Sunn hemp (*Crotalaria juncea* L.) as a Cover Crop for Winter Wheat

by

Anna Stallings

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Approved by

Kipling Balkcom, Chair, Affiliate Associate Professor, Crop, Soil, and Environmental Science, Auburn University
Elizabeth Guertal, Professor, Crop, Soil, and Environmental Sciences, Auburn University
David Weaver, Professor, Crop, Soil, and Environmental Sciences, Auburn University
C. Wesley Wood, Professor and Director, West Florida Research and Education Center, University of Florida

Abstract

The use of cover crops in conjunction with non-inversion tillage is a popular conservation system that is incorporated into production rotations to improve profitability and sustainability of depleted soils in the Southeast. Due to fluctuating fertilizer costs and potential environmental hazards, producers should look to relinquishing their heavy dependence on synthetic fertilizers and opt to utilizing legume cover crops as a biological alternative for Nitrogen (N) fertilization. Sunn hemp (*Crotalaria juncea* L.) is a tropical legume capable of producing large amounts of biomass and symbiotic N in as little as 8-12 weeks during summer months, which makes it an ideal candidate to include in crop rotations where time is limited. The inability of previous sunn hemp cultivars to produce viable seed in the temperate climate of the U.S. led to limited seed supply. Extensive use of this cover crop species has been limited due to high cost and low availability of the seed. However, the latest breeding efforts of Auburn University produced the sunn hemp cultivar ‘AU Golden’, capable of producing seed under temperate climate conditions. In order to maximize profitability of a new plant species, proper management strategies must be determined through performance evaluations. The first objective of this study was to compare three sunn hemp planting dates with regard to biomass production, N accumulation, and forage quality at three locations to determine an optimum planting date. A second objective was to determine if sunn hemp would be effective in reducing N fertilizer requirements for a subsequent winter wheat (*Triticum aestivum* L.) crop. The final objective was to monitor the decomposition and N release of sunn hemp residue in the field at two locations between cover crop termination and wheat planting. Overall, ‘AU Golden’ biomass production averaged 7.0 Mg ha^{-1} in 2012 and 5.9 Mg ha^{-1} in 2013. Sunn hemp N content corresponded to sunn hemp biomass production, while N concentration was inversely related. Biomass and N production were 87% and 55% higher for June and July plantings when compared with May during 2012, across the three locations. Excessive precipitation and milder temperatures reduced production for the second growing season. Biomass and N production were higher at the Tennessee Valley Research and Extension Center (TVS) and Wiregrass Research and Extension Center (WGS) locations compared to the Plant Breeding Unit (PBU), with superior production seen during May and June plantings compared with July plantings. Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) values for sunn hemp 25-30 days after planting (DAP) indicated that leaves would serve as suitable forage for livestock, but ADF and NDF measurements for stems were too high to be considered easily digestible. Wheat yields following sunn hemp resulted in little to no difference when compared with yields following a fallow area for the 2013 and 2014 growing seasons. Wheat yields for fallow plots were 30% higher than yields following sunn hemp plots when treated with recommended rates of urea ammonium nitrate (UAN) at the TVS location during the 2013 growing season. Little difference was observed among planting date treatments for 2014 wheat yields across three locations. Wheat yields were similar for the 2014 growing season at TVS and WGS in comparison with PBU, at which yields were 37% lower. Sunn hemp mineralization data suggests that N was released quickly, and the rapid decomposition limited the N contribution to the subsequent wheat crop. In

some cases, as much as 65% of N was lost within the first two weeks of decomposition, leaving little to no available N for wheat uptake. These results indicate that further evaluation of proper management systems for this cultivar must be conducted in order to successfully introduce ‘AU Golden’ sunn hemp as an advantageous cover crop in the Southeast.

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I. INTRODUCTION

CONSERVATION SYSTEMS

Land management mistakes that have occurred in the past drive the continuous conservation efforts of present day agriculture (Langdale et al., 1992). Conservation practices are highly valued today for the role they play in precision and sustainable agriculture production. Food production continues to increase in order to meet food security needs, and the future of global food production could be in jeopardy if the profitability of arable land is not sustained for future generations (Kassam et al., 2009). Present day agriculture places emphasis on enhancing economical and biological efficiency while diminishing agricultural impact on the environment. Conservation agriculture combines tillage and planting practices that prevent the exhaustion of our natural resources and maintain the quality of the surrounding environment while still maximizing profitability (Gebhardt el al., 1985). The majority of soils in the Southeast is low in fertility due to decades of intense row cropping and continuous tillage (Trimble, 1974). Incorporating practices such as conservation tillage, crop rotation, and cover cropping contributes to land profitability by improving soil fertility, decreasing production costs, and increasing productivity (Pierce, 1985). Utilizing conservation methods in production agriculture also benefits surrounding habitats by reducing contamination through sedimentation and chemical runoff (Aulakh et al., 1991).

Conservation tillage vs. Conventional tillage

For decades wide spread use of the moldboard plow was used to perform conventional tillage operations in order to eliminate weed competition, prepare seed beds, and incorporate fertilizers (Gebhardt et al., 1985). Today, it is well known that conventional tillage can degrade soils by destroying soil structure and organic matter, decreasing aggregate stability, and increasing soil erosion thereby leaving soils infertile and unproductive (Mathew et al., 2012). Conservation efforts have renewed interest in conservation tillage as an alternative to conventional tillage. Conservation tillage is defined as any tillage that allows at least 30% residue to remain on the soil surface (Allmaras and Dowdy, 1985). The Conservation Tillage Information Center stated that with at least 30% ground cover, a 50% reduction in soil erosion was observed (Allmaras and Dowdy, 1985). Previous research showed conservation tillage decreased soil loss by 75% due to the presence of corn (*Zea mays* L.) residue on the soil surface (Allmaras and Dowdy, 1985). The adoption of conservation tillage has proven to be advantageous in regard to soil quality in that it improves soil structure and aggregate stability, increases water infiltration and storage, and reduces soil compaction that could limit plant rooting zones, preventing nutrient and water uptake (Busscher et al., 2010). Conservation tillage also decreases labor and fuel consumption, thus lowering input costs for producers (Munawar et al., 1990).

COVER CROPS

Conservation tillage and cover cropping are often used in conjunction to benefit cropping systems. Cover crops include plant species such as grasses and legumes that are typically established for the sole purpose of reconditioning and protecting the soil during fallow intervals between cash crops (Hartwig and Ammon, 2002). Crop residue that remains on the soil surface can protect against land degradation through erosion by intercepting rainfall impact, decreasing the velocity of storm water runoff, as well as protecting against turbulent winds (Hoorman, 2009). Decomposing residue that remains on the soil surface returns organic matter back to the soil, thereby stabilizing soil pH, increasing nutrient availability, improving moisture retention, strengthening soil structure, and enhancing soil fertility through nutrient recycling (Bugg et al., 1994). Heavy amounts of residue cover are also capable of suppressing weed populations through shading and in some cases by emitting allelopathic compounds that inhibit weed growth (Price et al., 2007). This contribution to pest management could aid producers in relinquishing their heavy dependence on pesticides, thus decreasing farm inputs to offset the rise in production costs. A reduction in chemical usage is also advantageous to the surrounding environment in that it lessens the chance of contamination through runoff or drift (Doran et al., 1991).

LEGUMES

Cover crops are chosen based on their suitability for the specific goals of the producer. Legumes are further classified based on their climatic tolerance of either warm or cool season temperatures. Cool season cover crops are commonly grown following corn or cotton (*Gossypium hirsutum* L.) in the Southeast to protect the soil from winter precipitation and sequester excess N (Dabney et al., 2001). Warm season cover crops are utilized during summer rotations to complement vegetable crops or winter cash crops (Snapp et al., 2005). The financial capabilities of producers and time restrictions based on cash crop intervals can limit the species that would be acceptable in a particular rotation. Legumes offer an additional advantage in their symbiosis with rhizobia bacteria (*Rhizobium leguminosarum*) which allows them to fix N_2 from the atmosphere. Previous research has found that legumes are capable of replacing a substantial amount of N fertilizer for the following crop when utilized as a cover crop (Holderbaum et al., 1990). Producers often incorporate legumes into a crop rotation to serve as a renewable alternative biological source of N to subsequent crops, thereby lowering production cost and contributing to conservation efforts (Aulakh et al., 1991).

There are many variables impacting performance of legume cover crops in regard to their N contribution to subsequent crops. Factors such as environment, N concentration of legume species, dry matter production, stage of growth, C:N ratios and crop management can affect legume production and the amount of plant available N contributed (Balkcom et al., 2011; Holderbaum et al., 1990). In the southeastern region of the U.S., winter annual legumes are commonly utilized to benefit summer cash crops, while warm season cover crops are beneficial in vegetable rotations or prior to a winter cash crop (Creamer and Baldwin, 2000). Traditional warm season cover crops such as cowpea (*Vigna unguiculata* L.) and sericea lespedeza (*Lespedeza cuneata* L.) are not capable of producing adequate amounts of biomass and N in condensed time intervals between warm season harvest and cool season planting (Balkcom et al., 2011). Performance is limited due to confines surrounding adjacent harvest and planting schedules of cash crops (Mansoer et al., 1997). Tropical legumes grow very quickly in comparison to temperate warm season cover crops and are capable of producing superior amounts of biomass and symbiotic N in a shorter window of time (Yadvinder et al., 1992). Yadvinder et al. (1992) reported that tropical legumes are capable of producing 2.9 to 8.9 Mg of dry matter ha^{-1} 50 to 60 (DAP) during the summer months. Tropical legumes utilized in the past have proven to be a valuable source of N that improves soil health and enhances productivity of ensuing crops in rotation (Mansoer et al., 1997).

SUNN HEMP

Sunn hemp (*Crotalaria juncea* L.) is a tropical legume that is highly valued as a multi-purpose crop in its native country of India and surrounding tropical and subtropical regions. A majority of India's sunn hemp production is to accommodate the fiber production that serves as a major commodity to the area's local economy. India accounts for 23% of sunn hemp production with sunn hemp produced in about every state. There are six states which cultivate sunn hemp mainly for fiber purposes, and these states cover 87% of India's total area of production (Chaudhury et al., 1978). Additional uses of the legume include utilizing it as a fodder for livestock and as a green manure crop for soil improvement and fertility (Chaudhury et al., 1978).

Research involving sunn hemp in the United States (U.S.) was first conducted in the 1930's (Cook and White, 1996). In its native climate, sunn hemp is adapted year round below elevations of 305 m, but in the temperate climates, it behaves as a summer annual only growing during the summer months of southern and southwest regions (Rotar et al., 1983). Sunn hemp was introduced into to the U.S. with interest in utilizing it as a warm season cover crop or green manure crop (Mansoer et al., 1997). As a cover crop, sunn hemp has thus far proven successful in rotation after corn harvest as well as a hardy replacement for traditional warm season cover crops (Marshall et al., 2002). Despite its tropical origin, sunn hemp is said to be adaptable to variable amounts of rainfall and a variety of different soil types (Chaudhury et al., 1978). *Crotalaria juncea* is known to be the most aggressive species of its genus, despite its lack of winter hardiness (Mosjidis and Wang, 2011). As a result of sunn hemp's exuberant growth rate, little time is needed prior to the threat of cool temperatures for sunn hemp to achieve maximum production of biomass and symbiotic N. During periods of frost free warm weather, sunn hemp is capable of reaching heights of up to 1.8 m tall in as little as 8-12 weeks (NRCS, 1999). When compared with temperate warm season cover crops such as cowpea and velvetbean (*Mucuna pruriens*), sunn hemp accumulated the most N and phosphorus (P) as a result of its high biomass production (Wang et al., 2005). Depleted Ultisols, typical to the southeastern region, could benefit from organic matter and inorganic N contributed by decomposing sunn hemp residue (Schomberg et al., 2006). Sunn hemp's accelerated production would be well served during short intervals of fallow periods to contribute organic matter and N to beneficiary crops.

'Tropic Sun'

Of the commercially available cultivars, 'Tropic Sun' is the cultivar utilized most frequently used in cropping systems in the U.S. Released in 1983 by the University of Hawaii and the USDA Natural Resource and Conservation Service (NRCS) (Balkcom and Reeves, 2005), research has been conducted evaluating its performance as a warm season cover crop and green manure crop (Valenzuela and Smith, 2002). Performance results proved to be favorable when grown during auspicious conditions with biomass production of 5.9 Mg ha^{-1} in as little as 9-12 weeks and accumulation of 126 kg N ha^{-1} (Mansoer et al., 1997). This cultivar has also proven useful in pest management systems by displaying resistance to root knot nematodes which can be troublesome for a variety of plant species (Cook and White, 1996; Cook et al., 1998). Special interest has not been taken in additional cultivars for consistent use because of sunn hemp's inability to produce viable seed above 28˚ N latitude in our temperate climates (NRCS, 1999). Under ideal climatic conditions, sunn hemp is noted for producing as much as 448 kg of seed ha^{-1}, with a germination rate of at least 70% (Mosjidis, 2013). Subtropical and temperate climates do not have a long enough growing season to sustain sunn hemp seed production; therefore, seed availability is low and the domestic cost is high making it economically undesirable to producers (Cook and White, 1996). Current seeding operations in the U.S. are located in the extreme southern parts of Florida and Texas, but have proven to be unreliable for lack of consistent seed production due to frequent threats of early freezes (Cook and White, 1996).

