Soybeans can be classified in either vegetative or reproductive growth stages. The vegetative growth stages begin with V1, when there is only the unifoliate node, and continue based on the number of nodes. The reproductive stages are labelled R1 through

R8, with R1 consisting of a single flower on any node of the plant and R8 having 95% of the pods brown, the stage in which grain soybeans would be harvested [50]. The leaf proportion of soybeans declines as they mature from beginning bloom, stage R1, to stage R7 [46]. Forage soybean yield and nutritive value has been maximized by harvesting between full seed, stage R6, and beginning maturity, stage R7 [46,47].

Soybeans in maturity group V appear to be the best adapted for the majority of Alabama, with maturity group VI being better adapted for the most southern portions of Alabama [49]. Soybeans are sensitive to late planting dates and drought [47,48]; therefore, growers in Alabama need to plant early to avoid weather delays due to spring weather. Alabama also often receives late summer drought periods, which may make growing soybeans difficult without irrigation in some growing years.

***Forage Yield***

Forage yields in soybeans have been reported to range from 4.5 to 13.9 Mg/ha [46,47]. Maturity at harvest, environmental conditions, and management factors likely play a role in forage soybean yields. Sheaffer et al. [46] reported greater forage yields when plots were harvested at the R6 to R7 growth stage compared to those harvested at the R3 to R4 growth stage. A study conducted by Seiter et al. [47] observed decreases in yield due to below average temperatures and a late planting date. The authors reported row spacing to also play a role in forage yields, with narrower row spacings resulting in greater yields. This is in agreeance with Wax and Pendleton [51], who noted increased yields up to 20% in 25-cm row spacings compared to 102-cm row spacings. Planting density was not seen to have an influence on forage yields by Seiter et al. [47].

***Nutritive Value***

Whole plant CP concentrations in soybeans are reported to range from 13.2 to 23.3% [45,46]. Lower CP was found in forage- vs. grain-type soybeans by Sheaffer et al. [46]; the authors in this study speculated that this was due to higher quality pods in the grain-type soybeans. Results from this study also revealed lower CP concentration in stem fractions compared to leaf fractions, which was in agreeance with a study by Rao et al. [45]. Maturity likely also plays a role in CP concentrations; Seiter et al. [47] observed greater CP concentrations at the R5.5 growth stage compared to the R3 growth stage. The authors of this study believed that CP concentrations would have continued to rise as pods began to form.

Concentrations of NDF have been reported of 20 to 46.9% [46,47]. Greater NDF concentrations were observed in stem fractions compared to leaf fractions [46]. Seiter et al. [47] reported NDF concentrations at the high end of the range in forage-type soybeans harvested at the R5.5 growth stage, which was greater than those harvested at R3.

Previously reported ADF concentrations have ranged from 19 to 36.2%. Sheaffer et al. [46] observed ADF fractions to be consistent across both forage- and grain-type soybeans and found that ADF concentrations were also greater in stem vs. leaf fractions. Seiter et al. [47] noted ADF concentrations increased in soybeans harvested at the R5.5 growth stage compared to those harvested at R3. an average ADF of 36.2% in ‘Donegal’ forage soybeans that were harvested at the R5.5 growth stage. The authors in this study speculated that the increases in NDF and ADF concentrations from the R3 to R5.5 growth stages were likely due to an increase in the fiber of stem fractions prior to pod formation.

Vargas-Bello-Pérez et al. [52] observed that soybean silage had a lower ruminal degradability of DM, CP, and NDF fractions than alfalfa silage. The authors attributed the slower degradation of available NDF fractions of the soybean silage to a higher lignin composition than the alfalfa silage. It was also reported that DM intake of cows fed the soybean silage was lower than that of those fed the alfalfa silage, again likely due to the higher fiber fractions of the soybean silage.

## Alfalfa

Alfalfa is an important warm-season perennial forage legume which is commonly fed to equine and other livestock. It is mainly fed as preserved forage in the form of hay or silage due to poor grazing tolerance [53] and palatability. It is commonly used in crop rotations due to its ability to add N back into the soil, reducing the need for fertilization for crops which follow in rotation. Alfalfa is known for high forage yields, along with high CP and DE levels. These traits allow for a reduction in use of protein supplements when alfalfa is added to the diet of livestock [54]. Forage yields of alfalfa may be negatively impacted by high temperatures and low soil moisture, which are common summer growing conditions throughout the Southeastern U.S. [55].

### *Forage Yield*

Forage yields of alfalfa in the Southeast have ranged from 7.7 to 12.6 Mg/ha when grown for hay production and 2.4 to 6.4 Mg/ha when managed in a continuous grazing system [53,55,57]. Forage mass of alfalfa was observed to decrease with fewer seasonal cuttings [56]. Smith et al. [53] reported lower yields for grazed alfalfa compared to studies managing for hay production. These results were likely due to continuous animal pressure, whereas alfalfa managed for hay is allowed to regrow fully before being harvested again. Terrill et al. [57] observed alfalfa yields on the higher end of this range, which the authors attributed to sufficient and evenly distributed rainfall in each growing season.

### *Nutritive Value*

Previously reported values for CP in alfalfa range from 15.5 to 19.3%, NDF concentrations from 43.7 to 50.6%, concentrations of ADF from 31.2 to 41.4%, and *in vitro* dry matter digestibility from 54.2 to 59.0% [57,58]. Hoveland et al. [58] reported decreased digestibility and CP of alfalfa following a 2-wk grazing period. The authors suggested that this was potentially due to animals selecting for the more digestible components of the plant.

## Rhizoma Perennial Peanut

Rhizoma perennial peanut is a warm-season perennial legume which has recently become popular in the far Southern portion of the Southeast. Most of the research for this species has been based out of Florida due to ideal growing conditions in that state [57]. Perennial peanut may be costly to establish; however, it has been shown to have high persistence and recent studies have evaluated its use in pasture [59]. It has also been shown to have high yields and nutritive value [60].

### *Forage Yield*

Annual forage yield for rhizoma perennial peanut in previous literature ranges from 3.5 to 4.3 Mg/ha during the establishment year and 5.2 to 10.6 Mg/ha during later growing seasons [59]. Average harvest yields of 2.6 to 3.2 Mg/ha have been observed [60]. Hernández Garay et al. [60] noted that forage mass on grazed pastures decreased throughout the growing season, with the greatest forage yield at the beginning of grazing

(May to June) and the lowest forage yield in October. Mullenix et al. [59] reported decreased forage yield during the second year of grazing. The authors attributed the lower second year forage yields to heavy grazing resulting in decreased rhizome mass.

### *Nutritive Value*

Previous literature has reported CP in rhizoma perennial peanut of 14.6 to 23.0%, NDF concentrations of 46.0 to 50.0%, ADF ranging from 33.2 to 36.4%, concentrations of IVDMD of 50.5 to 61.6%, and *in vitro* organic matter disappearance of 61.5 to 73.2% [57,59-61]. Mullenix et al. [59] observed a negative effect on forage CP due to increased maturity. This was in agreeance with a study by Hernández Garay et al. [60], who found CP concentrations to decrease across the growing season. Valencia et al. [61] contributed variations in CP concentrations to changes in leaf:stem ratios as the forage matured. Similarly to CP concentrations, Valencia et al. [61] noted IVDMD concentrations to be decreased at a 12-wk harvest interval compared to a 6-wk harvest interval. Terrill et al. [57] reported NDF and ADF concentrations of rhizoma perennial peanut to be lesser than alfalfa during the establishment year, but greater than alfalfa in 2 subsequent growing seasons.

## Objectives

The objective of the current study was to evaluate alternative warm-season annual forages for potential inclusion in livestock production. This objective was addressed by conducting two field experiments. The specific objectives of experiment 1 were: 1) measure the herbage mass of three warm-season annual forages species (sorghum × sudangrass, cowpea, and large crabgrass), 2) analyze the nutritive value of the three warm-season annual forages, and 3) determine the sugarcane aphid incidence in sorghum

× sudangrass mono- and mixed cultures. Specific objectives of experiment 2 were: 1) evaluate the leaf area index of five soybean cultivars (‘Stonewall’, ‘Laredo’, ‘Tower of Leaves’, ‘AG64X8’, and ‘AG79X9’), 2) determine the herbage mass of the soybean cultivars, 3) analyze the soybean cultivars for nutritive value, and 4) evaluate the effects of row spacing, location, and stubble height on the measured parameters.

## II. Agronomic Responses and Sugarcane Aphid Pressure in Warm-Season Annual Forage Mixtures


### Abstract

Warm-season annual forages are a viable option to complement perennial forage systems. Sugarcane aphid [SCA; *Melanaphis sacchari* (Zehntner)] has emerged as a significant pest in *Sorghum spp* compromising forage production. This study evaluated herbage responses and SCA incidence in monoculture and mixtures of cowpea (*Vigna unguiculata* L. Walp), crabgrass (*Digitaria sanguinalis* L.), and sorghum × sudangrass [(*Sorghum bicolor* L. Moench) × (*Sorghum* × *drummondii*)]. Crude protein (CP), lignin, acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations were determined. Incidence of SCA was evaluated weekly on sorghum × sudangrass treatments. Forage mass was not affected ($P = 0.522$) by treatments and ranged from 1525 to 2358 kg dry matter (DM)/ha. Greater forage mass was observed in year 1 than 2 (1880 vs. 1177 kg DM/ha) most likely associated with higher rainfall on year 1. Greater ($P < 0.001$) CP was observed in year 2 and was also associated with mixtures containing cowpea. For treatments containing sorghum × sudangrass, the use of insecticide decreased losses in forage production. Although sorghum × sudangrass mixtures did not result in a reduction of SCA when compared to its monoculture. This response is most likely associated with less sorghum × sudangrass plant density in mixtures which may have resulted in a higher SCA incidence per plant. Based on our results, the use of warm-season annuals is a viable option to complement forage production; however, the use of insecticide may be needed to reduce yield and economical losses due to SCA.

## 1. INTRODUCTION

In the Southeastern U.S., warm-season annual forages are a viable option to improve forage production and nutritive value for pasture-based livestock production systems [6,17]. However, they can often be more expensive than perennial forage systems due to the need for annual establishment associated with shorter growing season [6]. Sorghum × sudangrass (SSG) is often used due to its high yield and tolerance to heat and drought [8]. Previous studies reported forage mass of SSG ranging from 1121 to 27100 kg dry matter (DM)/ha [15] and crude protein (CP) ranging from 9 to 21% [16]. However, SSG is susceptible to sugarcane aphid (SCA) infestations which reduce forage yield and nutritive value [19,22] and economic return of the forage system [18]. Previous literature has reported yields in forage sorghum reduced by as much as 447 kg/ha due to SCA infestations [21]. Forage mixtures could be a viable option to diversify forage systems, extend the forage production season, and reduce pest losses.