'AU Golden'

Breeding efforts of Auburn University have proven successful in the pursuit of developing a seed bearing cultivar of sunn hemp conducive to temperate climate conditions (Mosjidis, 2007). In 2003, selections were made from a base population derived from accession 'PI322377' obtained from an unknown origin in Brazil. Several years of meticulous seed production and phenotypic recurrent selection was performed before the affirmation of 'AU Golden' as a stable and uniform seed bearing cultivar was obtained. Comparisons between 'Tropic Sun' and 'AU Golden' at two locations in south Alabama showed that 100% of plants at maturity flowered with 'AU Golden' as opposed to the 5.4-6% of mature plants that flowered with 'Tropic Sun' (Mosjidis, 2013). Overall, 'AU Golden' only required half the amount of time that 'Tropic Sun' required in order to begin flowering. Two generations of seed increases were observed for 'AU Golden' before final confirmation of seeding capabilities was made (Mosjidis, 2013).

There is little known about the management of 'AU Golden' since its introduction; therefore, it is important to establish agronomic recommendations in order to ensure the success of its performance (Balkcom et al., 2011). As with many crop species, sunn hemp planting dates vary across different geographic regions. If deferred, the time of sowing is a key element that can negatively influence vegetative growth and N accumulation of sunn hemp (Wang et al., 2011).

The sunn hemp species is a short day facultative plant whose biomass production can be limited by day length. Cook et al., (1998) performed a study in the Lower Rio Grande Valley of Texas and saw noteworthy declines in biomass production when planting was delayed by 4 wk or longer from late March to mid-April. In additional studies done in the U.S, similar responses were seen as a result of delaying planting a mere 2 wks (White and Haun, 1965; Bhardwaj et al., 2005). Longer days create favorable conditions for sunn hemp's vegetative growth, but later plantings can cause a reduction in stalk yields as a result of initiation of the reproductive phase, which is triggered by shorter photoperiods (Chaudhury et al., 1978). In India, photoperiods of 14 h were proven to be the most effective in increasing sunn hemp dry weight accumulation and leaf area when compared against shorter photoperiods (Pandy and Sinha, 1978). The N production of sunn hemp has proven to be proportional to dry matter production. Research previously conducted on predicting biomass and N production from sunn hemp found that both were significantly influenced by planting date (PD), location, and days after planting (DAP) (Schomberg et al., 2007). Successful growth of sunn hemp within temperate regions that has occurred in the past favored long periods of warm weather and ample soil moisture; therefore, planting dates should be chosen to accommodate these environmental conditions (Kundu, 1964; White and Haun, 1965).

Timely planting and termination not only affect sunn hemp's performance as a high residue cover crop, but as a quality forage. Recently developed cultivars of sunn hemp such as 'Tropic Sun' and 'AU Durbin' have low amounts of alkaloids and lack the toxicity of other *Crotalaria* species like showy crotalaria, so they could be suitable for utilization as high quality forage (Mansoer et al., 1997; Mosjidis et al., 2012). Forage quality is dependent on several factors such as plant species, plant part, temperature, as well as stage of maturity (Ball et al., 2001). Maturity, as well as high temperatures, can increase lignin content in the cell wall of plants making them indigestible to livestock and can also decrease crude protein (CP), which is a vital nutrient supplemented in livestock diets (Ball et al., 2007). Evidence has proven that CP of plants high in tannins and late in maturity are more likely to bypass the rumen and be excreted through the urine rather than be absorbed by the animal for energy (Albrecht and Broderick, 1990; Merchen and Bourquin, 1994). Mansoer et al., (1997) discovered that neutral detergent fiber (NDF) and acid detergent fiber (ADF) for 'Tropic Sun' leaves met the recommended values for dairy cattle feed 6 to 12 weeks after planting (WAP), but stems were considered indigestible at this point of maturity. Further study is necessary for newly developed sunn hemp cultivars to properly coordinate planting and harvest times for the production of quality forages.

Sunn hemp mineralization

Termination of sunn hemp is of vital importance when the main concern is nutrient recycling. The cultivar ‘Tropic Sun’ is capable of producing 138-47-90 kg ha^{-1} of N-P_2O_5-K_2O in a growing season, which has proven to be comparable to a 3: 1: 2 fertilizer (Marshall et al., 2002). Marshall et al., (2002) recommended sunn hemp termination at early to mid-bloom stage would be best suited to meet suggested fertilizer requirements for vegetables. However, the potential of sunn hemp as a valuable fertilizer source is unknown and the rate at which decomposition occurs and N is released is a key factor to efficiently utilize its residual nutrients.

The decomposition rate of organic residues is highly specific to species, stage of maturity at termination, carbon (C) to N ratios, residue placement, and temperature (Breland, 1994). Legumes typically have a low C: N ratio (<20:1); therefore, decomposition and N release occur much more rapidly than in nonlegume species (>20:1) (Cherr et al., 2006). Similarly, labile fractions of legumes, such as leaves and flowers, decompose quickly in comparison with recalcitrant stem fractions that break down slowly and contribute to SOM (Mulvaney et al., 2010).

Field decomposition trials determined that within 4 weeks of mowing, 50% of total sunn hemp N was already released due to the rapid decomposition of leaf and flower fractions which contain 80.6% of total N and 66.5% of total P (Mansoer et al., 1997; Marshall et al., 2002). The remaining residue was comprised of sunn hemp stems which contain only 17.6% of total plant N (Marshall et al., 2002). Premature termination of sunn hemp can result in major N losses due to asynchronization between residue N mineralization and crop uptake. Coordinating sunn hemp termination with the uptake of N by the succeeding crop is imperative in order to maximize nutrient availability.

Further study is necessary in order to determine the viability of N synchronicity between decaying sunn hemp residue and subsequent crops (Mansoer et al., 1997).

Balkcom and Reeves (2005) determined that sunn hemp integrated into a rotation with corn proved successful at reducing synthetic N requirements for the growing season. However, N losses were significant during the fallow interval prior to spring planting with sunn hemp residue contributing only 58 kg of N ha^{-1} (Balkcom and Reeves, 2005). Due to rapid mineralization of labile fractions, a majority of the N from the residue was available with no means of sequestration. Precipitation often surpasses evapotranspiration during the winter months in the Southeast, leaving unaccompanied N vulnerable to denitrification and leaching (Balkcom and Reeves, 2005). Incorporating sunn hemp in a rotation with a winter cereal could prove to be more synchronous with N release of sunn hemp residue and might be more successful in capturing the N released (Mansoer et al., 1997).

Winter cereals such as rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) are valued as high residue producing winter cover crops that provide excessive ground cover and are proficient in scavenging residual N in the soil that could have been left from the previous crop (Schomberg et al., 2007). Over application of synthetic fertilizers can lead to excess NO_3-N leaching below the rooting zone and that can contaminate groundwater, particularly in high water table situations. Reports of ryes' scavenging abilities found that leaching was reduced anywhere from 29- 94% as opposed to 6-48% reduction by hairy vetch (*Vicia villosa* Roth) (Sainju et al., 1998). The ability of cereal grains to quickly establish an extensive root system contributes to its proficiency in capturing residual N from the soil (Sainju et al., 1998).

Wheat planted following termination of ‘AU Golden’ sunn hemp N would reduce potential N losses that could occur before spring cash crops are planted by taking advantage of the residual N available from the decomposed residue. Wheat is adept in augmenting the recycling of N, P, and K (Brinsfield and Staver, 1991). In prior studies by Brinsfield and Staver (1991) they showed that wheat seeded in September was capable of absorbing 45 kg N kg^{-1} within 90 days, which would exceed fall N fertilizer requirements according to Alabama N recommendations (Ortiz et al., 2012). As with most crops, N is the most limiting nutrient for wheat production and can be a costly expenditure. Nitrogen recovered from sunn hemp residue could contribute to lowering fertilizer requirements for a succeeding wheat crop thereby decreasing production costs for the growing season (Balkcom et al., 2011; Marshall et al., 2002).

Cover crops such as sunn hemp have been proven to provide a biological source of N, while also protecting and improving the health of the soil. There is little knowledge on the performance and management requirements of ‘AU Golden’ sunn hemp, but further investigation would contribute to expanding its use in conservation efforts.

OBJECTIVES

Three objectives were considered for this research thesis in order to evaluate the performance of ‘AU Golden’ sunn hemp:

1. Determine a sunn hemp planting date that maximizes biomass and N production as well as produce high quality forage.
2. Monitor decomposition and N release of sunn hemp residue in the field to determine nutrient availability for winter wheat.

3. Compare winter wheat performance following sunn hemp and fallow to determine if sunn hemp can be successful in reducing N fertilizer requirements.

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II. 'AU GOLDEN' BIOMASS PRODUCTION, N ACCUMULATION, AND FORAGE QUALITY.

ABSTRACT

The tropical legume sunn hemp (*Crotalaria juncea* L.) has the potential to perform as a beneficial cover crop and quality forage in the southeastern U. S. due to its ability to accumulate large amounts of biomass and symbiotic nitrogen (N) in a short period of time during the summer months. The release of the new cultivar 'AU Golden' has potential to enhance sunn hemp use due to its seed producing capabilities. This study was conducted to evaluate the performance of the new sunn hemp cultivar 'AU Golden' in regards to biomass production, N accumulation, and forage quality. Treatments consisted of three planting dates (May, June, and July) arranged in a randomized complete block design with four replications at three locations in Alabama during the 2012 and 2013 growing seasons. Sunn hemp biomass, N concentration, and fiber quality were measured at 25-30 and at 50-60 days after planting (DAP). Sunn hemp biomass production was consistently higher during the months of June and July for the 2012 growing season while production during the 2013 growing season was unpredictable. Sunn hemp biomass production averaged 7.0 Mg ha^{-1} during the 2012 growing season and 5.9 Mg ha^{-1} during the 2013 growing season. Nitrogen concentrations were inversely related to sunn hemp biomass production with maximum accumulation occurring early in sunn hemp development and decreasing as sunn hemp matured. Nitrogen content performance corresponded to biomass production averaging

152 kg N ha^{-1} during the 2012 growing season and 128 kg N ha^{-1} during the 2013 growing season. The decline in sunn hemp performance during the 2013 growing season was attributed to excessive precipitation that resulted in unfavorable growing conditions. Sunn hemp leaf fractions exhibited potential to serve as high quality forage at 25-30 days after planting (DAP), but increasing neutral detergent fiber (NDF) reduced palatability as sunn hemp reached maturity. Sunn hemp leaves grazed or cut within the first 30 d after planting would be best suited as a quality food source for livestock. Despite restrictions in sunn hemp's performance during the second growing season, sufficient biomass and N were produced to serve as a beneficial cover crop in southeastern cropping systems.

INTRODUCTION

Continuous row crop production managed with conventional tillage was a common practice for decades that left soils of the Southeast depleted of organic matter and fertility (Langdale et al., 1992). Cover crops have become a popular practice for conservation efforts to promote sustainability and profitability of croplands. In conjunction with conservation tillage, cover crops are known to contribute to soil fertility, pest management, and nutrient recycling (Langdale et al., 1990). Concerns have arisen within the last decade over the use of synthetic fertilizers that have driven some producers back to legume rotations as a means of crop fertilization to offset the expense of fluctuating fertilizer costs and to prevent potential runoff from over application (Aulakh et al., 1991). Traditional cool season and warm season annual legumes are often limited by asynchronization of planting schedules between the cover crop and the cash crop and are not capable of high residue and N production in short time intervals (Mansoer et al., 1997). It was discovered by Yadvinder et al. (1992) that the growth rate of tropical legumes is much more accelerated in comparison with temperate legumes commonly utilized in rotations and could potentially benefit succeeding winter or spring crops.

Adapted tropical legumes have gained renewed interest in the U. S. with a focus on utilization as a high residue cover crop and green manure crop (Marshall et al., 2002). Although extremely sensitive to cool temperatures, tropical legumes are very tolerant of temperatures ranging from >35 to 40˚ C (Cherr et al., 2006). Sunn hemp is a tropical legume indigenous to regions of India that accumulates substantial amounts of biomass and N quickly. In its native habitat, sunn hemp is grown year round, but in temperate regions it is grown as a summer annual (Rotar and Joy, 1983). Cherr et al. (2006) reported sunn hemp performance achieving 8.0 Mg ha^{-1} of biomass and 146 kg N ha^{-1} in 12 weeks on a sandy soil in north Florida. Similar reports have been made in the past regarding the superior growth habits of sunn hemp in temperate regions validating its suitability as a valuable cover crop and N source.