The use of legume-grass mixtures has increased in the southern U.S. aiming to improve forage production and nutritive value. Large crabgrass (CRAB) is often considered a weed [40,41], but has forage mass ranging from 1599 to 10000 kg DM/ha [44] and CP ranging from 8.0 to 17.0% [7]. Cowpea (COW) is a high-protein legume, well adapted to a wide range of environments and tolerant to drought [33,34]. Cowpea forage mass ranges from 5301 to 21801 kg DM /ha [34,37] with CP averaging 18.0% [32]. There is need to identify forage combinations that allow for increased resilience and forage production, while reducing SCA incidence in SSG systems, and incorporation of a legume may be an alternative. In this study, forage agronomic responses and SCA infestation were determined for mono-, bi- and tri-mixtures of annual warm-season forages. Warm-season annual species were selected to reflect forage types commonly used by forage-livestock producers, with SSG being the most used forage which suffers from SCA infestations. This study aimed to evaluate how these forages performed when planted in mixtures with each other, and how diverse forage mixtures affected SCA populations.

The objectives of this study were to determine: a) if use of bi- and tri-mixtures reduced damage caused by SCA compared to an insecticide treatment and a non-treated monoculture, b) forage mass of forages in mono-, bi-, and tri-cultures and c) nutritive value of the mono- and mixed cultures.

# 2. MATERIALS AND METHODS

## 2.1 Experimental Site and Treatments

A 2-year study was conducted at the E.V. Smith Research Center (EVSREC) in Shorter, AL, U.S. (32.3951° N, 85.9184° W). The predominant soil is a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludults). Weather data were recorded using the Agricultural Weather Information Service station located at the research site. Weather data for both growing seasons is presented in Figure 3.

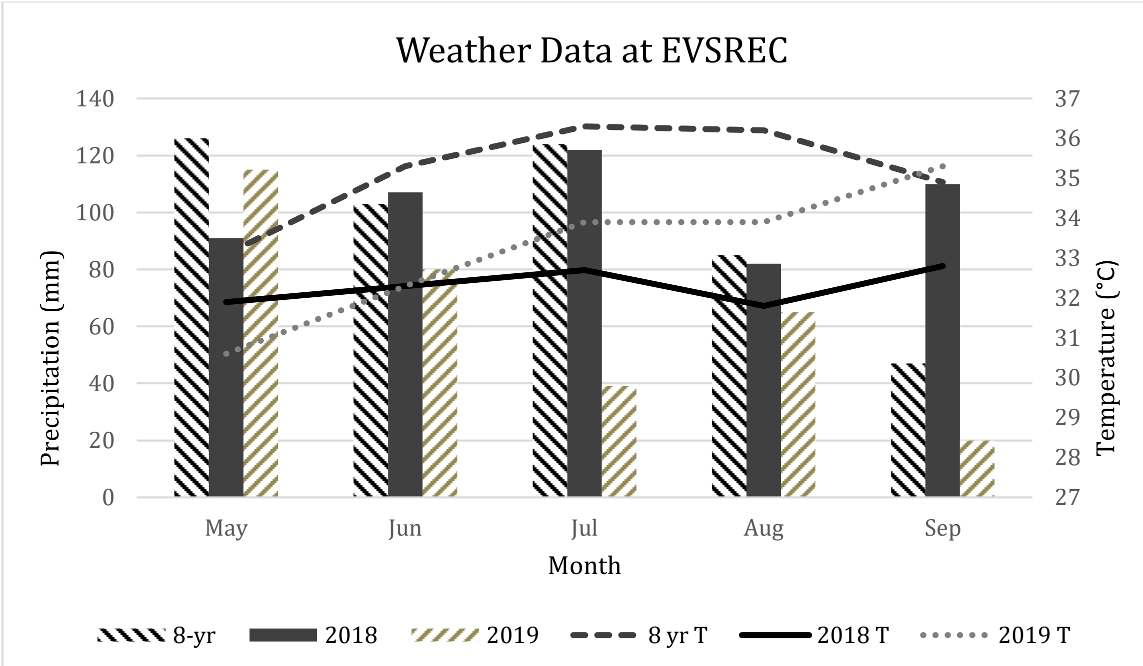


Figure 3. Weather data at EVSREC for both growing seasons.

Treatments consisted of eight forage combinations described in Table 2. Treatments were replicated eight times in a generalized randomized design resulting in 64 experimental units (9 $m^2$ each). On 12 June 2018 (year 1) and 14 June 2019 (year 2), forage treatments were planted using a no-till drill (Great Plains, Salina, KS). Seeding rates are presented in Table 1. At planting, plots were fertilized with 75 kg N/ha and P, K, and lime was applied according to soil testing recommendations [63]. In the SSGI treatment, flupyradifurone (Sivanto HL®, Bayer Crop Science LP, Research Triangle Park, NC) was applied at 292 mL/ha on 19 July and 4 September 2018 and 18 July and 28 August 2019. Spinosad (Blackhawk® Naturalyte®, DOW AgroSciences®, Indianapolis, IN) was applied on all treatments at 161 mL/ha on 4 September 2018 and 28 August 2019. Spinosad has little effect on beneficial SCA predators, such as Ladybugs (*Coccinella septempunctatae*) [64]. Spinosad was applied when Fall armyworms (*Spodoptera frugiperda*) reached an economic threshold.

Table 1. Seeding rates of eight forage treatments established at Shorter, AL.

| Forage treatment | Treatment abbreviation | Seeding rate† (kg ‡PLS/ha) |
|---|---|---|
| Cowpea | COW | 20.5 |
| Large crabgrass | CRAB | 3.3 |
| Cowpea + large crabgrass | COW + CRAB | 10.5 + 1.8 |
| Sorghum × sudangrass | SSG | 21.7 |
| Sorghum × sudangrass + cowpea | SSG + COW | 6.4 + 10.5 |
| Sorghum × sudangrass + large crabgrass | SSG + CRAB | 6.4 + 1.8 |
| Sorghum × sudangrass + cowpea + large crabgrass | SSG + COW + CRAB | 4.2 + 6.8 + 1.4 |
| Sorghum × sudangrass + flupyradifurone (Sivanto 200SL®) | SSGI | 21.7 |

†In mixtures, seeding rates correspond to each species, respectively.

‡ PLS = pure live seed

## 2.2 Response variables

### *2.2.1 Forage mass and Nutritive Value*

Plots were harvested on 26 July and 14 September in year 1 and 1 August and 12 September in year 2. Forage was harvested to 15 cm stubble height using a self-propelled forage harvester (Carter Manufacturing Company, Inc, Brookston, IN). In the field, harvested forage mass from each experimental unit was weighed using a mounted hanging scale basket. A subsample was dried in a forced air oven at 60°C for 72 h, then weighed to determine dry matter yield. Subsamples were ground to pass a 1-mm screen in a Wiley Mill (Thomas Scientific, Philadelphia, PA) prior to laboratory analysis. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined using the Van Soest et al. [4] method in an ANKOM 2000® (Ankom Technology Corporation, Fairport, NY). Samples were also analyzed for lignin [4]. Nitrogen concentration was determined using Micro-Kjeldahl digestion [65]. Crude protein concentration was calculated by multiplying N concentration by 6.25.

### *2.2.2 Sugarcane Aphid Incidence*

For both experimental years, SCA scouting was initiated at first detection on 12 July in treatments containing SSG (SSG, SSGI, SSG + COW, SSG + CRAB, SSG + COW + CRAB) and occurred weekly thereafter throughout the growing period. At each sampling event, SCA were counted on the uppermost completely unfurled and the bottommost non-senescent leaves of 10 randomly selected SSG plants per plot. Total SCA population per leaf was determined using the methods described by Haar et al. [66]. If under approximately 50 aphids were present the total numbers were counted. Otherwise, a grid was used to determine the area of infested leaf and the total number of aphids was estimated by multiplying each 0.16 inches$^2$ area by 20, which is an approximate average number of aphids per 0.16 in$^2$.

### 2.3 Statistical Analysis

Data were analyzed using PROC GLIMMIX of SAS version 9.4 (SAS Institute, Cary, NC). Harvest date was considered a repeated measure, with forage treatment and year considered fixed effects and block as a random effect. For SCA responses, forage treatment, year, and collection date were considered fixed effects and block and plant within plot were random effects. The SCA counts were averaged across top and bottom leaves per plant and lognormal transformation was used. After statistical analyses, data were transformed back to non-lognormal values. Mean comparisons in analyses of forage mass, nutritive value, and SCA were conducted using Fisher-protected least square means and all effects and interactions were considered significant at $P \leq 0.05$.

## 3. RESULTS

### 3.1 Forage mass

Forage mass (FM) was 60% greater in year 1 than 2 ($P = 0.001$; 1881 vs. 1177 kg DM/ha, respectively) due to higher rainfall during the growing season in year 1 than 2 (42.2 vs. 20.6 cm, respectively; table 2). Forage mass was not affected by forage treatments ($P = 0.927$). Between years, FM ranged from 956 to 2358 kg DM/ha (Table 2).

Table 2. Forage mass of warm-season annual forage mixtures for two experimental years at Shorter, AL.

| Forage Treatment | Herbage Mass (kg DM/ha) | |
|---|---|---|
| | Year 1 | Year 2 |
| COW[†] | 1808[‡] | 1226 |
| CRAB | 1918 | 956 |
| COW + CRAB | 1888 | 1167 |
| SSG | 1525 | 1191 |
| SSG + COW | 2018 | 1178 |
| SSG + CRAB | 1812 | 1038 |
| SSG + COW + CRAB | 1715 | 1175 |
| SSGI | 2358 | 1480 |
| SE | 302.9 | |

[†]COW = cowpea; COW + CRAB = cowpea + crabgrass; CRAB = crabgrass; SSG = sorghum × sudangrass; SSG + COW = sorghum × sudangrass + cowpea; SSG + COW + CRAB = sorghum × sudangrass + cowpea + crabgrass; SSGI = sorghum × sudangrass + flupyradifurone; SSG + CRAB = sorghum × sudangrass+ crabgrass.