Widespread use of sunn hemp in the U. S. has not been adopted by producers, despite all its benefits, due to restricted domestic seed production. ‘Tropic Sun’ has been the most commonly exploited commercially available cultivar in the United States since its release in 1983, but is incapable of producing a viable seed crop above 28 ˚ N latitude in our short growing season (NRCS, 1999). Attempts at seed production in southern Texas and Florida have been unreliable due to early freezes threatening the crop. The domestic seed supply is scarce resulting in low availability and high cost (Cook and White, 1996). Producers might be more apt to embrace incorporation of sunn hemp into cropping systems with an adequate source of affordable seed.

Recent efforts of plant breeders at Auburn University in Auburn, AL have resulted in a new sunn hemp cultivar derived from a Brazilian selection ‘PI322377’ that is capable of suppression of southern root-knot (*Meloidogyne incognita)* and reniform (*Rotylenchulus reniformis*) nematodes, and able to produce seed in temperate climates (Marla et al., 2008). The release of this new sunn hemp cultivar ‘AU Golden’ could foster greater adoption of sunn hemp as a cover crop in the Southeast by increasing availability of affordable domestic seed. Agronomic standards are required in order to maximize contributions of this new sunn hemp cultivar ‘AU Golden’ (Balkcom et al., 2011). Planting and management guidelines need to be established in order to efficiently manage the cover crop to benefit subsequent cash crops.

Establishment delays can negatively impact biomass and N accumulation of sunn hemp due to photosensitivity of the species. Sunn hemp is a short day facultative plant whose vegetative growth is reduced by flowering response once day length begins to shorten; therefore, sowing seed too late could restrict biomass production (Wang et al., 2011). Nitrogen fixation of sunn hemp is determined by species, dry matter production, environment, maturity, and plant part. Past studies have determined that sunn hemp N fixation is highly variable, fixing anywhere from 27% to 91% of its total N over various geographic regions and climate conditions (Cherr et al., 2006). Environmental factors can impact the amount of dry matter produced as well as N production. Previous cultivars have flourished during long periods of high temperature with medium to high humidity and adequate soil moisture (Kundu, 1964; White and Haun, 1965). Climatic conditions of the southeastern U.S. during the summer months are said to be consistent with those in tropical areas (Kimmel, 2000). Determination of proper planting practices is necessary in order to achieve maximum biomass and N accumulation that will optimize contributions to subsequent crops in rotation over multiple geographical regions.

Legumes utilized in rotations often serve dual purposes for producers with multiple commodities. Insufficient knowledge has been acquired on the suitability of sunn hemp quality forage for livestock. Toxicity studies conducted revealed that sheep (*Ovis aries*) did not suffer from severe illness when fed up to 45% sunn hemp hay (Reddy et al.,1999). Broiler chickens (*Gallus domesticus*) did suffer from performance issues, but their mortality rate was not affected (Hess and Mosjidis, 2008). Recent selections of sunn hemp are nontoxic to animals, unlike several of the *Crotalaria* species that contain toxic pyrrolizidine alkaloids in the seeds that can oxidize in the liver (Cook and White, 1996). Sunn hemp cultivar ‘Tropic Sun’ is considered non-toxic to livestock according to the Agriculture Research Services Poisonous Plant Laboratory and the University of Hawaii (Rotar and Joy, 1983).

Palatability is said to vary with different cultivars and stage of maturity of the plant. Studies have determined that NDF and acid detergent fiber (ADF) values of ‘Tropic Sun’ leaves 6 weeks after planting (WAP) were comparable to that of alfalfa (*Medicago sativa* L.) at early maturity, but stems were considered indigestible (Mansoer et al., 1997). When utilized as a dehydrated leaf material for livestock and poultry supplements it can contribute anywhere from 25-30% crude protein (CP) (Chaudhury et al., 1978). Planting and termination of sunn hemp is a factor to consider when utilizing as a food source for livestock. Recommendations call for early grazing and harvest for sheep and goats (*Capra aegagrus hircus*) before flowering, when a high proportion of the plant consists of digestible leaf fractions. Once sunn hemp begins to reach maturity and flower, there is an increase in stem production, which is not palatable to the majority of livestock (Mosjidis et al., 2013). High temperatures can also increase lignin content of forages making planting an important contributor to forage quality (Ball et al., 2007). The suitability of ‘AU Golden’ as a forage warrants further investigation via performance evaluations determining appropriate planting and termination dates.

Establishing best management practices for sunn hemp cultivar ‘AU Golden’ will contribute to its performance as an advantageous cover crop. Ideal planting guidelines are unknown for this specific cultivar and should be identified to promote high biomass and N production to benefit crops following in rotation. The objective of this study was to determine appropriate planting dates for sunn hemp across three geographical locations that provide optimum biomass and N production, as well as quality forage.

MATERIAL AND METHODS

The performance of 'AU Golden' sunn hemp as a cover crop was evaluated at three locations during the summer of 2012 and 2013 for a total of six site-years. The experiment was conducted at the Plant Breeding Unit (PBU) in Tallassee, AL (32˚32' N, 85˚53' W), the Wiregrass Research and Extension Center (WGS) in Headland, AL (31°30' N, 85°17' W), and at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL (34˚4' N, 86˚53' W). Soil types included a Wickham sandy loam (Fine-loamy, mixed, semiactive, thermic Typic Hapludults) (PBU), Decatur and Dewey silt loams (Fine, kaolinitic, thermic Plinthic Typic Kandiuduts) (TVS), and Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiuduts) (WGS). Treatments consisting of three sunn hemp planting dates (May, June, and July) were arranged in a randomized complete block design with four replications at each location. The designated area for the experimental site was relocated the second year and planting date treatments were re-randomized. Individual plot dimensions were 3.6 m wide and 12.2 m long at the WGS location and 3.0 m wide and 12.2 m long at the PBU and TVS location with 4.6 m alleys between plots. Weed populations within the sunn hemp plots were controlled by a pre-emergence application of Pursuit (imazethapyr) (0.28 L /ha^{-1}) and Prowl 400 (pendimethalin) (2.27 L/ ha^{-1}) mixtures according to agronomic recommendations.

Soil sampling

Prior to Sunn hemp planting each year, soil samples were collected to a depth of 15 cm per replication for all three locations. Samples were collected using a 1.9 cm diameter probe and compositing 10-12 cores to determine initial inorganic soil N and fertility requirements. Soils were measured for NH_4-N and NO_3-N concentration by extracting 10 g of each soil with 50 mL of 2 M KCl and filtering the soil solution through Whatman no. 42 filter paper (GE Healthcare Ltd, Little Chalfont, UK) and measuring spectrophotometrically (Keeney and Nelson, 1982). Fertilizer/lime recommendations were determined by the Auburn University Soil Testing Laboratory and recommendations were adhered to prior to sunn hemp establishment. An application of lime was applied at TVS for 2012 at a rate of 2.24 Mg ha^{-1} as well as 0-20-20 fertilizer at 179 kg ha^{-1}. For the 2013 growing season a 0-46-0 fertilizer was applied to comply with phosphorous recommendations for TVS at 89 kg ha^{-1}.

Soil samples collected prior to sunn hemp planting revealed NH_4-N was highest at the PBU location during 2012 and at the TVS location during 2013 (Table 2.02). Elevated levels of NO_3-N at the TVS location were also observed during the 2012 and 2013 growing seasons, in comparison with those at PBU and WGS. Nitrate levels at TVS averaged 17.3 mg kg^{-1} during 2012 and 8.7 mg kg^{-1} during 2013 (Table 2.02). Soil extractable nutrients (P, K, Mg, Ca) ranged from low to very high across the three locations while pH was 5.8-6.7.

Biomass collection

Sunn hemp was planted at 34 kg seed ha^{-1} with a 3.0 m wide Great Plains® (GP) drill at TVS, a 3.6 m wide (GP) drill at WGS, and a 3.0 m wide John Deer® conventional drill at PBU between the 10^{th} and 20^{th} of each corresponding month (Table 2.01).

Biomass was only allowed to accumulate for 60 d after which sunn hemp was rolled down with a cover crop roller and crimper (Ashford and Reeves, 2003). An application of glyphosate (*N*-(phosphonomethyl) glycine) was then applied to the rolled down sunn hemp to ensure complete termination. The height to the first leaf and total height were measured for five random plants selected from each plot for each planting date for four replications at 25-30 DAP and 50-60 DAP. Sunn hemp biomass samples were also collected at this time by removing the above ground plant material from a 0.25 m^2 quadrant within each plot for the corresponding planting date. The stem and leaf fractions for each biomass sample collected were divided into separate entities and oven dried at 55˚ C for a minimum of 72 hours. Sunn hemp dry weights of the plant parts were recorded before being ground with a Wiley mill and a Cyclone sample mill to pass through a 1-mm screen size (Thomas Scientific, Swedesboro, NJ). Samples were analyzed for total carbon (C) and N through dry combustion using a LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI). The remaining sunn hemp biomass samples were utilized for forage quality analysis performed by the Auburn University Soil Testing Laboratory. Fiber analysis included NDF and ADF values measured by means of Near Infrared Reflectance Spectroscopy (Marten et al., 1989). Crude protein values were also determined for sunn hemp samples by multiplying the sunn hemp N percentages (dry matter basis) by the conversion factor 6.25.

Daily maximum and minimum temperatures for growing degree day (GDD) calculations along with daily precipitation amounts were obtained from AWIS Weather Services Inc., monitoring stations located in proximity to the experimental sites in Belle Mina, AL, Headland, AL, and Tallassee, AL (Alabama Mesonet Weather Data, 2012). A

63 year (1950 to 2013) average was calculated to determine a “normal” growing season for each location. Rainfall during the 2012 growing season was below normal with the exception of TVS where rainfall was above normal (Table 2.03). The second growing season was unusually wet with precipitation exceeding the normal across all three locations. Heavy rainfall was particularly concentrated from June to August at the PBU and WGS locations, where monthly rainfall averaged well above the normal (Table 2.03). Saturated soil conditions resulted in the flooding of sunn hemp plots at the PBU and WGS locations during 2013. Sunn hemp failed to emerge in one plot for the June planting at PBU as a result of excessively wet conditions.

Monthly sunn hemp growing degree days (GDD) from planting to termination for ‘AU Golden’ was determined for three sunn hemp planting dates at each location. The earliest planting and latest termination time for each sunn hemp planting date treatment was chosen to calculate the 63 year average of GDD’s from 1950-2013 for comparison. Sunn hemp GDD were greater during the 2012 growing season compared to the 2013 growing season with the exception of July at the PBU location and May at the TVS location (Table 2.04). The accumulation of GDD was more rapid at the WGS location across both growing seasons, particularly during the month of June (Table 2.04).

Statistical analysis

Whole plant sunn hemp biomass and N data was analyzed using the GLIMMIX procedure in Statistical Analysis System (SAS) software (SAS Inst., Cary, NC). Sunn hemp leaf and stem values were combined to obtain total sunn hemp biomass, N concentrations, and N content. Among classification variables, replication was considered random while location, planting date, and interactions were fixed. Analysis variables measured included total sunn hemp biomass, plant height, N concentration, and N content. Sunn hemp leaf and stem fractions were also analyzed separately using the GLIMMIX procedure to determine C: N ratios, CP, ADF, and NDF. Treatment means were compared when the F-test was significant ($P \leq 0.05$) by determining least significant differences (LSD) at 5% probability ($\alpha = 0.05$).

RESULTS AND DECUSSION

Sunn hemp growth

Final sunn hemp plant heights were consistently influenced by a planting date x location interaction at 25-30 DAP and 50-60 DAP across the two growing seasons ($p = <0.0001$) (Table 2.05). Noticeable trends during 2012 at 25-30 DAP saw total sunn hemp plant height increase with later planting dates across the three locations while 2013 planting date x location interactions were inconsistent (Figure 2.01A and 2.01B). Sunn hemp plant heights at 50-60 DAP after planting were similar across growing seasons. During the 2012 growing season at 50-60 DAP, plant height increased from May to June across the three locations, but were comparable from June to July (Figure 2.01C). These results correspond to similar findings that observed a significant planting date effect on sunn hemp height with later planting dates producing shorter stalks (Cook et al., 1998). Plant heights were greatest for the month of June during the 2013 growing season at WGS while May and July plant heights were similar. Height of plants at PBU increased for the July planting date while TVS decreased (Figure 2.01D). Months when average precipitation was above the normal appeared to impact sunn hemp plant height (Table 2.03).

Flowering dates of sunn hemp recorded were similar between the June and July planting dates when compared to May at the TVS and WGS locations while the flowering days for the three planting dates were comparable at the PBU (Table 2.01). Trials done during the development of ‘AU Golden’ observed that flowering occurs in half the time of ‘Tropic Sunn’ at 48-49 DAP (Mosjidis, 2013). In most cases, sunn hemp planted in May took less time than those planted in June and July to begin flowering (Table 2.01).