[‡] Means within a row followed by a common letter are not different ($P < 0.05$).

### 3.2 Nutritive Value

There was a forage treatment by year interaction for NDF concentration ($P$ < 0.001). Differences occurred due to decrease in NDF concentrations for treatments from year 1 to year 2 ($P \leq 0.017$), except for CRAB ($P$ = 0.448) and SSG ($P$ = 0.052; Table 3). Concentration of NDF was also affected by forage treatment ($P$ < 0.001) with lower NDF concentrations in COW-containing treatments ($P \leq 0.003$). Concentration of NDF was affected by year ($P$ < 0.01) and greater concentration was observed in year 1 than 2 (66.1 vs. 55.9%, respectively).

Acid detergent fiber concentration was affected by year ($P$ < 0.001). Concentration of ADF was double in year 1 than 2 ($P$ < 0.001, 38.9 vs. 19.1%; Table 3) which is most likely associated with slower growth in year 2 resulting in reduced forage maturity. There were no differences in ADF concentration associated with forage treatments ($P$ = 0.999) and observed range was 16.5 to 39.6%.

Lignin concentration was affected by year ($P$ < 0.001), but there was no effect of forage treatment ($P$ = 0.206). Greater lignin concentration occurred in year 1 than 2 ($P$ < 0.001; 7.8 vs. 4.6%, respectively) most likely associated with less forage maturity in year 2. Among years, lignin concentration ranged from 2.7 to 9.2% (Table 3).

There was a forage treatment by year interaction for CP concentration ($P$ < 0.001). Differences occurred due to greater CP ($P$ < 0.001) for all forage treatments, except SSG ($P$ = 0.06), in Yr 2 than 1 (Table 3). Forage treatment also affected CP concentration ($P$ < 0.01). Greater CP was observed for COW ($P$ < 0.001; 12.7%) over other treatments, except COW + CRAB ($P$ = 0.098).

Table 3. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and lignin concentrations of warm-season annual forage mixtures for two experimental years at Shorter, AL.

| Forage Treatment | Response Variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CP | NDF | ADF | Lignin | CP | NDF | ADF | lignin |
| | Year 1 | | | | Year 2 | | | |
| | ---------------------------------------%--------------------------------------- | | | | | | | |
| COW† | 8.9ab‡ | 63.5b | 39.1 | 9.2 | 16.6a | 47.4d | 20.3 | 6.8 |
| COW + CRAB | 8.0bc | 63.6b | 38.2 | 9.2 | 15.8ab | 47.8d | 19.9 | 6.1 |
| CRAB | 7.2bc | 66.6ab | 38.5 | 8.6 | 9.6ab | 64.8a | 20.2 | 3.1 |
| SSG | 7.2bc | 66.6ab | 38.8 | 7.4 | 10.1cd | 64.4ab | 19.2 | 3.3 |
| SSG + COW | 6.7c | 66.4ab | 38.9 | 7.8 | 15.2ab | 49.8cd | 18.5 | 5.6 |
| SSG + COW + CRAB | 6.9c | 66.4ab | 38.6 | 7.1 | 14.5b | 52.2c | 19.2 | 5.4 |
| SSGI | 6.6c | 67.7a | 39.6 | 6.8 | 10.3cd | 61.9ab | 16.5 | 2.7 |
| SSG + CRAB | 6.7c | 67.6a | 39.3 | 6.4 | 12.1c | 59.0b | 18.7 | 3.8 |
| SE | 3.4 | 6.4 | 9.4 | 2.1 | 3.4 | 6.4 | 9.4 | 2.1 |
| *P* value | < 0.0001 | < 0.0001 | 0.999 | 0.206 | < 0.0001 | < 0.0001 | 0.999 | 0.206 |

†COW = cowpea; COW + CRAB = cowpea + crabgrass; CRAB = crabgrass; SSG = sorghum × sudangrass; SSG + COW = sorghum × sudangrass + cowpea; SSG + COW + CRAB = sorghum × sudangrass + cowpea + crabgrass; SSGI = sorghum × sudangrass + flupyradifurone; SSG + CRAB = sorghum × sudangrass+ crabgrass.

‡ Means within a row followed by a common letter are not different (*P* > 0.05)

### 3.3 Sugarcane Aphids Incidence

There was a forage treatment × collection date × year interaction ($P = 0.040$) for SCA infestations. In both years, populations of SCA increased weekly until the first forage harvest at 14 and 21 days after infestation (DAI) in year 1 and 2, respectively. In year 1, at 14 DAI, SSG + COW + CRAB and SSG + COW had greater SCA density than SSG and SSGI ($P \leq 0.048$; 419 and 397 vs. 256 and 256 aphids/leaf, respectively). After the first harvest, reappearance of SCA was observed at 35 DAI in year 1 (Fig. 4), and a second small peak was observed at 49 DAI. On 49 DAI, SSG + COW and SSG + COW + CRAB had greater SCA incidence than SSGI, SSG + CRAB, and SSG ($P \leq 0.021$; 41 and 56 vs. 13, 16, and 21 aphids/leaf, respectively). In year 2, at 21 DAI, SSG and SSGI had lower count numbers than SSG + CRAB and SSG + COW ($P \leq 0.044$; 5 and 13 vs. 35 and 24 aphids/leaf, respectively), while SSG was also lower than SSG + COW + CRAB ($P = 0.005$; 5 vs. 19 aphids/leaf, Fig. 5). Following the first harvest in year 2, SCA incidence remained below 2 aphids/leaf throughout the remaining period.

Differences between trends observed in year 1 and year 2 were likely influenced by differences in the total population sizes. There was a year × collection date interaction ($P < 0.01$), and populations of SCA were greater ($P = 0.006$) throughout the collection period in year 1 than year 2, except 21 DPI, when year 2 was greater ($P < 0.001$) than year 1, and differences in counts between years were influenced by timing of the first harvest. There was also a forage treatment × year interaction ($P = 0.001$). In year 1, SSG + COW and SSG + COW + CRAB had greater SCA incidence than other treatments ($P \leq 0.001$; 19 and 20 vs. 14, 14, and 14 aphids/leaf, respectively). In year 2, SSG + COW + CRAB and SSG + CRAB were greater than SSG and SSGI ($P \leq 0.029$; 4 and 4 vs. 2 and

2 aphids/leaf, respectively). Populations of SCA were greater in year 1 than 2 ($P < 0.01$, 16 vs. 3 aphids/leaf, respectively).

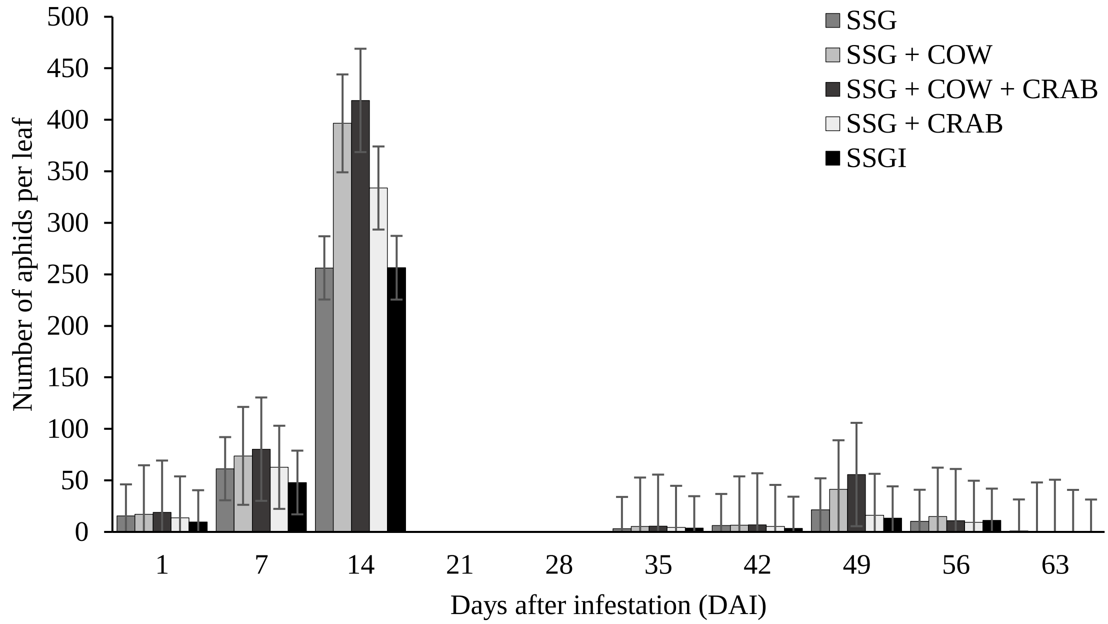


Figure 4. Sugarcane aphid population during 63-d period (from 7/12 to 9/13) in year 1. The first harvest occurred on day 14, while Sivanto HL® applications occurred prior to 14 and on 54 days after infestation (DAI).

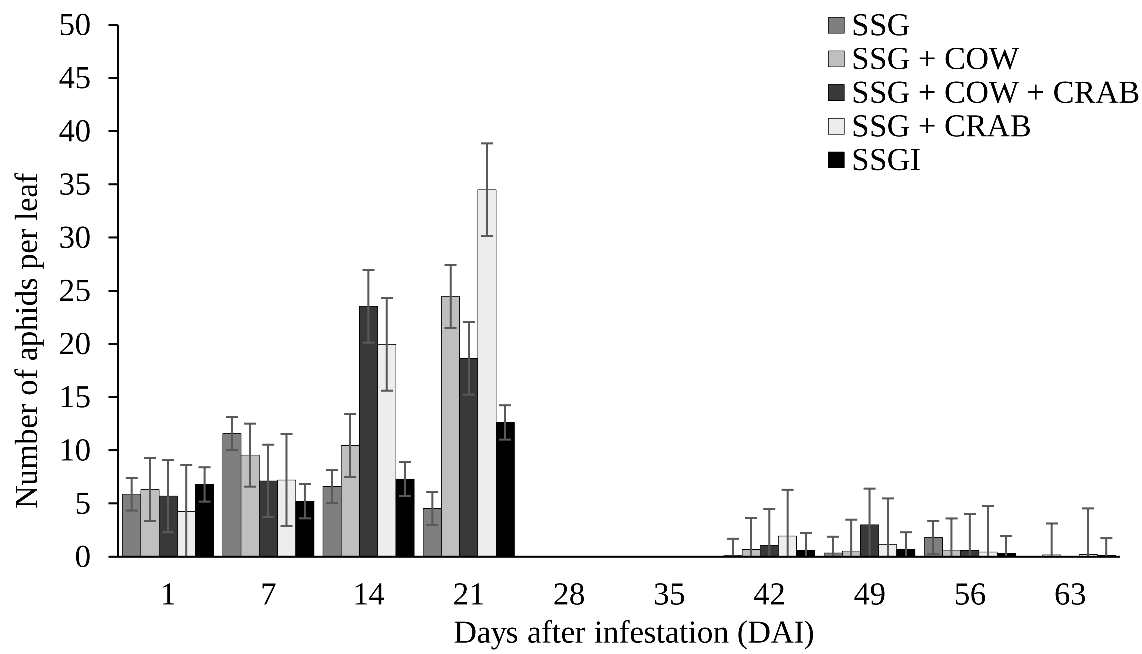


Figure 5. Sugarcane aphid population during 63-d period (from 7/11 to 9/12) in year 2. The first harvest occurred on day 21, while Sivanto HL® applications occurred prior to 14 and on 47 days after infestation (DAI).