Sunn hemp biomass production

Sunn hemp biomass production was impacted by planting date, location, and the planting date x location interaction ($p = <0.0001$) for the 2012 and 2013 growing seasons (Table 2.05). Trends were observed during early sunn hemp development at 25-30 DAP for the 2012 growing season, where sunn hemp biomass production increased with later planting dates across the three locations (Figure 2.02A). Sunn hemp biomass production at 25-30 DAP during 2012 differed across locations for the May and July planting dates, while production at PBU was significantly higher than TVS and WGS for the June planting date (Figure 2.02A). Final biomass production at 50-60 DAP averaged across the three locations was 87% higher during the months of June and July when compared to May for the 2012 growing season with maximum production observed at PBU (Figure 2.02B). Days typically begin to get longer and temperatures higher during June and July in comparison with May, which coincides with reports by Chaudhury et al., (1978) that stated that extended day length and higher temperatures are conducive to the vegetative growth of sunn hemp.

Sunn hemp biomass production was reduced for the 2013 growing season, particularly during the months of July across the three locations (Figure 2.02). Severe flooding that followed heavy rain resulted in the loss of an entire plot for June sunn hemp planting at the PBU, and reduced biomass production by 44% (Figure 2.02B). Although sunn hemp is adapted to a variety of different soil conditions, it is reported that it has a low tolerance for water logged soils (Chaudhury et al., 1978). Comparable trends continued at 50-60 DAP during the 2013 growing season, sunn hemp planted in July accumulating the lowest amount of biomass in comparison with those planted in May and June (Figure 2.02C). July sunn hemp biomass production did not significantly differ across locations, but production differed in May and June sunn hemp across both stages of growth (Figure 2.02B and Figure 2.02C). Overall biomass production averaged 7.0 Mg ha^{-1} during the 2012 growing season and 5.9 Mg ha^{-1} during the 2013 growing season. Despite sunn hemp's sensitivity to climate fluctuations and unfavorable weather conditions, biomass accumulations still exceeded the production of several traditional winter legumes produced across the Southeast, including hairy vetch (4.9 Mg ha^{-1}; Touchton et al., 1984) and crimson clover (5.0 Mg ha^{-1}; Reeves et al., 1993). Winter legumes utilized in rotations for subsequent summer crops are often restricted in the amount of biomass they can produced with the limited time allotted during the winter growing season. The accelerated growth rate of sunn hemp allows for high biomass production during these condensed time frames (Balkcom and Reeves, 2005).

Sunn hemp N concentration

Location, planting date, and location x planting interactions were significant for sunn hemp N concentrations in most cases. The location x planting date interaction did not affect sunn hemp N concentrations at 50-60 DAP during the 2012 growing season ($p = 0.3459$) (Table 2.05). Sunn hemp N concentrations were affected by location and planting date effects individually (p = <0.0001) (Table 2.05). Maximum accumulation occurred at the WGS location and for the May planting date at 24.1 and 25.6 g N kg^{-1} (Table 2.06).

Nitrogen concentration of sunn hemp was inversely related to biomass production as observed in previous studies evaluating 'AU Golden' sunn hemp (Balkcom et al., 2011). As sunn hemp biomass production increased with plant maturity, N concentrations decreased across sampling times during the 2012 and 2013 growing seasons. Concentrations measured at 25-30 DAP for the 2012 and 2013 growing seasons resulted in comparable production with slightly higher values during 2012 the majority of the time (Figure 2.03A and Figure 2.03B). Sunn hemp N concentration decreased 46% at 50-60 DAP during the 2013 growing season in comparison with N concentrations at 25-30 DAP (Figure 2.03C). Legume tissues typically decreased in N concentrations as the plant reaches maturity (Wagger, 1989). This is most likely due to higher sunn hemp leaf production during the first 3 weeks after planting (WAP) and the increase in stem dry matter at 6 WAP as reported by Mansoer et al., (1997). Legume leaf fractions typically have higher N concentrations in comparison with stem and root fractions making whole plant concentrations higher during early maturity (Muller et al., 1988).

Location, planting date, and the location x planting date interaction were significant at 25-30 and 50-60 DAP across both growing seasons for sunn hemp nitrogen content (Table 2.05). Nitrogen content at 25-30 DAP during the 2012 growing season continued to increase across planting dates at the PBU location while N content at the TVS and WGS locations did not differ greatly with the exception of July sunn hemp at TVS (Figure 2.04A). Nitrogen content was reduced for the 2013 growing season due to reduced biomass levels as a result of heavy precipitation. Sunn hemp N contents were the lowest at PBU particularly during the month of June as a result of flooding (Figure 2.04B). Sunn hemp N content corresponded to biomass levels during the 2012 growing season with June and July averaging 55% higher than May (Figure 2.04C). During the 2013 growing season, N contents for May and June averaged higher than July (Figure 2.04D). Overall, sunn hemp N content averaged 152 kg N ha^{-1} during the 2012 growing season and 128 kg N ha^{-1} during the 2013 growing season. Similar production was reported by Rotar and Joy who found that 165 kg N ha^{-1} was accumulated by sunn hemp grown under tropical conditions in Hawaii. Nitrogen content for 'AU Golden' sunn hemp also proved to be similar to values reported for hairy vetch and crimson clover (Balkcom and Reeves, 2005; Reeves, 1994).

Forage quality

Due to the importance of herbage maturity on forage quality, sunn hemp data was presented by sample time for the 2012 and 2013 growing seasons. Stem quality in regards to C: N ratios and CP were affected by location, planting date, as well as location x plating date interactions at 25-30 DAP across both growing seasons and at 50-60 DAP during the 2013 growing season (Table 2.07). Sunn hemp stem ADF and NDF values showed location x planting date interactions (<.0001) across both sample times during the 2012 and 2013 growing seasons (Table 2.07).

Although interaction effects were not observed for stem C:N ratios at 50-60 DAP during the 2012 growing season (p = 0.0983), location and planting date effects were significant (p = <.0001) (Table 2.07). Higher stem C:N ratios were measured at the PBU when compared to WGS, but comparable with TVS (Table 2.08). Sunn hemp planted during the months of June and July produced comparable C:N ratios, but were higher than the May sunn hemp planting (Table 2.08). Stem C:N ratios ranged from 14.5 to 32.8 at 25-30 DAP across locations and planting dates (Figure 2.05A and Figure 2.05B), and increased as maturity was reach to range from 30.4- 51.4 (Figure 2.05C). Sunn hemp stem C:N ratios were generally high across sampling times and growing seasons (>20:1) which typically indicates low digestibility due to high amounts of lignified cell wall material (Van Soest, 1994). Fibrous food sources require more time in the digestive tract in order to complete digestion which can reduce the digestible energy intake of the animal if retained for too long (Demment and Van Soest, 1985; Van Soest, 1994).

Stem CP values were similarly affected by location, planting date, and location x planning date interactions, but the location x planting date interaction was not significant at 50-60 DAP during the 2012 growing season ($p = 0.0831$) (Table 2.07). Location and planting date effects were significant ($p = <0.0001$) for CP measured during this time with TVS and WGS both averaging 69 g kg^{-1} compared to 62 g kg^{-1} at PBU while May averaged 78 g kg^{-1} compared to an average of 61 g kg^{-1} between June and July (Table 2.08). Sunn hemp stems CP values showed greater differences at 25-30 DAP during the 2013 growing season in comparison with the 2012 growing season. Values during 2012 measured across locations for the three sunn hemp planting dates were within a similar range with fluctuations seen during the month of June at TVS and WGS (Figure 2.06A). Fluctuations among CP values were more drastic at 25-30 DAP during the 2013 growing season with May sunn hemp at WGS measuring over 200 g CP kg^{-1} and then decreasing to below 100 g CP kg^{-1} during June. A steady increase in CP values was observed at TVS during this time while peak production was seen during June and July at PBU

(Figure 2.06B) However, stem nutritive properties decreased by the second sampling at 50-60 DAP with CP measuring as low as 57 g CP kg^{-1} (Figure 2.06C). Quality standards set for alfalfa hay by the USDA for CP content based on a 100% dry matter (DM) is 180 g kg^{-1} or higher from early maturity to mid bloom (Orloff and Putnam, 2007) which indicates that stems are not a suitable source of CP.

Fiber analysis for ADF and NDF values exhibited values too high to be considered quality forage. Stem ADF showed a significant increase across sample times with increases ranging from 418 to 663 g ADF kg^{-1}(Figure 2.07A and Figure 2.07C) during the 2012 growing season and from 401 to 628 g ADF kg^{-1} during the 2013 growing season (Figure 2.07B and Figure 2.07D). Digestibility in regards to ADF values decreased from May to July with values increasing across the three locations in July compared to May and June during the 2012 growing season at 25-30 DAP (Figure 2.07A). Differences observed during this time for the 2013 growing season were minimal with the exception of May ADF values at WGS which were noticeable lower than PBU and TVS (Figure 2.07B). Sunn hemp leaf ADF values were higher at 50-60 DAP particularly at the PBU location during 2012 where TVS and WGS ADF values were comparable. Values gradually increased from May to July, but differences were subtle (Figure 2.07C). Differences among locations and planting date treatments were minor during the 2013 growing season with the exception of June where ADF values decreased at PBU and increased at WGS (Figure 2.07D).

Sunn hemp stem NDF value increases ranged from 516 to 784 g NDF kg^{-1} (Figure 2.08A and Figure 2.08C) during 2012 and 474 to 753 g NDF kg^{-1} (Figure 2.08B and Figure 2.08D) during 2013. Trends observed for NDF values were similar to that of stem ADF values across the sample times and growing seasons. Locations shared similar values at 25-30 DAP during the 2012 and 2013 growing seasons with NDF values for the July planting date averaging higher compared to May (Figure 2.08A and Figure 2.08B). Differences among NDF values were more discernable at 50-60 DAP during both growing seasons with a greater decreased observed at PBU for the June planting date (Figure 2.08B and Figure 2.08D). This decrease could be attributed to late maturation for June sunn hemp at the PBU location due to saturated growing conditions that slowed sunn hemp development during the 2013 growing season. Stem values even at 25-30 DAP were not considered suitable as a quality food source for livestock. Quality alfalfa cut during early vegetative growth show values to be around 280 g ADF kg^{-1} and 380 g NDF kg^{-1} (National Research Council, 1988). Higher temperatures can contribute to greater lignin production in forages; therefore, planting dates and cutting dates should be coordinated in order to produce high quality forage (Ball et al., 2007).

Sunn hemp leaf fractions were identical to stem fractions in that location, planting date, and location x planting date interactions were significant with the exception of 50-60 DAP during 2012 for C: N ratio and CP (Table 2.09). Fiber analyses for sunn hemp leaves were significant across the two sampling times for the 2012 and 2013 growing seasons with respect to location, planting date, and their interactions.

At 25-30 DAP during the 2013 growing season there was not a significant planting date effect (p = 0.0811) for sunn hemp leaf C:N ratios (Table 2.09). Only the location effect was significant for sunn hemp leaf C: N ratios at 50-60 DAP during the growing season of 2012 (p = <.0001) (Table 2.09). Location means for PBU and WGS were both significantly different from the C:N ratio for TVS which averaged 10.0 (Table

2.10). The planting date effect and the location x planting date interaction were not significant (p = 0.4450; p = 0.3300) (Table 2.09). Sunn hemp leaf C:N ratios were consistent with previous findings for sunn hemp ratios throughout maturity and across growing seasons ranging from 8.9 to 10.4(< 20:1) (Mansoer et al., 1997). Similar ratios were observed across location x planting date treatment interactions with the exception of the planting dates at PBU at 25-30 DAP during the 2012 growing season (Figure 2.09A). Leaf C:N ratios during the 2013 growing season were the same across locations for the June planting while variations were observed across locations for the May and July planting dates (Figure 2.09B). Final C: N ratios at 50-60 DAP during 2013 decline from May to July with the exception of the WGS location (Figure 2.09C).

Location and planting date effects were observed for sunn hemp leaf CP at 50-60 DAP during the 2012 growing season with maximum accumulation occurring at PBU and for the May and July sunn hemp plantings (Table 2.09). Overall sunn hemp leaf CP values were comparable with stem fraction values particularly at 25-30 DAP where values ranged from 262 to 314 g CP kg^{-1} during 2012 and from 211 to 348 g CP kg^{-1} during 2013 (Figure 2.10A and Figure 2.10B). Consistent increases were observed in CP values at the PBU location across sampling times for the two growing seasons with the exception of a slight decrease in June at 25-30 DAP during the 2013 growing season (Figure 2.10A, Figure 2.10B, and Figure 2.10C). Values at the WGS location also showed similar trends with values decreasing during the month of June (Figure 2.10A, Figure 2.10B, and Figure 2.10C). There was no planting date effect on CP values observed during the 2012 growing season at 25-30 DAP for the TVS location (Figure 2.10A). Effects were observed during the 2013 growing season with CP values at TVS gradually increasing from May to June at 25-30 DAP and at 50-60 DAP (Figure 2.10B and Figure 2.10C). Although CP values of forages typically decrease with maturity, leaf CP values at 50-60 DAP increased in the majority of cases ranging from 243.2 to 330.6 g CP kg-^{1} (Figure 2.09C) (Buxton, 1996). Sunn hemp leaf CP values were higher than that of common temperate legume forages such as white clover ranging from 180 to 250 g CP kg^{-1}(Ball et al., 2002). Sunn hemp leaves would serve as a sufficient CP supplement in livestock diets whose requirements range from 70 g kg^{-1} for mature beef cows up to 190 g kg^{-1} for high producing dairy cows (Buxton, 1996).

In addition to being rich in CP, the digestibility of sunn hemp leaves is suitable to serve as quality forage. Location x planting date interactions were significant across sampling times for both ADF and NDF values during both growing seasons (Table 2.09). Subtle decreases in digestibility of sunn hemp leaves were observed as maturity was reached, but not to the extent of sunn hemp stems. The ADF and NDF patterns of leaves behaved similarly across sampling times and growing seasons. Changes in ADF values that occurred across sunn hemp planting dates were minor compared to the changes that occurred in NDF values (Figure 2.11 and Figure 2.12). May ADF values were similar during the month of May across locations at 25-30 DAP during the 2012 and 2013 growing seasons (Figure 2.11A and Figure 2.11B). Subtle increases occurred at PBU and at TVS during 2012 for June and July while WGS values for June were low compared to May and July (Figure 2.11A). A gradual increase was seen across planting dates at WGS during 2013 while ADF values remained constant for July at PBU and decreased at TVS (Figure 2.11B). At 50-60 DAP during 2012 PBU was higher during May compared to TVS and WGS, but similar values were observed across June and July (Figure 2.11C).

Values were also similar during May and June across locations; however, during July TVS ADF values showed a noticeable decrease (Figure 2.11D).

Similar NDF values were observed at 25-30 DAP for May during 2012 and for June during 2013 across the three locations (Figure 2.12A and Figure 2.12B). Sunn hemp leaves grown during 2012 for June at the PBU location and for July at PBU and WGS at 25-30 DAP resulted in the highest NDF values while TVS values were the lowest across the three planting date treatments (Figure 2.12A). Sunn leaf NDF values for July at the PBU location and for May at the WGS location were the only noticeable differences seen in NDF values during the 2013 growing season at 25-30 DAP (Figure 2.12B). Trends that occurred for NDF values at 50-60 DAP during the 2012 and 2013 growing season behaved similarly to ADF values during this time with May at PBU showing a large difference compared to TVS and WGS during 2012 and July at TVS showing a large decrease (Figure 2.12B and Figure 2.12C).

Sunn hemp leaf forage quality corresponds with quality forage standards for common legumes such as red and white clover and alfalfa at bud stage with values ranging from 240-380 g ADF kg^{-1} and 300-470 g NDF kg^{-1} (Ball et al., 2002). Although the digestibility of sunn hemp stems was too low to be considered high quality forage, sunn hemp leaves would be a suitable feed source for livestock.

CONCLUSION

Biomass and N concentrations for ‘AU Golden’ sunn hemp did not relate, but N content corresponded with biomass production. A dilution effect was seen for sunn hemp nitrogen concentration where concentrations decreased as biomass accumulation increased consistently across both growing seasons. Sunn hemp biomass production thrived during the months of June and July for 2012, but climatic fluctuations throughout the second growing season reduced biomass yields and N production. ‘AU Golden’ production proved to be sensitive to extended periods of rainfall and temperature fluctuations that occurred during the 2013 growing season. As a result, biomass and N content was similar during May and June while, July performance was the poorest out of the three planting dates. Sunn hemp production corresponded positively under favorable conditions of frost free warm weather and moderate rainfall. Despite reductions in ‘AU Golden’ performance during the second growing season, there was adequate accumulation of biomass and N that could prove beneficial in a crop rotation.

Flowering dates were fairly consistent across the planting date treatments. Comparable days during June and July exceeded the number of days until flowering for May sunn hemp in most cases. In several instances, vegetative growth continued after the initiation of the reproductive phase which could indicate that ‘AU Golden’ sunn hemp’s short day photoperiodism could also be triggered by climatic fluctuations and that biomass is not limited by the initiation of flowering. Further investigation is warranted to confirm these suspicions.

Sunn hemp’s potential as quality forage is limited by indigestibility of the fibrous stems. Stem ADF and NDF values were too high at the 25-30 DAP sampling time to be considered as a quality food source for livestock. The lack of palatability increased with maturity as the stem proportion increased and became more lignified. Sunn hemp leaf values corresponded with several temperate legume forages such as alfalfa and white clover and could serve as forage for early cutting. The CP levels of sunn hemp leaves would serve as an adequate protein supplement in livestock diets with values measuring over 180 g kg^{-1} in most cases. Consistent trends revealed that sunn hemp leaves became less palatable as maturity was reached as well as at later planting dates. In pursuit of a quality food source for livestock, sunn hemp leaves would be suited when planted at an earlier planting date and utilized within the first 4 weeks of growth. 'AU Golden' sunn hemp was proficient in accumulating sufficient ground cover and symbiotic N in a short time interval and could prove to be a beneficial cover crop and quality forage in the Southeast.

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Table 2.01. Sunn hemp field calendars at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension (TVS) Center in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2012 and 2013 growing seasons.

	PBU			TVS			WGS		
Sunn Hemp Data	May	June	July	May	June	July	May	June	July
	-----2012 Sunn Hemp Growing Season-----								
Planting date	18-May	18-Jun	18-Jul	22-May	19-Jun	24-Jul	17-May	13-Jun	7-Jul
Termination date	13-Jul	15-Aug	12-Sep	17-Jul	14-Aug	18-Sep	11-Jul	10-Aug	7-Sep
Growing days†	56	58	56	56	56	56	55	58	56
Days to flowering‡	38	39	40	35	42	42	40	42	42
	-----2013 Sunn Hemp Growing Season-----								
Planting date	16-May	17-Jun	12-Jul	24-May	25-Jun	26-Jul	13-May	11-Jun	9-Jul
Termination date	12-Jul	6-Aug	3-Sep	26-Jul	20-Aug	12-Sep	9-Jul	8-Aug	5-Sep
Growing days	57	56	53	60	52	50	57	58	58
Days to flowering	39	50	43	38	45	43	38	43	45

† Number of sunn hemp growing days from planting to termination

‡ Number of days from planting until appearance of first flower.

Table 2.02. Soil NH_4-N and NO_3-N, soil pH, and soil recommendations (N, P_2O_5, K_2O) for soil samples taken to a depth of 15 cm averaged over four replications at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2012 and 2013 growing seasons.

	2012						2013					
Location	NH_4-N	NO_3-N	pH	N	P_2O_5	K_2O	NH_4-N	NO_3-N	pH	N	P_2O_5	K_2O
	-----mg kg^{-1}-----			-------kg ha^{-1}------			-----mg kg^{-1}-----			-------kg ha^{-1}------		
PBU	8.8	4.6	6.1	0	44	0	3.4	1.6	6.4	0	44	56
TVS	3.9	17.3	6.4	0	0	0	5.7	8.7	6.2	0	44	44
WGS	2.0	2.0	6.1	0	0	0	3.8	3.1	6.5	0	67	44

Table 2.03. Monthly precipitation recorded during the sunn hemp growth periods at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2012 and 2013 growing seasons.

Location	Month	2012	2013	Normal†
		---------------------mm‡--------------------		
PBU	May§	22.1	7.2	48.7
	June	76.7	180.3	109.7
	July	83.8	163.6	133.1
	August	135.4	131.1	109.5
	September¶	26.2	2.1	36.2
	Total	344.2	484.2	437.2
TVS	May	9.2	0.0	31.1
	June	34.0	84.8	96.5
	July	221.5	249.7	116.8
	August	86.9	56.1	86.4
	September	140.8	11.0	57.02
	Total	492.4	401.6	387.8
WGS	May	3.3	2.2	58.6
	June	83.8	135.9	119.4
	July	63.2	414.3	149.9
	August	176.5	281.9	121.9
	September	73.3	58.5	31.7
	Total	400.1	892.7	481.5

† 1950-2013 means. The normal for the months of May and September were calculated based on the earliest planting date and the latest termination date between the 2012 and 2013 growing seasons.
‡ Alabama Mesonet Weather Data.
§May corresponds to the 17 May, 2012 and the 13 May, 2013.
¶September corresponds to the 18 September, 2012 and the 3 September 2013.

Table 2.04. Growing degree days measured for sunn hemp during the 2012 and 2013 growing seasons for three planting dates (PD) at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL.

		2012			2013			
Location	Month	PD1[†]	PD2[‡]	PD3[§]	PD1	PD2	PD3	Normal[¶]
		----Growing Degree Days[#]----						
PBU	May	176	—	—	195	—	—	202
	June	424	186	—	458	201	—	482
	July	225	539	230	170	467	297	545
	August	—	238	484	—	97	472	536
	September	—	—	50	—	—	51	190
	Total	825	963	764	823	765	820	1955
TVS	May	131	—	—	68	—	—	111
	June	424	186	—	429	79	—	440
	July	299	533	117	378	444	66	509
	August	—	213	443	—	278	445	494
	September	—	—	232	—	—	193	246
	Total	854	932	792	875	801	704	1800
WGS	May	229	—	—	271	—	—	257
	June	496	307	—	507	329	—	496
	July	212	596	348	133	501	368	541
	August	—	174	526	—	143	509	533
	September	—	—	121	—	—	80	113
	Total	937	1077	995	911	973	957	1940

[†] PD1 corresponds to 17 May, 2012 and 13 May, 2013, respectively.

[‡] PD2 corresponds to 13 June, 2012 and 11 June, 2013, respectively.

[§] PD3 corresponds to 7 July, 2012 and 9 July, 2013, respectively.

[¶] Growing degree days averaged from 1950-2013 utilizing the earliest planting date and latest termination date for each planting date treatment.

[#] Growing degree days measured from planting date until termination. Calculated as [(maximum temperature + minimum temperature)/2] - 10˚ C.

2.05. Analysis of variance for sunn hemp total plant height, biomass production, N concentration, and N content measured at two sampling times for three sunn hemp planting dates (PD) across three locations (Loc) during the 2012 and 2013 growing seasons.

			Plant Height		Biomass Production		N Concentration		N Content	
Year	Effect	df	F Value	P Value	F Value	P Value	F Value	P Value	F Value	P Value
2012			---25-30 DAP[†]---							
	Loc	2	76.78	<0.0001	63.44	<0.0001	60.35	<0.0001	36.92	<0.0001
	PD	2	168.94	<0.0001	60.01	<0.0001	4.68	0.0109	61.53	<0.0001
	Loc x PD	4	5.95	0.0002	16.85	<0.0001	8.13	<0.0001	15.45	<0.0001
2013	Loc	2	24.01	<0.0001	17.79	<0.0001	35.50	<0.0001	39.10	<0.0001
	PD	2	23.71	<0.0001	42.95	<0.0001	24.22	<0.0001	36.15	<0.0001
	Loc x PD	4	73.27	<0.0001	31.66	<0.0001	37.41	<0.0001	15.31	<0.0001
2012			---50-60 DAP---							
	Loc	2	91.87	<0.0001	34.9	<0.0001	26.01	<0.0001	21.47	<0.0001
	PD	2	340.06	<0.0001	65.3	<0.0001	80.37	<0.0001	39.58	<0.0001
	Loc x PD	4	15.46	<0.0001	3.0	0.0222	1.13	0.3459	2.60	0.0391
2013	Loc	2	32.59	<0.0001	14.86	<0.0001	44.53	<0.0001	13.68	<0.0001
	PD	2	3.00	0.0533	6.48	0.0021	4.19	0.0172	6.74	<0.0016
	Loc x PD	4	23.58	<0.0001	11.31	<0.0001	7.65	<0.0001	10.69	<0.0001

[†]Days after planting.

Table 2.06. Sunn hemp N concentrations for three sunn hemp planting dates at 50-60 days after planting (DAP) across three locations for the 2012 growing seasons.

Treatment	N Concentration 50-60 DAP
	2012 Sunn hemp Growing Season
	---g kg^{-1}---
Location†	
PBU	21.1
TVS	22.6
WGS	24.1
$LSD_{0.05}$	1.2
Planting Date	
May	25.6
June	21.4
July	20.8
$LSD_{0.05}$	1.0

† PBU is the Plant Breeding Unit in Tallassee, AL; TVS is the Tennessee Valley Research and Extension Center in Belle Mina, AL; WGS is the Wiregrass Research and Extension Center in Headland, AL.

Table 2.07. Analysis of variance for sunn hemp stem C:N ratio, crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) measured at two sampling times during the 2012 and 2013 growing seasons.