# 4. DISCUSSION

Nave et al. [67] evaluated SSG in a monoculture and a mixture with COW managed under monthly harvests. The authors reported FM in year 1 and 2 of 2146 and 2111 kg DM/ha, respectively for the mixture, and 2030 and 2426 kg DM/ha for the monoculture. In the current study, FM was lower than results from Nave et al. [67] and differences are most likely due to geographical location, harvest frequency, and lower SSG seeding rate used than in Nave et al. [67] (33.6 vs. 12.7 kg/ha, respectively). In Turkey, Ayan et al. [32] evaluated nine cowpea cultivars planted at two locations (Samsun and Kavak) managed under irrigation, and reported FM ranging from 5502 to 8400 kg DM/ha. These values were greater than those observed in the current study, and differences were likely due to the use of irrigation, contrasting cultivars and soil types used in Ayan et al. [32]. In a study conducted in AR, U.S., Beck et al. [43] evaluated CRAB managed under 49-day regrowth period and reported FM of 9788 kg DM/ha. This response was greater than our observations in the current study and may reflect well-established hayfields used in Beck et al. [43] versus newly established fields for the current study.

Contreras-Govea et al. [68] evaluated ‘PS210BMR’, a different cultivar of SSG, and reported NDF of 52.0%, which was less than in the current study but, the difference is likely associated with differences in cultivar responses. In CRAB pastures managed under 49-d harvest interval, Beck et al. [43] reported NDF concentration of 70.0%, and the same average value was observed in the current study for CRAB (69.8%). Ayan et al. [32] reported NDF concentration for COW ranging from 29.0 to 39.0%. Differences observed between values from our and Ayan et al. [32] are most likely associated with differences between cultivars and growing conditions, including use of irrigation.

Contreras-Govea et al. [68] reported ADF concentration of 33.0% for SSG. In a CRAB hayfield managed under 49-d regrowth interval, Beck et al. [43] reported ADF concentration of 43.0% which was greater than the value observed in the current study. Ayan et al. [32] reported ADF concentration ranging from 24.0 to 31.0% for COW, similar to the range observed in the current study.

Nave et al. [67] reported CP of 7.3 and 9.9% for a SSG + COW mixture. These values were intermediate to those observed in the current study (6.7 and 15.2%, respectively, in year 1 and 2). Contreras-Govea et al. [68] reported CP concentration of 13.1% for SSG, which was greater than values observed in the current study. This difference is most likely associated with the cultivars used (‘SugarPro55’vs. ‘PS210BMR’) and N fertilization rate, 109 vs. 75 kg N/ha, for the current study and Contreras-Govea et al. [68], respectively. Beck et al. [43] reported CP of 11.0% in CRAB plots harvested every 49 d, which was higher than values reported in the current study. Ayan et al. [32] reported CP concentration ranging from 16.0 to 19.0% for COW managed under irrigation which might have played a role in CP differences between the current study and Ayan et al. [32].

In previous studies, lignin concentration reported for SSG silage was 4.8% [69], and ranges for CRAB and COW were, respectively, 1.9 to 2.9% [70] and 11.6 to 14.1% [71]. These lignin concentration values were greater than those observed in the current study and differences are most likely associated with management strategies and growing conditions.

Inter-annual variation in SCA population density has been reported in other studies [72]. In the current study, this may have been associated with poor SSG stand establishment leading to decreased forage mass (Table 2), and differences in local weather conditions [18], such as lower rainfall in year 2. The use of SSG in mixtures with other warm-season annual forages increased SCA populations when compared to SSG and SSGI monocultures. This response is most likely associated with decreased density of SSG plants in the mixtures. The decreased plant density of SSG likely led to an increased incidence of SCA per plant rather than an increase in SCA in the entire plot. Populations of SCA did not recover following the first harvest. This may be contributed to a low harvest height, which left no leaf material for SCA habitat. By the time SSG produced sufficient leaf material, SCA numbers were likely beginning to decline due to the natural seasonal cycle of the SCA. The use of a low rate of insecticide did not decrease SCA density.

## 5. SUMMARY AND CONCLUSIONS

Greater herbage mass was observed in year 1 than 2 which was associated with twice as much rainfall in year 1 during the growing season. Greater forage nutritive value was associated with year 2 and inclusion of cowpea increased CP concentration. We used a low rate of insecticide to find a more economical application rate. However, the results of our study indicate that a full rate is necessary to significantly reduce SCA below the level of a non-treated plot. We also evaluated the use of SSG in mixtures with COW and CRAB as a method to decrease SCA populations without insecticide use. The results of this study did not show a decrease in SCA populations with the use of mixtures, and in fact, mixed cultures had the higher populations. This response is likely associated with higher SCA incidence per plant due to reduction of SSG plant density per plot. These results suggest that a full rate of insecticide is needed in order to reduce SCA densities beyond a non-treated monoculture.

Based on the results of this study, the cow + crab mixture is recommended. This mixture provided the nutritive value of cowpea and the regrowth potential of crabgrass, while avoiding the use of SSG and issues with SCA infestations. The use of insecticides (e.g. flupyradifurone) in SSG is recommended to decrease herbage mass losses and economical costs due to SCA incidence. If it is of importance to avoid insecticide usage, the use of SSG in forage systems should be avoided.

Further research is needed to identify forage mixtures that can be a viable option to forage systems. Future research should also be conducted to determine the optimum application rates of insecticide to decrease expenses while containing SCA populations.

# III. Forage mass and nutritive value of grain- and forage-type soybean cultivars


## Abstract

Legumes are important sources used in feeding strategies by horse owners. In the U.S., alfalfa (*Medicago sativa L.*) and rhizoma perennial peanut (*Arachis glabrata* B.) are two common options for inclusion in horse diets. However, alfalfa acreage has decreased overtime in some regions of the country, elevating the cost due to shipping from regions of high alfalfa production (e.g., Western U.S.). Therefore, identifying alternative forages that can provide a regional resource as a forage-based protein source for horse diets is crucial. The objective of this study was to evaluate forage mass (FM), nutritive value and persistence of five soybean (*Glycine max*) cultivars ('Stonewall', 'Laredo', 'Tower of Leaves', Asgrow® 'AG64X8', and Asgrow® 'AG79X9') at two locations in two growing seasons under two management strategies (row spacing and stubble height). Years and location did vary, but overall Stonewall consistently had the highest FM with high nutritive value. Tower of Leaves had high FM but had lower nutritive value the Stonewall. The grain cultivars (AG64X8 and AG79X9) had high crude protein, but otherwise were inconsistent in nutritive value and had moderate FM. Laredo consistently had the lowest FM. Lower stubble heights resulted in increased FM but decreased nutritive value. Row spacing did not consistently influence either FM or nutritive values. Due to the high nutritive value and FM, Stonewall should be evaluated alone and in mixtures with other summer annual forages inclusion in equine diets.


## 1. INTRODUCTION

Forage legumes are important feed sources for horses. One of the most common protein sources is alfalfa (*Medicago sativa* L.) due to its high nutritive value and high forage mass (FM) production [73]. In some regions of the U.S. (e.g., the Southeast), there has been a decline in alfalfa acreage overtime due to harsh weather and increased pest pressure. Therefore, use of alfalfa elevates feeding costs in these regions because locally produced alfalfa is not available and it must be transported in. Another popular legume used in the Southeast is rhizoma perennial peanut (RP; *Arachis glabrata* B.) which is a perennial legume. It is well adapted to the Gulf Coast Region and is widely spread in Florida and southern regions of Georgia and Alabama [73]. However, its adoption among producers is low due to difficulties establishing RP on-farm [74]. Recently, research efforts have focused on identifying alternative high-quality forage legumes to improve feasibility of feed sources for horse producers in regions of low-alfalfa production.

One viable alternative is soybean (*Glycine max* L.), an annual legume with high nutritive value and forage production ranging from 4.5 to 13.9 Mg/ha [47]. As recently as the 1930's, soybean was an important forage crop [76] and is regaining acreage in the U.S. with the release of new forge-type cultivars [46,47]. Soybean cultivars are classified as forage or grain types, with their FM averaging 9.3 and 7.6 Mg/ha, respectively [47]. Previous studies reported similar neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations across grain- and forage-type cultivars ranging from 34.8 to 57.1% and 28.3 to 49.2%, respectively [46,47] and crude protein (CP) concentration ranges from 12.2 to 18% [46,47]. This is similar to nutritive value that has been reported for alfalfa and rhizoma perennial peanut. Alfalfa has been reported to have NDF ranging from 43.7 to 50.6%, ADF of 31.2 to 41.4%, and CP of 15.5 to 19.3% [57,58]. Rhizoma perennial peanut has been reported to have NDF of 46 to 50%, ADF of 33.2 to 36.4%, and CP of 14.6 to 23% [57,59-61].

Previous studies evaluating row spacing effects on forage soybeans have reported an increase in FM from narrower row spacings (≤ 25 cm) [46,47,74]. However, these studies have reported conflicting results on the effects of row spacing on forage nutritive value. Seiter et al. [47] observed high nutritive value at an 18-cm row spacing compared to a 36-cm spacing; however, Sheaffer et al. [46] and Hintz et al. [76] reported no row spacing effects on forage nutritive value. Seiter et al. [47] also reported taller plants when using a wider row spacing.

The adaptability of soybean cultivars to specific regions is designated by a maturity group. Maturity groups are based on time of flowering and growth stage of the soybean. This scale ranges from 00 to VIII with groups assigned a lower number better adapted to northern locations, while groups with a higher number to more southern regions [49]. The objectives of this study were to evaluate FM, persistence and nutritive value of five soybean cultivars (managed under three stubble heights with two row spacings) at two locations in Alabama.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site Description

A two year study was conducted at two locations, the E.V. Smith Research and Extension Center (EVSREC) in Shorter, AL (32°25’28”N 85°53’26”W) and the Wiregrass Research and Extension Center (WREC) in Headland, AL (31°21'23.7"N 85°19'11.7"W). At EVSREC, the predominant soils are classified as Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludults), while soils at WREC consisted of Dothan fine sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). The Agricultural Weather Information Service, Inc. stations located at each research site were used for the purpose of weather data collection. Weather data during the growing season for both sites is presented in Figures 6 and 7.

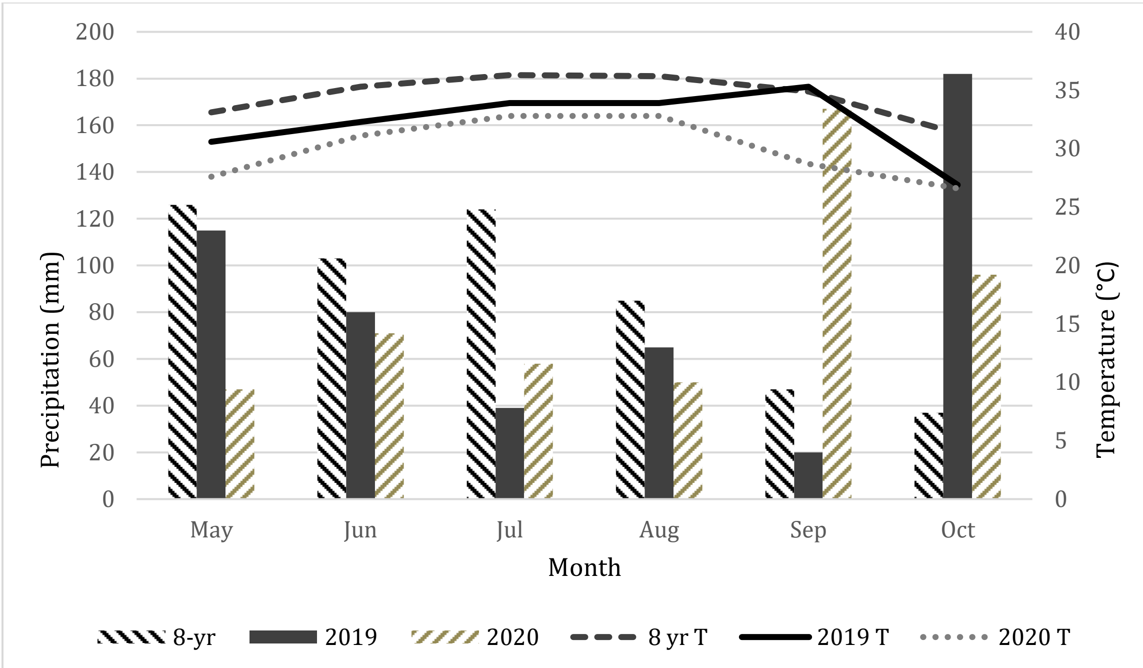


Figure 6. Weather data for both growing seasons at E.V. Smith Research and Extension Center (EVSREC) in Shorter, AL.

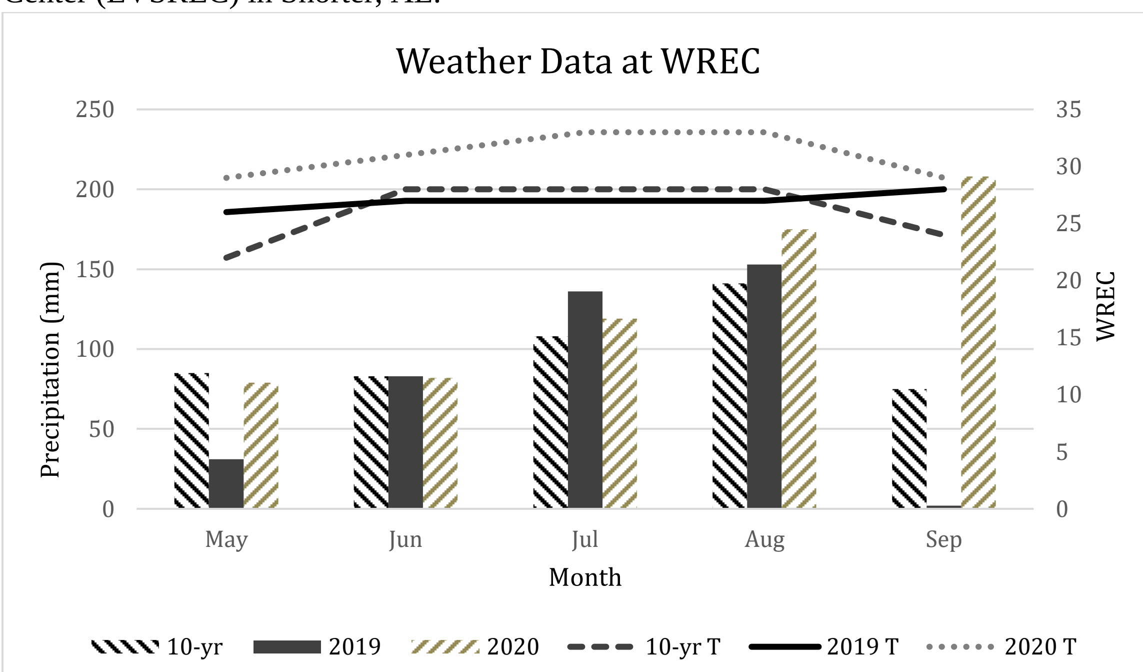


Figure 7. Weather data for both growing seasons at Wiregrass Research and Extension Center (WREC) in Headland, AL.

**2.2 Treatments and Experimental Design**

Treatments consisted of five soybean cultivars [‘Stonewall’ (PI 531068), ‘Laredo’ (PI 438495), ‘Tower of Leaves’, ‘AG64X8’, and ‘AG79X9’] managed under three stubble heights (10, 15 and 20 cm) with two row spacings (36 and 71 cm) at two locations consisting of a 5 × 3 × 2 × 2 factorial in a randomized complete block design (n = 4). Laredo and AG64X8 were maturity VI soybeans [77-79], and Stonewall and AG79X9 were maturity VII soybeans [80,81], and Tower of Leaves is described as a later maturing soybean [82]. Laredo, Tower of Leaves, and Stonewall have been bred for forage purposes while AG64X8 and AG79X9 have been bred for grain purposes [77-82]. There was a total of 120 experimental units (9 $m^2$ each) per location. In year 1 (2019), plots were planted on 21 May and 17 May at EVSREC and WREC, respectively. In year 2 (2020), plots were planted on 15 June and 3 June at EVSREC and WREC, respectively.

At planting, seeds were sown using a grain drill at rate of 518,921 pure live seed (PLS)/ha. At EVSREC, plots were fertilized with 17.6 kg N/ha in year 1, with no N added in year 2, and in both years, P, K, and lime were added according to soil test results. Based on the soil test report, no N, P, K, or lime was used at the WREC site in either year.

Plots were harvested at 25 to 50% bloom. In year 1, plots were harvested on 12 July and 8 August at EVSREC and WREC locations, respectively. Only at EVSREC, there was significant regrowth before a second harvest which occurred on 12 September (62 d regrowth period) in year 1. During year 2, plots were harvested on 11 August and 28 July at EVSREC and WREC locations, respectively. Only regrowth at WREC warranted a second harvest which occurred on 2 September (36 d regrowth period). At both locations, a Lawn Genie forage harvester (Mathews Company, Crystal Lakes, IL) was used to harvest plots.

## 2.3 Response Variables

### *2.3.1 Leaf area index*

Leaf area index (LAI) was determined prior to the first harvest at each location by taking three measurements randomly per plot below canopy using a Li-Cor LAI-2200C Plant Canopy Analyzer (LI-COR Biosciences, Lincoln, NE).

### *2.3.2 Forage mass and nutritive value*

Forage mass was determined by harvesting the whole plot and weighing each sample in the field. A subsample was taken from each plot and the wet weight was taken, the subsamples were then dried at 55°C in forced air oven for 72 hours and weighed for dry matter (DM) determination. Samples were ground to pass a 1-mm screen using a Wiley Mill (Thomas Scientific, Philadelphia, PA) for laboratory analysis. Samples were analyzed by near-infrared spectroscopy (NIR) analysis at the Auburn University Soil and Forage Testing Laboratory (Auburn, AL) during year 1 and at the University of Georgia Agricultural and Environmental Services Laboratory (Athens, GA) during year 2. Ten percent of samples were randomly selected for wet chemistry analysis to validate NIR results.

Samples selected for wet chemistry analysis were analyzed for DM, NDF, ADF, and CP. During both years, the Van Soest et al. [59] method was used to determine NDF and ADF concentrations in an ANKOM 2000® (Ankom Technology Corporation, Fairport, NY). In year 1, N concentration was determined using an elementar rapid max N [83]. Nitrogen concentration was then multiplied by 6.25 to determine CP concentration. Laboratory DM was analyzed using procedures of the AOAC [60] by drying samples overnight in a 105°C oven. In year 2, N concentration was determined by Micro-Kjeldahl digestion [65] and laboratory DM was determined by procedures of the AOAC [65] by drying samples overnight in a 105°C oven. For *in vitro* dry matter digestibility (IVDMD) concentration determination, feces were collected from four horses housed at the Auburn University Horse Center (Auburn, AL). Animals had *ad libitum* access to mixed-species pasture and were fed different proportions of Nutrena® Proelite Performance concentrate depending on their specific nutritional needs. Immediately after feces collection, feces were placed in an air-tight container in a 39°C water bath for transportation to the Auburn University Animal Nutrition Laboratory. Feces were immediately homogenized and a 400 g composite sample was blended with 1600 mL buffer solution. Buffer solution was made according to the Weller and Pilgrim method [84]. The forage samples were analyzed using a Daisy II® incubator system (ANKOM Technology Corporation, Fairport, NY) according to the Lattimer et al. [5] method.