			C:N Ratio		CP		ADF		NDF	
Year	Effect	df	F value	P value	F value	P value	F value	P value	F value	P value
			-----25-30 DAP[†]-----							
2012										
	Loc	2	16.86	<0.0001	3.12	0.0473	75.20	<0.0001	51.23	<0.0001
	PD	2	9.58	<0.0001	4.08	0.0190	146.15	<0.0001	93.24	<0.0001
	Loc x PD	4	10.10	<0.0001	12.97	<0.0001	23.69	<0.0001	11.60	<0.0001
2013										
	Loc	2	2.12	0.1242	18.53	<0.0001	1.62	0.2012	4.43	0.0138
	PD	2	17.28	<0.0001	14.06	<0.0001	2.09	0.1283	6.03	0.0031
	Loc x PD	4	68.77	<0.0001	90.85	<0.0001	16.42	<0.0001	22.67	<0.0001
			-----50-60 DAP-----							
2012										
	Loc	2	14.79	<0.0001	8.45	0.0004	53.16	<0.0001	166.45	<0.0001
	PD	2	50.95	<0.0001	59.53	<0.0001	45.29	<0.0001	144.63	<0.0001
	Loc x PD	4	2.00	0.0983	1.95	0.1057	5.70	0.0003	5.41	0.0005
2013										
	Loc	2	59.75	<0.0001	36.15	<0.0001	1.93	0.1498	1.22	0.2981
	PD	2	2.43	0.0917	1.41	0.2477	6.43	0.0022	6.46	0.0021
	Loc x PD	4	18.29	<0.0001	6.63	<0.0001	4.55	0.0018	4.22	0.0030

[†] Days after planting.

Table 2.08. Sunn hemp stem C:N ratios and crude protein (CP) for three locations at 50-60 days after planting (DAP) across three planting date for the 2012 growing seasons.

	C:N Ratio	CP
Treatment	50-60 DAP	50-60 DAP
	2012 Sunn Hemp growing season	
		---g kg^{-1}---
Location†		
PBU	48.3	62
TVS	44.7	69
WGS	41.0	69
$LSD_{0.05}$	3.6	5.1
Planting Date		
May	37.7	78
June	47.7	62
July	50.6	60
$LSD_{0.05}$	3.1	4.1

† PBU is the Plant Breeding Unit in Tallassee, AL; TVS is the Tennessee Valley Research and Extension Center in Belle Mina, AL; WGS is the Wiregrass Research and Extension Center in Headland, AL.

Table 2.09. Analysis of variance for sunn hemp leaf C:N ratio, crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) measured at two sampling times during the 2012 and 2013 growing seasons.

			C:N Ratio		CP		ADF		NDF	
Year	Effect	Df	F value	P value	F value	P value	F value	P value	F value	P value
			--25-30 DAP[†]--							
2012										
	Loc	2	7.02	0.0013	7.88	0.0006	52.55	<0.0001	55.65	<0.0001
	PD	2	22.72	<0.0001	18.45	<0.0001	33.17	<0.0001	56.02	<0.0001
	Loc x PD	4	10.07	<0.0001	7.10	<0.0001	5.22	0.0006	19.06	<0.0001
2013										
	Loc	2	12.39	<0.0001	47.37	<0.0001	19.52	<0.0001	28.55	<0.0001
	PD	2	2.56	0.0811	27.39	<0.0001	21.81	<0.0001	2.61	0.0774
	Loc x PD	4	7.75	<0.0001	16.88	<0.0001	2.59	0.0397	4.95	0.0010
			--50-60 DAP--							
2012										
	Loc	2	28.19	<0.0001	37.13	<0.0001	30.21	<0.0001	33.53	<0.0001
	PD	2	0.81	0.4450	5.95	0.0033	20.19	<0.0001	12.17	<0.0001
	Loc x PD	4	1.16	0.3300	2.11	0.0831	13.41	<0.0001	16.54	<0.0001
2013										
	Loc	2	24.72	<0.0001	11.75	<0.0001	24.74	<0.0001	37.22	<0.0001
	PD	2	17.00	<0.0001	19.79	<0.0001	0.33	0.7208	0.81	0.4470
	Loc x PD	4	5.38	0.0005	3.69	0.0069	7.85	<0.0001	4.37	0.0024

[†] Days after planting.

Table 2.10. Sunn hemp leaf C:N ratios and crude protein (CP) for three sunn hemp planting dates at 50-60 days after planting (DAP) across three locations for the 2012 growing seasons.

	C: N Ratio	CP
Treatment	50-60 DAP	50-60 DAP
	2012 Sunn Hemp growing season	
		---g kg^{-1}---
Location†		
PBU	9.4	301
TVS	10.0	277
WGS	9.2	281
$LSD_{0.05}$	0.2	6.4
Planting Date		
May	9.5	289
June	9.6	280
July	9.5	290
$LSD_{0.05}$	0.2‡	7.5

† PBU is the Plant Breeding Unit in Tallassee, AL; TVS is the Tennessee Valley Research and Extension Center in Belle Mina, AL; WGS is the Wiregrass Research and Extension Center in Headland, AL.

‡ Data no significantly different.

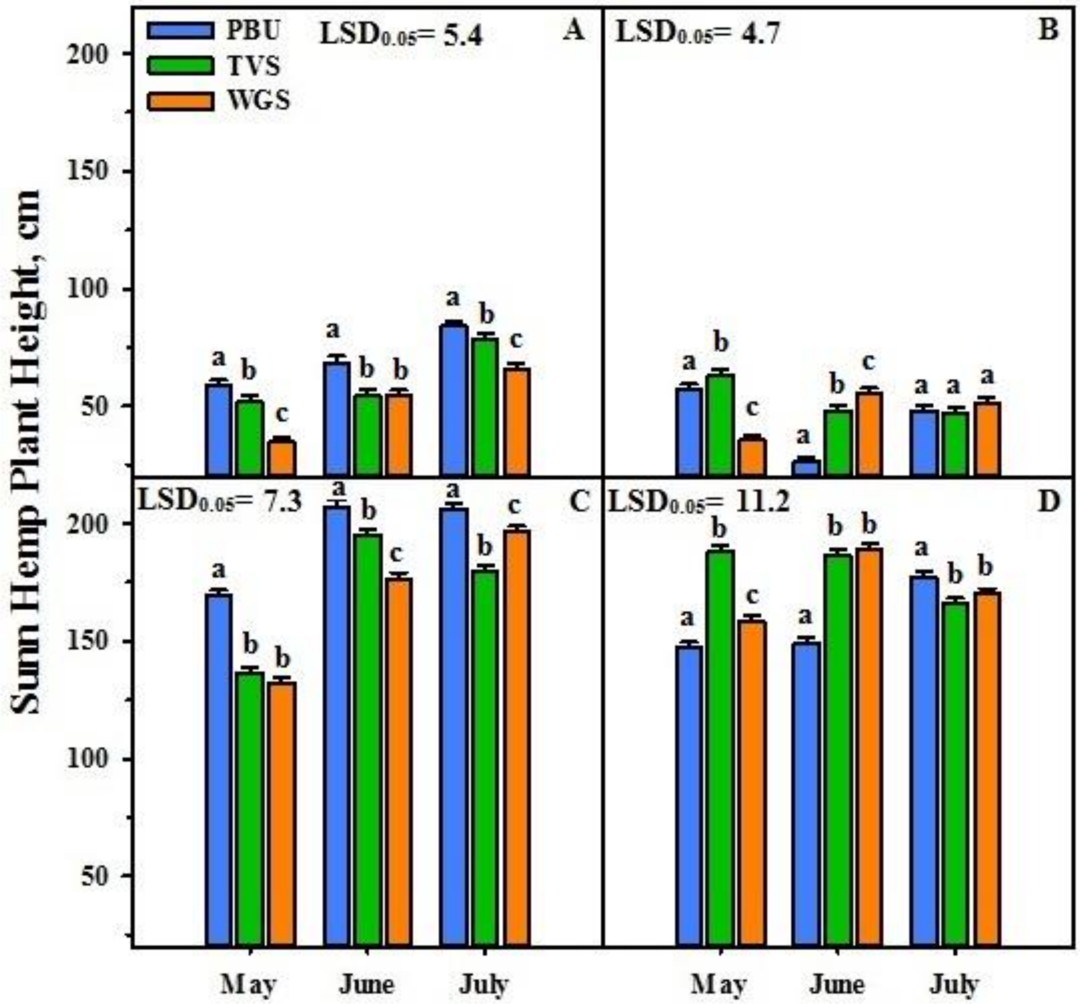

Figure 2.01. Sunn hemp total plant height (cm) measured across three sunn hemp planting dates and locations at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at P>0.05.

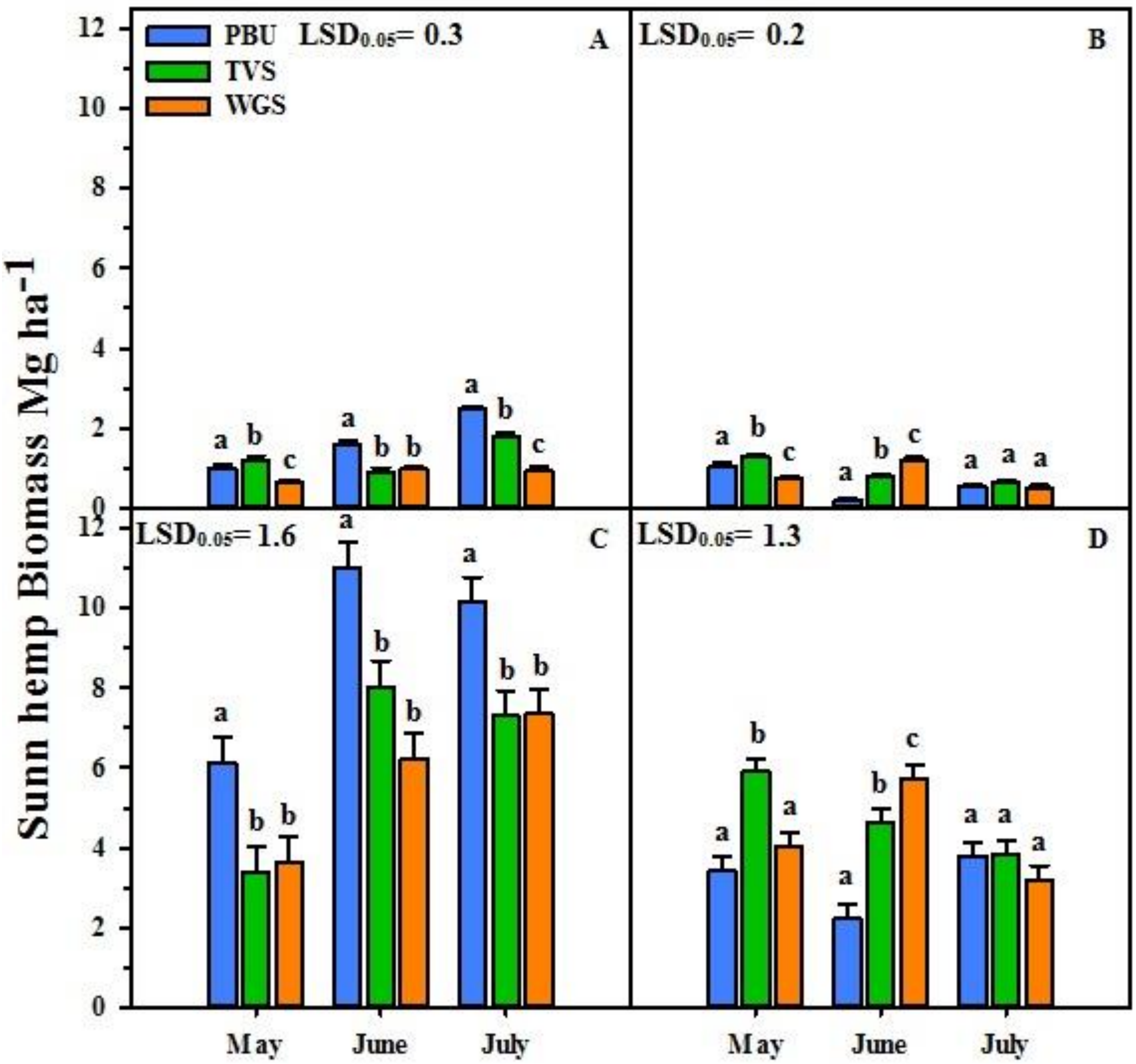

Figure 2.02. Sunn hemp biomass production measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at P>0.05.