Digestible energy was determined by Equation 1 and horse total digestible nutrients (TDN) was determined by Equation 2 [2].

$$\text{DE (Mcal/kg)} = 4.22 - (0.11 \times \text{ADF}) + (0.0332 \times \text{CP}) + (0.00112 \times \text{ADF} \times \text{ADF}) \quad (1)$$

$$\text{TDN} = (\text{DE}/4.409) \times 100 \quad (2)$$

**2.4 Statistical Analysis**

Data were analyzed using PROC MIXED of SAS version 9.4 (SAS Institute, Cary, NC). Forage mass was summed across harvests to provide a total annual FM and nutritive value responses reported as the average across harvests. Cultivar, row spacing, and stubble height were considered fixed effects, block was considered a random effect, and harvest date was considered a repeated measure. Due to the large number of samples and the lack of statistical differences between row spacings and sites, IVDMD was only performed on samples from the first harvest at one location (EVSREC) each year and at one row spacing (36-cm). Due to only being run for one location, year was considered a fixed effect for IVDMD. Mean separations were performed using Fisher-Protected LSMeans with a significance level set at $P \leq 0.05$ for all effects and interactions.

# 3. RESULTS

A combined ANOVA across all effects resulted in both location and year producing significant main effects which resulted in multiple significant interactions. Therefore, each year and individual location were analyzed separately to highlight the treatment effects of row spacing, cultivar, and stubble height (Table 4).

Table 4. Analysis of Variance table of all main effects and interactions for forage mass (FM) and nutritive value responses of soybeans in 2019 and 2020 at two locations, EVSREC and WREC.

| Year | Location | Effect | FM† | LAI‡ | CP | DE | ADF | NDF | TDN |
|---|---|---|---|---|---|---|---|---|---|
| 2019 | EVSREC | Row spacing | 0.846 | **0.023** | 0.073 | **0.019** | **0.025** | **0.036** | **0.025** |
| | EVSREC | Stubble height | **<.0001** | 0.787 | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| | EVSREC | Row spacing* stubble height | 0.236 | 0.405 | 0.372 | 0.322 | 0.281 | 0.623 | 0.329 |
| | EVSREC | Cultivar | **0.024** | 0.446 | **0.001** | 0.082 | 0.061 | 0.125 | 0.072 |
| | EVSREC | Row spacing* cultivar | 0.476 | 0.495 | 0.893 | 0.966 | 0.883 | 0.810 | 0.943 |
| | EVSREC | Stubble height *cultivar | 0.504 | 0.133 | 0.438 | 0.304 | 0.281 | 0.200 | 0.297 |
| | EVSREC | Row Spacing* stubble height* cultivar | 0.901 | **0.045** | 0.638 | 0.559 | 0.364 | 0.499 | 0.441 |
| 2020 | EVSREC | Row spacing | 0.084 | 0.331 | 0.382 | 0.283 | 0.623 | 0.740 | 0.459 |
| | EVSREC | Stubble height | **<.0001** | 0.710 | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| | EVSREC | Row spacing* stubble height | 0.018 | 0.204 | 0.141 | **0.030** | 0.296 | 0.259 | 0.114 |
| | EVSREC | Cultivar | **<.0001** | **<.0001** | **0.025** | 0.071 | 0.170 | 0.065 | 0.055 |
| | EVSREC | Row spacing* cultivar | 0.689 | 0.762 | 0.415 | 0.384 | 0.541 | 0.434 | 0.327 |
| | EVSREC | Stubble height *cultivar | 0.214 | 0.203 | 0.348 | 0.921 | 0.783 | 0.762 | 0.473 |
| | EVSREC | Row spacing* stubble height* cultivar | 0.004 | 0.054 | 0.185 | 0.494 | 0.898 | 0.927 | 0.453 |
| 2019 | WREC | Row spacing | **0.015** | 0.065 | 0.192 | 0.266 | 0.147 | 0.063 | 0.227 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WREC | Stubble height | **<.0001** | 0.339 | **0.001** | **0.018** | 0.192 | 0.531 | **0.011** |
| | WREC | Row spacing* stubble height | **0.020** | 0.620 | 0.857 | 0.979 | 0.973 | 0.672 | 0.991 |
| | WREC | Cultivar | **0.002** | 0.416 | 0.227 | **0.015** | **<.0001** | **0.012** | **0.012** |
| | WREC | Row spacing* cultivar | 0.195 | 0.886 | 0.206 | 0.072 | 0.053 | 0.136 | 0.166 |
| | WREC | Stubble height *cultivar | 0.321 | 0.998 | 0.684 | 0.746 | 0.719 | 0.766 | 0.750 |
| | WREC | Row spacing* stubble height* cultivar | 0.239 | 0.569 | 0.328 | 0.328 | 0.442 | 0.564 | 0.407 |
| 2020 | WREC | Row spacing | 0.948 | **<.0001** | **0.002** | **0.001** | 0.064 | **0.024** | **0.005** |
| | WREC | Stubble height | **<.0001** | 0.349 | **0.000** | **0.000** | **0.001** | 0.156 | **0.000** |
| | WREC | Row spacing* stubble height | 0.869 | 0.082 | 0.951 | 0.871 | 0.253 | 0.449 | 0.796 |
| | WREC | Cultivar | **<.0001** | **0.000** | **<.0001** | **<.0001** | **0.001** | **0.004** | **<.0001** |
| | WREC | Row spacing* cultivar | 0.469 | 0.053 | 0.448 | 0.343 | 0.325 | 0.569 | 0.361 |
| | WREC | Stubble height *cultivar | 0.396 | 0.336 | 0.816 | 0.911 | 0.587 | 0.928 | 0.806 |
| | WREC | Row spacing* stubble height* cultivar | 0.376 | 0.685 | 0.889 | 0.812 | 0.469 | 0.676 | 0.845 |

† LAI = leaf area index FM = forage mass; DE= digestible energy; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = horse total digestible nutrients; IVDMD = *in vitro* dry matter digestibility; TDN = horse total digestible nutrients

‡ LAI was not evaluated for stubble height.

### 3.1 E.V. Smith Research and Extension Center

Table 5. Forage mass (FM) and nutritive value of soybeans grown during two years and at EVSREC

| **Item** | | **Year** | **FM**[†] | | **LAI** | | **CP** | | **DE** | | **ADF** | | **NDF** | | **TDN** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Kg DM/ha | | -- | | % | | Mcal/kg | | --------------------%--------------- | | | | | |
| **Row spacing (cm)** | 36 | 2019 | 1501[‡] | | 1.56 | B | 17.0 | | 2.51 | A | 30.1 | B | 39.2 | B | 56.9 | A |
| | 71 | 2019 | 1520 | | 1.78 | A | 16.5 | | 2.43 | B | 31.5 | A | 40.7 | A | 55.2 | B |
| | LSD | | ns | | 0.20 | | ns | | 0.06 | | 1.22 | | 1.39 | | 1.43 | |
| | 36 | 2020 | 1303 | | 3.17 | | 19.7 | | 2.22 | | 43.2 | | 52.0 | | 50.4 | |
| | 71 | 2020 | 1219 | | 3.25 | | 19.4 | | 2.21 | | 43.4 | | 52.1 | | 50.1 | |
| | LSD | | ns | | ns | | ns | | ns | | ns | | ns | | ns | |
| **Stubble Height (cm)** | 10 | 2019 | 1914 | A | 1.66 | | 14.9 | B | 2.31 | C | 33.1 | A | 41.3 | A | 52.4 | C |
| | 15 | 2019 | 1332 | B | 1.64 | | 17.4 | A | 2.47 | B | 31.0 | B | 41.1 | A | 56.2 | B |
| | 20 | 2019 | 1286 | B | 1.71 | | 17.9 | A | 2.63 | A | 28.2 | C | 37.5 | B | 59.5 | A |
| | LSD | | 237 | | ns | | 0.61 | | 0.08 | | 1.5 | | 1.7 | | 1.74 | |
| | 10 | 2020 | 1498 | A | 3.21 | | 18.3 | B | 2.15 | B | 45.0 | A | 53.5 | A | 48.8 | B |
| | 15 | 2020 | 1131 | B | 3.17 | | 20.3 | A | 2.25 | A | 42.5 | B | 51.4 | B | 51.0 | A |
| | 20 | 2020 | 1155 | B | 3.25 | | 20.0 | A | 2.24 | A | 42.3 | B | 51.2 | B | 50.8 | A |
| | LSD | | 115 | | ns | | 0.71 | | 0.04 | | 1.22 | | 1.02 | | 0.81 | |
| **Cultivar** | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AG64X8 | 2019 | 1643 | AB | 1.51 | | 17.3 | A | 2.46 | 31.4 | 40.4 | 55.9 |
| AG79X9 | 2019 | 1351 | BC | 1.69 | | 17.4 | A | 2.51 | 30.0 | 39.4 | 57.2 |
| Laredo | 2019 | 1294 | C | 1.66 | | 15.9 | C | 2.44 | 30.8 | 40.4 | 55.4 |
| Stonewall | 2019 | 1744 | A | 1.81 | | 16.7 | AB | 2.53 | 29.4 | 38.4 | 57.4 |
| Tower of Leaves | 2019 | 1521 | ABC | 1.68 | | 16.5 | BC | 2.40 | 32.2 | 41.1 | 54.5 |
| LSD | | 307 | | ns | | 0.79 | | ns | ns | ns | ns |
| AG64X8 | 2020 | 1365 | B | 3.32 | B | 19.8 | A | 2.21 | 43.7 | 52.2 | 50.3 |
| AG79X9 | 2020 | 1183 | C | 3.12 | B | 19.7 | A | 2.24 | 42.6 | 51.5 | 50.6 |
| Laredo | 2020 | 869 | D | 3.64 | A | 19.5 | A | 2.20 | 43.7 | 52.7 | 50.1 |
| Stonewall | 2020 | 1362 | B | 2.64 | C | 18.6 | B | 2.18 | 44.0 | 52.7 | 49.4 |
| Tower of Leaves | 2020 | 1528 | A | 3.33 | D | 20.0 | A | 2.24 | 42.4 | 51.2 | 50.9 |
| LSD | | 150 | | 0.27 | | 0.92 | | ns | ns | ns | ns |

† FM = forage mass; LAI = leaf area index; DE= digestible energy; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = horse total digestible nutrients; IVDMD = *in vitro* dry matter digestibility; LSD = least significant difference; ns = not significant

‡ Means from a main effect within a column followed by a common letter are not different ($P < 0.05$).