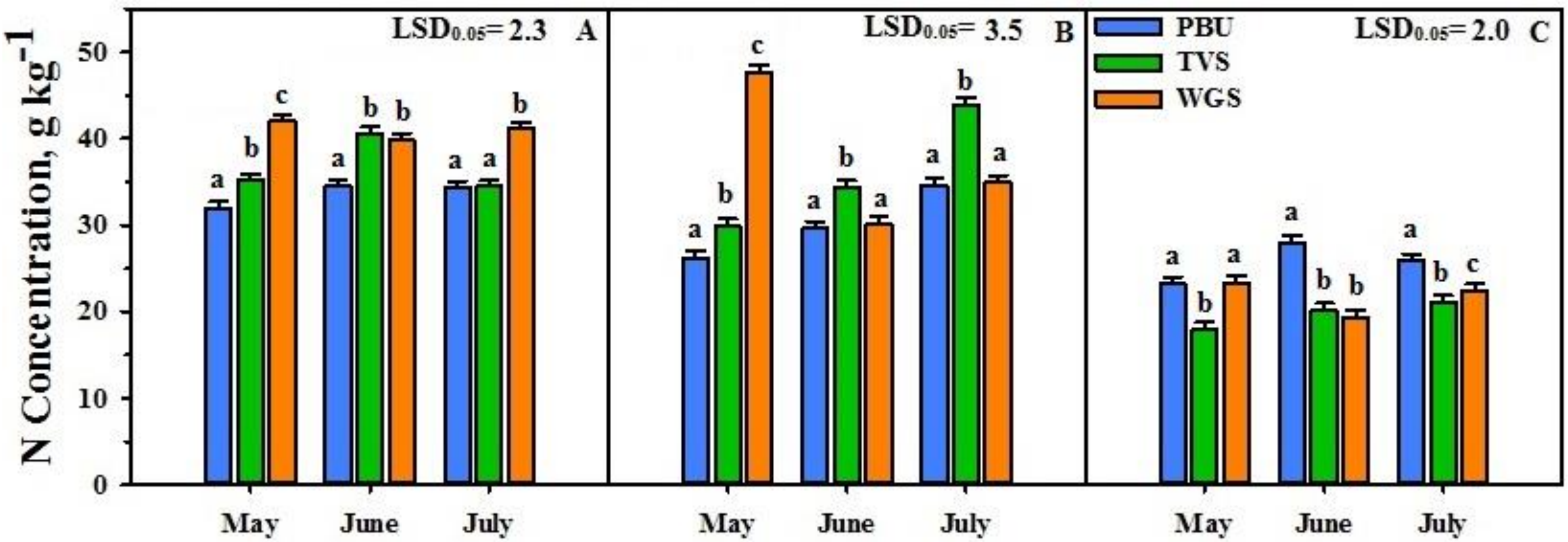

Figure 2.03. Sunn hemp N concentration measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2013 growing season (C). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

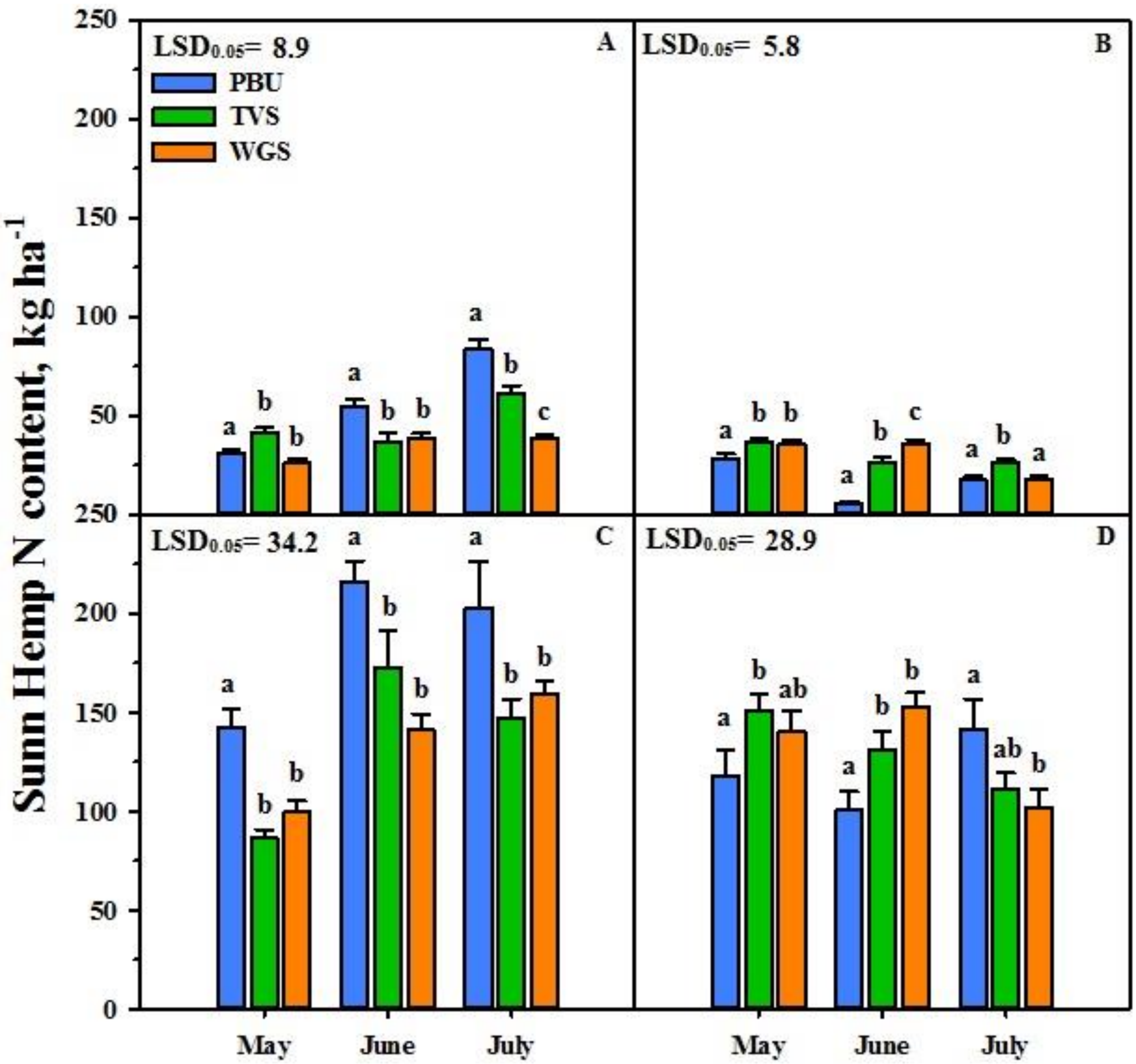

Figure 2.04. Sunn hemp N content measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

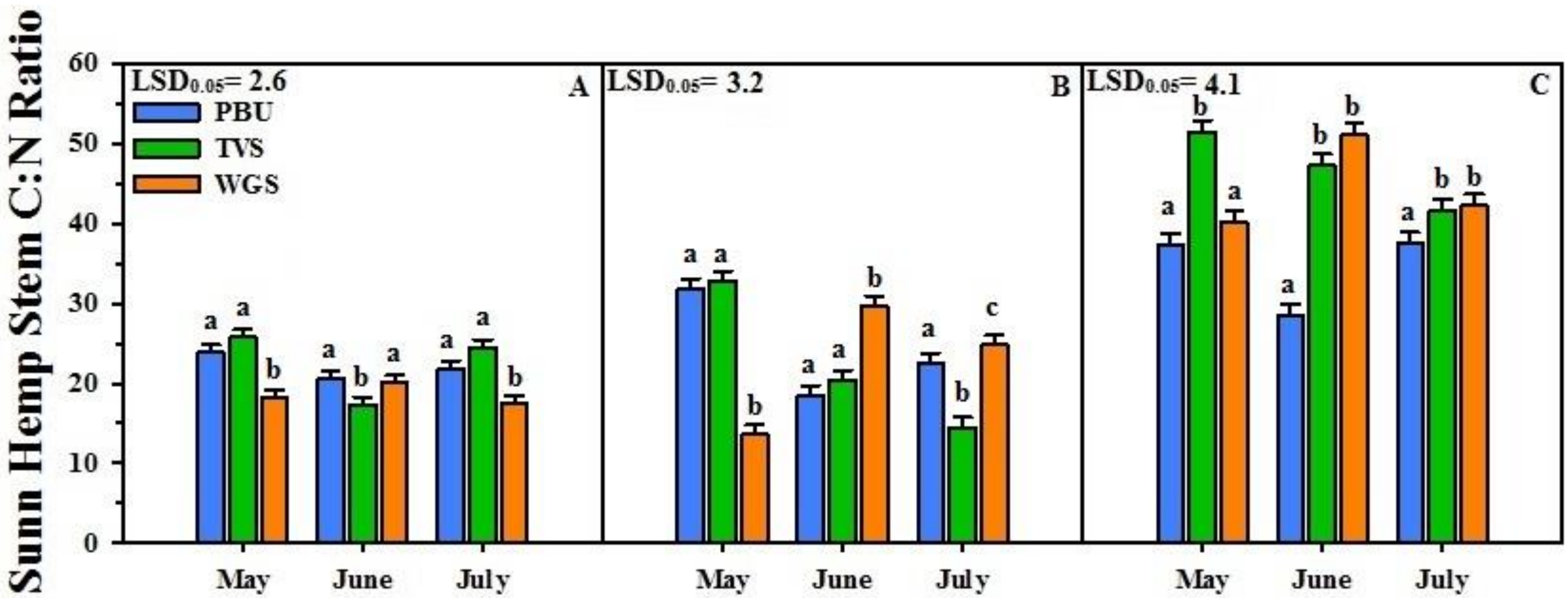

Figure 2.05. Sunn hemp stem C: N ratios measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL at 25-30 days after planting (DAP) for the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP for the 2013 growing season (C). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

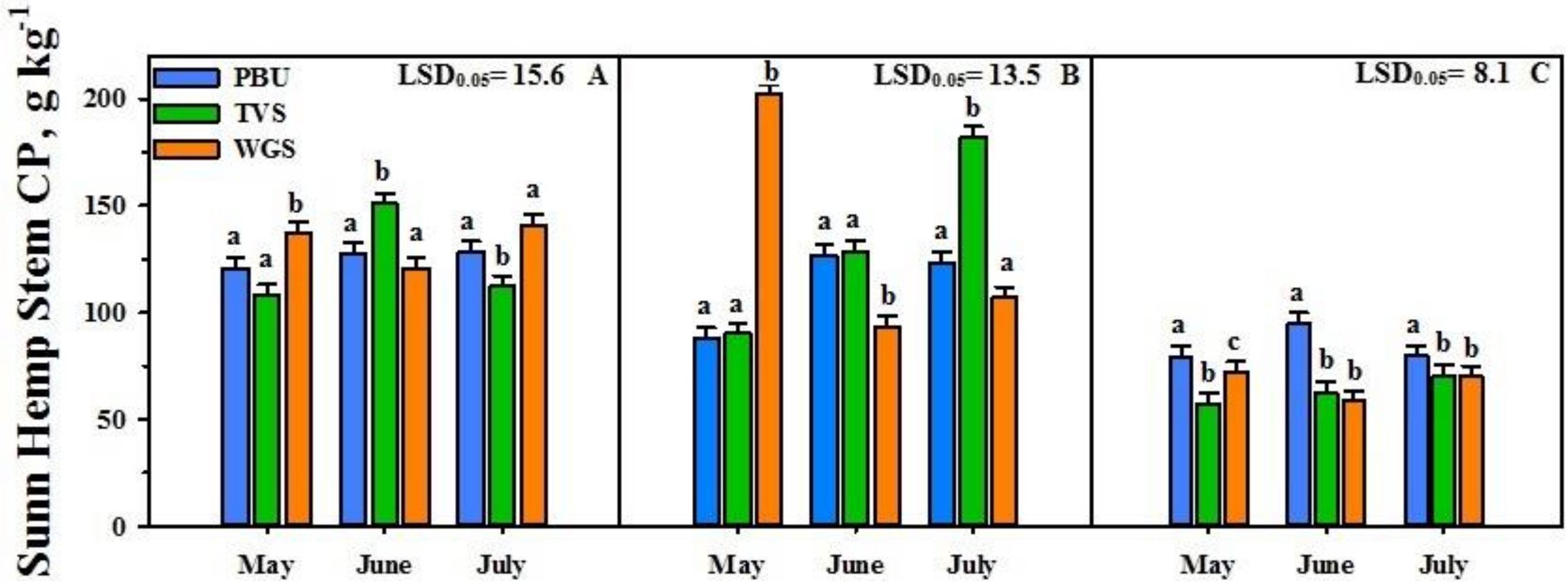

Figure 2.06. Sunn hemp stem crude protein (CP) measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display CP measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2013 growing season (C). Error bars represent the standard error of the means. The least significant difference ($LSD_{0.05}$) was calculated for location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