### *3.1.1 Year 1*

During the 1st year at EVSREC, there was an effect of row spacing on LAI, DE, ADF, NDF, and TDN. The greatest LAI, ADF, and NDF was seen from the 71-cm row spacing, where the 36-cm row spacing produced the greatest DE and TDN. There was no effect of row spacing on FM and CP.

Stubble height affected FM, CP, DE, ADF, NDF, and TDN. Forage mass was greatest and CP was least in the 10-cm stubble height, while there were no differences in those two parameters between the 15- and 20-cm stubble heights. The 20-cm stubble height produced the greatest DE and TDN, while the 15-cm stubble height also had greater DE and TDN than the 10-cm stubble height. The greatest ADF was seen in plots harvested at 10-cm, while the 15-cm stubble height also resulted in greater ADF than the 20-cm height. There was greater NDF in the 10- and 15-cm stubble heights than the 20-cm stubble height. There was no effect of stubble height on LAI.

There was an influence of cultivar on FM and CP. Tower of Leaves had no differences in FM compared to any other cultivar. Laredo had lesser FM than AG64X8 and Stonewall, and Stonewall also had greater FM than AG79X9. Stonewall, AG64X8, and AG79X9 had greater CP than Laredo, and AG64X8 and AG79X9 also had greater CP than Tower of Leaves. Leaf area index, DE, ADF, NDF, and TDN were not affected by cultivar.

### *3.1.2 Year 2*

In year 2, there was no influence of row spacing on any parameter tested (FM, LAI, CP, DE, ADF, NDF, and TDN).

There was an effect of stubble height on FM, CP, DE, ADF, NDF, and TDN. The 10-cm stubble height produced the greatest FM, ADF, and NDF and the least CP DE, and TDN. There were no differences between the 15- and 20-cm stubble heights for any parameter. There was no effect of stubble height on LAI.

Cultivar affected FM, LAI, and CP. Laredo had the least FM and Tower of Leaves had the greatest. Stonewall and AG64X8 had greater FM than AG79X9. The greatest LAI was seen in Laredo, while the least was in Tower of Leaves. Stonewall had lesser LAI than AG64X8 and AG79X9. Stonewall had the least CP, and there were no differences in CP between the other cultivars. There was no influence of cultivar on DE, ADF, NDF, and TDN.

### 3.2 Wiregrass Research and Extension Center

Table 6. Forage mass (FM) and nutritive value of soybeans grown during two years and at WREC

| Item | | Year | FM† | | LAI | | CP | | DE | | ADF | | NDF | | TDN | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kg DM/ha | | | | % | | Mcal/kg | | --------------------%-------------------- | | | | | |
| Row spacing (cm) | 36 | 2019 | 1073‡ | B | 2.15 | | 13.3 | | 2.21 | | 34.3 | | 39.7 | | 50.3 | |
| | 71 | 2019 | 1234 | A | 2.4 | | 13.8 | | 2.24 | | 33.8 | | 38.3 | | 51.0 | |
| | LSD | | 128 | | ns | | ns | | ns | | ns | | ns | | ns | |
| | 36 | 2020 | 2100 | | 2.34 | B | 13.6 | B | 2.00 | B | 43.9 | | 52.6 | A | 45.5 | B |
| | 71 | 2020 | 2095 | | 2.62 | A | 14.7 | A | 2.05 | A | 43.3 | | 52.0 | B | 46.5 | A |
| | LSD | | ns | | 0.12 | | 0.73 | | 0.03 | | ns | | 0.47 | | 0.69 | |
| Stubble Height (cm) | 10 | 2019 | 1459 | A | 2.21 | | 12.4 | B | 2.18 | B | 34.5 | | 39.6 | | 49.4 | B |
| | 15 | 2019 | 1132 | B | 2.42 | | 14.0 | A | 2.25 | A | 33.6 | | 38.6 | | 51.3 | A |
| | 20 | 2019 | 869 | C | 2.2 | | 14.2 | A | 2.25 | A | 34.0 | | 38.9 | | 51.2 | A |
| | LSD | | 157 | | ns | | 0.98 | | 0.06 | | ns | | ns | | 1.37 | |
| | 10 | 2020 | 2720 | A | 2.52 | | 13.0 | B | 2.0 | B | 44.5 | A | 52.7 | | 45.0 | B |
| | 15 | 2020 | 2010 | B | 2.42 | | 14.5 | A | 2.0 | A | 43.0 | B | 52.1 | | 46.5 | A |
| | 20 | 2020 | 1562 | C | 2.5 | | 15.0 | A | 2.1 | A | 43.3 | B | 52.2 | | 46.7 | A |
| | LSD | | 182 | | ns | | 0.89 | | 0.04 | | 0.75 | | ns | | 0.84 | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AG64X8 | 2019 | 1095 | BC | 2.41 | | 13.0 | | 2.22 | B | 33.7 | B | 38.9 | A | 50.4 | B |
| | AG79X9 | 2019 | 1035 | C | 2.08 | | 14.0 | | 2.23 | B | 34.4 | AB | 39.1 | A | 50.7 | B |
| | Laredo | 2019 | 1005 | C | 2.16 | | 13.3 | | 2.19 | B | 34.9 | AB | 40.6 | A | 49.8 | B |
| | Stonewall | 2019 | 1372 | A | 2.31 | | 14.2 | | 2.31 | A | 32.1 | C | 36.6 | B | 52.6 | A |
| | Tower of Leaves | 2019 | 1259 | AB | 2.41 | | 13.4 | | 2.19 | B | 35.1 | A | 39.8 | A | 49.8 | B |
| **Cultivar** | LSD | | 204 | | ns | | ns | | 0.08 | | 1.28 | | 2.30 | | 1.77 | |
| | AG64X8 | 2020 | 2130 | BC | 2.72 | A | 15.6 | A | 2.08 | A | 43.3 | B | 51.9 | B | 47.2 | A |
| | AG79X9 | 2020 | 2057 | C | 2.58 | A | 14.0 | B | 2.03 | AB | 42.9 | B | 51.8 | B | 46.1 | AB |
| | Laredo | 2020 | 1507 | D | 2.34 | B | 15.7 | A | 2.07 | A | 43.7 | B | 52.8 | A | 47.1 | A |
| | Stonewall | 2020 | 2344 | AB | 2.33 | B | 13.2 | BC | 2.00 | B | 43.1 | B | 52.0 | B | 45.4 | BC |
| | Tower of Leaves | 2020 | 2449 | A | 2.43 | B | 12.3 | C | 1.95 | C | 44.8 | A | 52.9 | A | 44.4 | C |
| | LSD | | 235 | | 0.19 | | 1.15 | | 0.05 | | 0.97 | | 0.74 | | 1.09 | |

† FM = forage mass; LAI = leaf area index; DE= digestible energy; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = horse total digestible nutrients; IVDMD = *in vitro* dry matter digestibility; LSD = least significant difference; ns = not significant

‡ Means from a main effect within a column followed by a common letter are not different ($P < 0.05$).

### *3.2.1 Year 1*

There was an influence of row spacing on FM in year 1. The greatest FM was produced from the 71-cm row spacing. There was no effect of row spacing on LAI, CP, DE, ADF, NDF, and TDN.

Stubble height effected FM, CP, DE, and TDN. Forage mass was greatest in the 10-cm stubble height and least in the 20-cm stubble height. The 10-cm stubble height resulted in the least CP, DE, and TDN. There were no differences between the 15- and 20-cm stubble heights for those parameters. Leaf area index, ADF, and NDF were not affected by stubble height.

Forage mass, DE, ADF, NDF, and TDN were affected by cultivar. Stonewall had greater FM than AG64X8, AG79X9, and Laredo, and Tower of Leaves was also greater than AG79X9 and Laredo. Stonewall had the greatest DE and TDN, while there were no differences between the other cultivars. Stonewall had the least ADF and AG64X8 also had less ADF than Tower of Leaves. Stonewall had lesser NDF than all other cultivars, and there were no differences between other cultivars. There was no influence of cultivar on LAI and CP.

### *3.2.2 Year 2*

Row spacing influenced LAI, CP, DE, NDF, and TDN during the 2$^{nd}$ year. The 36-cm row spacing produced the least LAI, CP, DE, and TDN, while the 71-cm row spacing produced the least NDF. There was no effect of row spacing on FM and ADF.

There was an effect of stubble height on FM, CP, DE, ADF, and TDN. Forage mass was greatest in the 10-cm stubble height and least in the 20-cm stubble height. The 10-cm stubble height produced the least CP, DE, and TDN, and the greatest ADF. There were no differences between the 15- and 20-cm stubble heights for those parameters. Leaf area index and NDF were not influenced by stubble height.

All parameters (FM, LAI, CP, DE, ADF, NDF, and TDN) were influenced by cultivar. Laredo had the least FM, while AG79X9 had lesser FM than Stonewall and Tower of Leaves and AG64X8 had lesser FM than Tower of Leaves. AG64X8 and AG79X9 had greater LAI than Laredo, Stonewall, and Tower of Leaves. Laredo and AG64X8 had the greatest CP and AG79X9 also had greater CP than Tower of Leaves. Tower of Leaves had the least DE and TDN and Stonewall also had lesser DE and TDN than Laredo and AG64X8. Tower of Leaves had greater ADF than all other varieties, while Tower of Leaves and Laredo had the greatest NDF.

### 3.3 *in vitro* Dry Matter Digestibility-

Table 7. *in vitro* dry matter digestibility (IVDMD) means and *P*-values across 2019 and 2020 at EVSREC for stubble height and cultivar

| | | IVDMD | | |
|---|---|---|---|---|
| | | % | | |
| Stubble height | 10 | 67.3 | C | |
| | 15 | 75.1 | B | |
| | 20 | 76.6 | A | |
| LSD† | | 1.5 | | |
| Cultivar | AG64X8 | 74.3 | A | |
| | AG79X9 | 73.0 | ABC | |
| | Laredo | 72.0 | BC | |
| | Stonewall | 73.8 | AB | |
| | Tower of Leaves | 71.8 | C | |
| LSD | | 1.88 | | |
| *P*-value | Stubble height | | | <.0001 |
| | Cultivar | | | 0.044 |
| | Stubble height* cultivar | | | 0.097 |

†LSD = least significant difference

There were effects of stubble height and cultivar on IVDMD. Plots harvested to 10-cm had the least IVDMD, while those harvested to 20-cm had the greatest. Tower of Leaves had lesser IVDMD than AG64X8 and Stonewall and Laredo also had lesser IVDMD than AG64X8.

## 4. DISCUSSION

There were multiple significant interactions between years and locations, which necessitated analyzing years and individual locations separately. Differences in FM between locations and years are likely due to differences in weather patterns, soil type, weed influences, and planting date. A late planting at EVSREC in year 2 resulted in decreased FM for that location in year 2 compared to year 1. Low early-season precipitation and weed pressure resulted in decreased FM at WREC in year 1 compared to year 2. The greatest FM was seen at WREC in year 2, when over half of the plots were able to be harvested twice.

The current study found FM to increase at wider row spacings at WREC in year 1 but found no differences between row spacings in other years and locations. This is different from what previous studies have found; studies by Wax and Pendleton [51] and Seiter et al. [47] observed greater FM at narrower row spacings. Potential differences between FM responses due to row spacings may be due to a much broader range of row spacings used in the previous studies compared to the current study. The greatest FM was consistently observed at the 10-cm stubble height. Harvesting at lower stubble heights results in more overall plant material being collected, which produces a greater FM.

Forage cultivars (Stonewall and Tower of Leaves) typically had greater average yearly FM than varieties which had been bred for grain use (AG79X9 and AG64X8). The only exception to this was Laredo, which is thought to be the oldest soybean cultivar still in use, dating back to as early as 1915 [77]. Due to being an older cultivar, Laredo may not have been selectively bred for a higher forage yield to the same extent as the newer cultivars. Additionally, Laredo was visually observed to be much slower germinating than the other cultivars in year 2 and therefore had a poor stand at the time of harvest. There did not appear be an effect of cultivar maturity ratings on FM which is likely due to the narrow range of maturity ratings tested in the current study.

The FM observed in the current study was greater than those reported by Rao et al. [45], but similar or less than FM observed by Sturkie [75] and Hintz et al. [76]. Sturkie [75] also found greater FM for Laredo than the current study. Differences between studies may potentially be attributed to different soybean cultivars used, as well as differences in different climatic conditions among locations [45,75,76]. Additionally, maturity at the time of harvest and differences in seeding rates could play a factor in differences in FM.

Leaf area index and FM did not follow the same pattern. A high LAI did not always correlate with a high FM and vice versa. This may be influenced by the growth habits of the soybeans at different locations and years, as well as possible weed presence. These results potentially demonstrate that LAI is not a good indicator of yield in forage soybeans.

Weber et al. [86] reported an effect of row spacing on LAI; however, greater LAI was associated with narrower row spacings, whereas our study found greater LAI in wider row spacings. Differences between studies in the effect of row spacing on LAI may have been due to a much broader range of row spacings used in the previous study (13 –

102 cm vs. 36 – 71 cm) [86]. It is likely that the greater LAI seen in wider row spacings in the current study is due to the wider row spacing allowing for more room for the individual plants and therefore resulting in a more horizontal growth habit. The current study also found lower LAI than the previous study, which reported a mean LAI of 4.9 from a 51 cm row spacing [86]. It is possible that differences seen in LAI are due to differences in methods of determining LAI, with the previous study taking place in the 1960s [86] before the current technology was available. There did not appear to be a consistent influence of cultivar on LAI, and therefore LAI was also likely not influenced by forage maturity rating or cultivar type.

Differences in nutritive value responses between locations and years may have been due to factors influencing plant maturity at the time of harvest, including planting date, harvest dates, and number of harvests, as well as weather conditions and weed pressure. Decreased forage nutritive value during year 2 at EVSREC may have been due to increased forage maturity due to a harvesting a month later because of a late planting. Increased CP at that location and year may have also been associated with increased pod biomass on more mature forage. Nutritive value at WREC was slightly decreased during year 2 due to higher fiber fractions. A possible explanation for this is the second harvest in year 2, which may have resulted in less leaf biomass as the soybeans were nearing the end of their growing season.

There was an inconsistent influence from row spacing on nutritive value responses. Row spacing produced opposite responses in nutritive values at EVSREC in year 1 and WREC in year 2, while it did not affect EVSREC year 2 and WREC year 1. This makes it difficult to determine the influence of row spacing on nutritive value responses. A study conducted by Hintz et al. [76] found no influence of row spacing on nutritive value. Seiter et al. [47] however, did find an effect of row spacing on nutritive value responses. The authors attributed this to an increased stem diameter in wider spaced rows and observed this in 18- and 36-cm row spacings [47]. It could be hypothesized that a smaller row spacing would have put the plants in separate rows in much closer proximity to each than 36- or 71-cm row spacings did, which may cause differences in observed nutritive value.

Stubble height consistently influenced nutritive value responses at all locations and years. Decreased nutritive value with decreasing stubble heights is likely the result of an increased stem fraction at the shorter stubble heights as compared to the taller heights, increasing overall fiber fractions within the harvested forage.

The influence of cultivar on nutritive value was not as profound at EVSREC compared to WREC. This may have been influenced by differences in adaptability of the soybean cultivars to WREC, as well as influences due to drought during the first study year at WREC. The two grain cultivars, AG64X8 and AG79X9 had frequently had higher CP than the other cultivars. This is likely influenced by an increased pod biomass in these two cultivars compared to the forage cultivars.

The lowest DE and TDN was produced from Tower of Leaves at WREC during year 2, however, it was still high enough to satisfy the DE requirements [2] of horses with varying maintenance energy requirements when fed at levels below 2% of body weight, and horses in moderate exercise when fed at 2.4% of body weight.

There did not seem to be a consistent effect on either maturity rating or cultivar type on nutritive value. The only influence from cultivar type appeared to be in CP and

IVDMD, where grain cultivars often had a higher CP and IVDMD than forage cultivars. There did not appear to be an influence from maturity on any nutritive value response, however.

Concentrations of CP and ADF by cultivar were intermediate to previously reported values [46,76], while NDF was on the lower end of previously observed ranges [46,76]. Soybean nutritive value responses are likely influenced by plant maturity. Therefore, these differences may be partially attributable to differences in planting dates and maturity at the time of harvest between studies. Concentrations of IVDMD in the current study were greater than those reported in a previous study by Acikgoz et al. [87]. This may be attributable to differences in cultivars used; however, it is likely largely due to the previous study using sheep *in vivo* digestibility method [87], while the current study used an *in vitro* batch culture fermentation using equine fecal inoculum. The current study is likely the first study to report DE and horse TDN on forage soybean.

Soybeans appear to be a viable, safe alternative to alfalfa and RP in horse production systems. Forage mass observed in soybeans was lower than previous reports for the other two species; however, nutritive value responses were similar. The greatest total yearly FM seen in the current study was 2449 kg DM/ha, which was seen in Tower of Leaves at WREC in year 2, while previously observed FM in alfalfa has ranged from 7700 to 12600 kg DM/ha, and FM in RP has been reported to range from 3450 to 4330 kg DM/ha during the establishment year and 5200 to 10600 kg DM/ha for subsequent years [56,57,59]. Alfalfa and RP are usually harvested multiple times per growing season. In the current study, soybeans were not consistently harvestable more than once per growing season, as a result, it can be concluded that soybean likely has less in-season persistence than the other two species. This may contribute to the reduced yields seen in soybean compared to its warm-season perennial counterparts.

Crude protein concentrations for soybeans in the current study were within or slightly lower than the previously noted ranges of 15.5 to 19.3% in alfalfa and 14.6 to 23.0% in RP [57-61]. Concentrations of NDF for soybeans averaged across years in the current study were also similar to those reported for alfalfa of 43.7 to 50.6% and RP of 46.0 to 50.0%, while average ADF concentrations in the current study were greater than the observed range of 33.2 to 36.4% in RP and comparable to the previously noted range of 31.2 to 41.4% in alfalfa [57-61]. The IVDMD observed in soybeans was greater than that reported in either alfalfa (54.2 to 59.0%) or RP (50.5 to 61.6%) in previous studies [57,58,61]. It is difficult to make direct comparisons of IVDMD due to the use of equine fecal inoculum in the current study, however a study using sheep also reported slightly higher *in vivo* DM digestibility than those reported in alfalfa and RP [87]. Assuming a DM intake of 2.5% of body weight, alfalfa, RP, and soybeans meet the CP requirements of all classes of horses listed by the NRC [2].

While soybean does not produce as high FM, it is highly competitive with alfalfa and RP in regards to nutritive value. Soybeans provide a “short season” crop option compared to alfalfa and RP, which have longer establishment periods. This may make soybeans a useful option to use for a crop rotation system, whereas alfalfa and RP require an establishment year and therefore require fields to be committed for multiple years. Another useful option for soybeans is during years of hay shortage and poor soybean grain performance. Soybean crops which have been planted for grain may potentially be harvested for hay, to provide an “emergency” forage option and recoup some of the losses which would have incurred from a poor grain harvest.

## 5. CONCLUSIONS

Soybean did not produce as high of FM as reported previously in alfalfa or RP; however, its nutritive value was highly competitive with the other two species. Therefore, soybean may be a viable forage option when alfalfa and RP are unavailable. Another viable option for soybean is to cut it for hay during periods of hay shortage and when grain harvests are not looking promising.

The cultivar Stonewall had greater FM and had better nutritive value than other cultivars tested. The CP observed for Stonewall was typically on the lower end, however, the biggest difference seen was at WREC during year 2, when Stonewall had 2.5% less CP than Laredo, which had the greatest CP. Stonewall also still meets the nutritional requirements reported by the NRC [2] for all classes of horses when assuming a DM intake of 2.5% of body weight.

Row spacing had an inconsistent influence on the parameters tested. Previous studies have shown the optimum row spacing to be narrower than this study testing. Future research with soybean planting in narrower row spacings, comparable to other annual forage plantings, may provide additional information on forage performance. Stubble height had an inverse relationship with FM, but forage nutritive value was reduced with decreased stubble heights. Producers likely need to balance FM with forage quality when deciding on an appropriate stubble height. The 15-cm stubble height appeared to have the best mix of FM and nutritive value and is likely the ideal cutting height.

There is still much that needs to be studied in regards to soybeans for forage production. Due to inconsistencies between the current study and previous literature, further research needs to be done to find the ideal row spacing for forage soybeans. Grazing and cutting may produce different responses in forage; therefore, grazing studies should be conducted in the future to truly determine the promise of soybeans as a grazing forage. Finally, because soybeans are likely a one-harvest hay crop research needs to be done to determine the planting dates and harvest maturity which optimize forage mass and nutritive value.

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