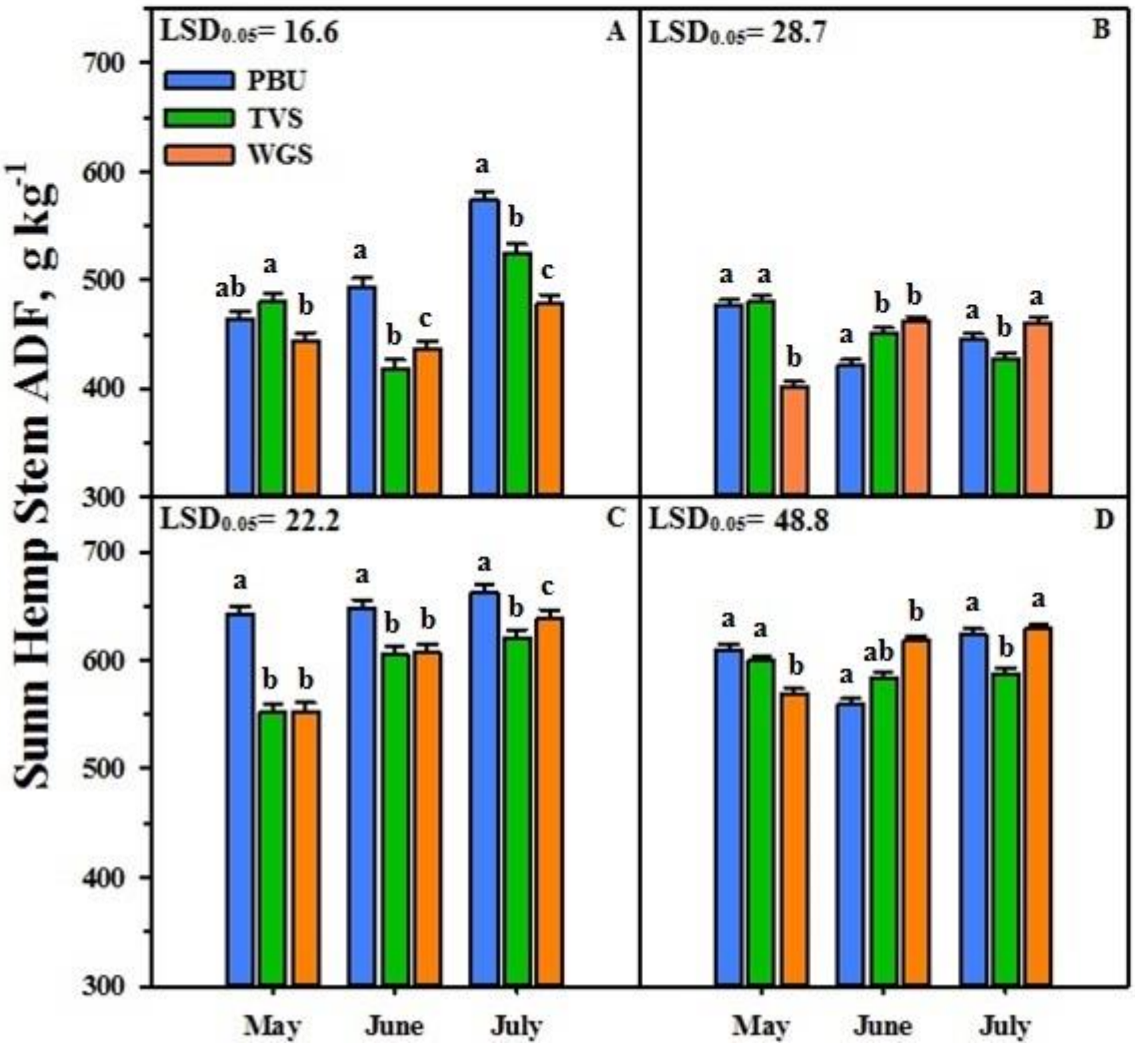

Figure 2.07. Sunn hemp stem acid detergent fiber (ADF) measured across three sunn hemp planting date at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display ADF measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at P>0.05.

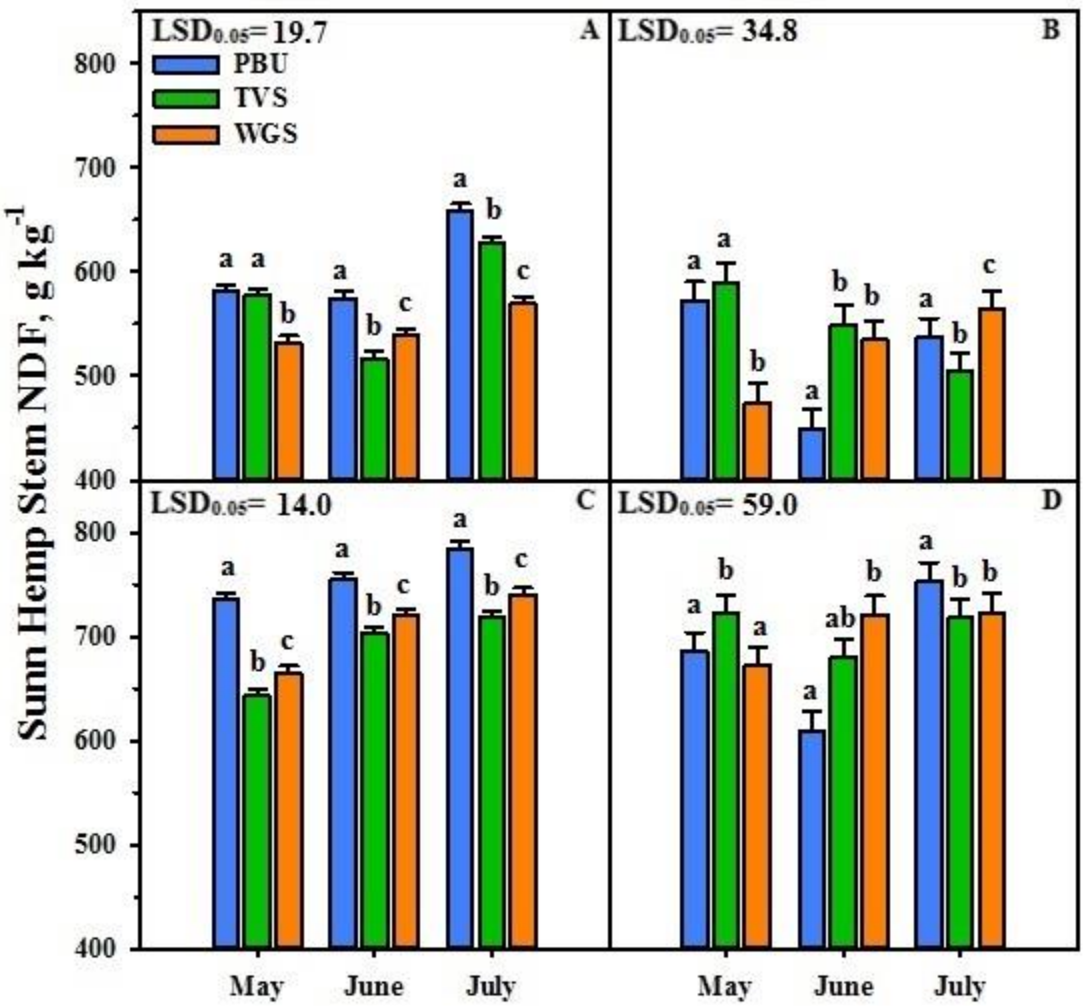

Figure 2.08. Sunn hemp stem neutral detergent fiber (NDF) measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display NDF measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for location x planting date means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

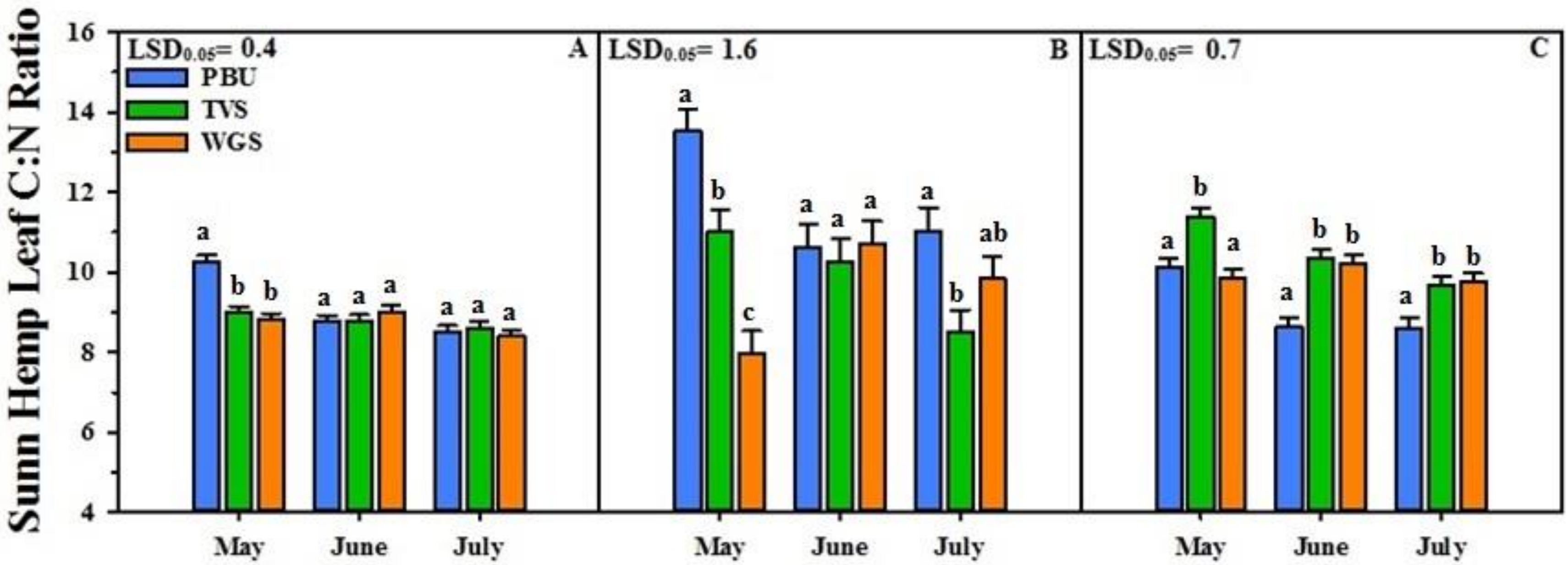

Figure 2.09. Sunn hemp leaf C: N ratio measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display C: N ratio measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2013 growing season (C). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for location x planting date means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at P>0.05.

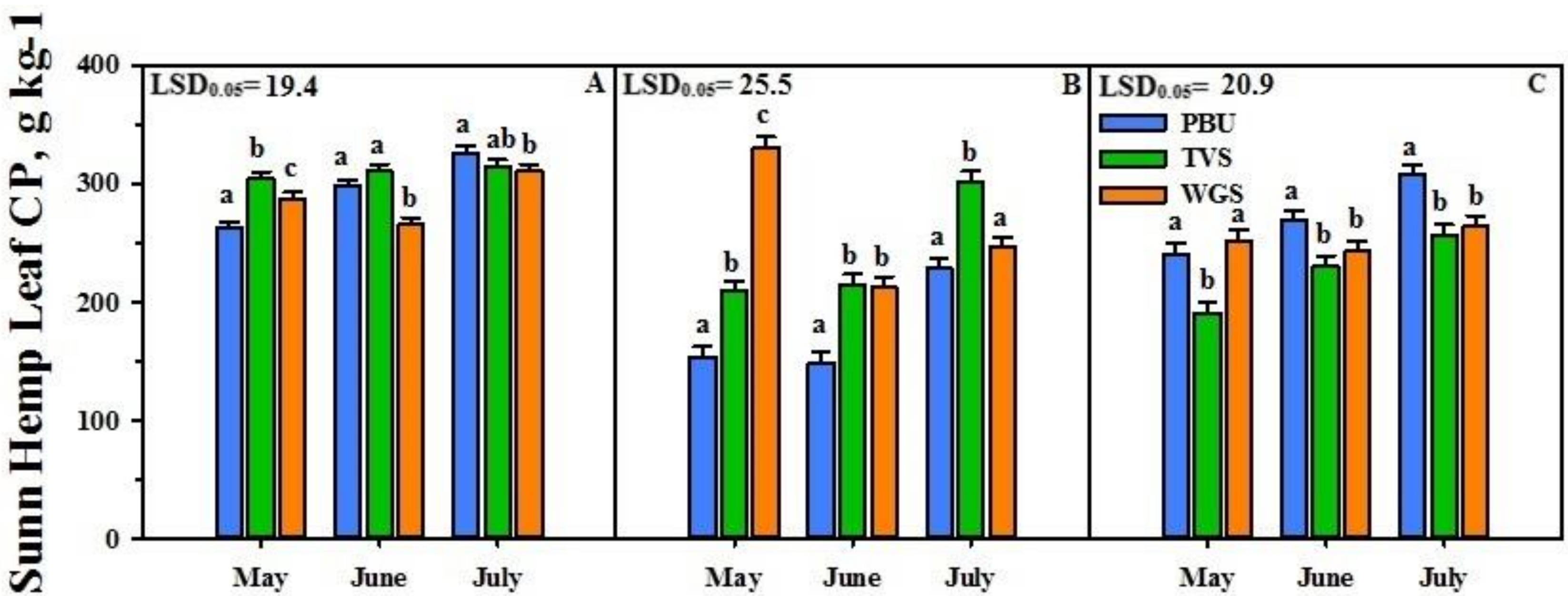

Figure 2.10. Sunn hemp leaf crude protein (CP) measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display CP measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2013 growing season (C). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at P>0.05.

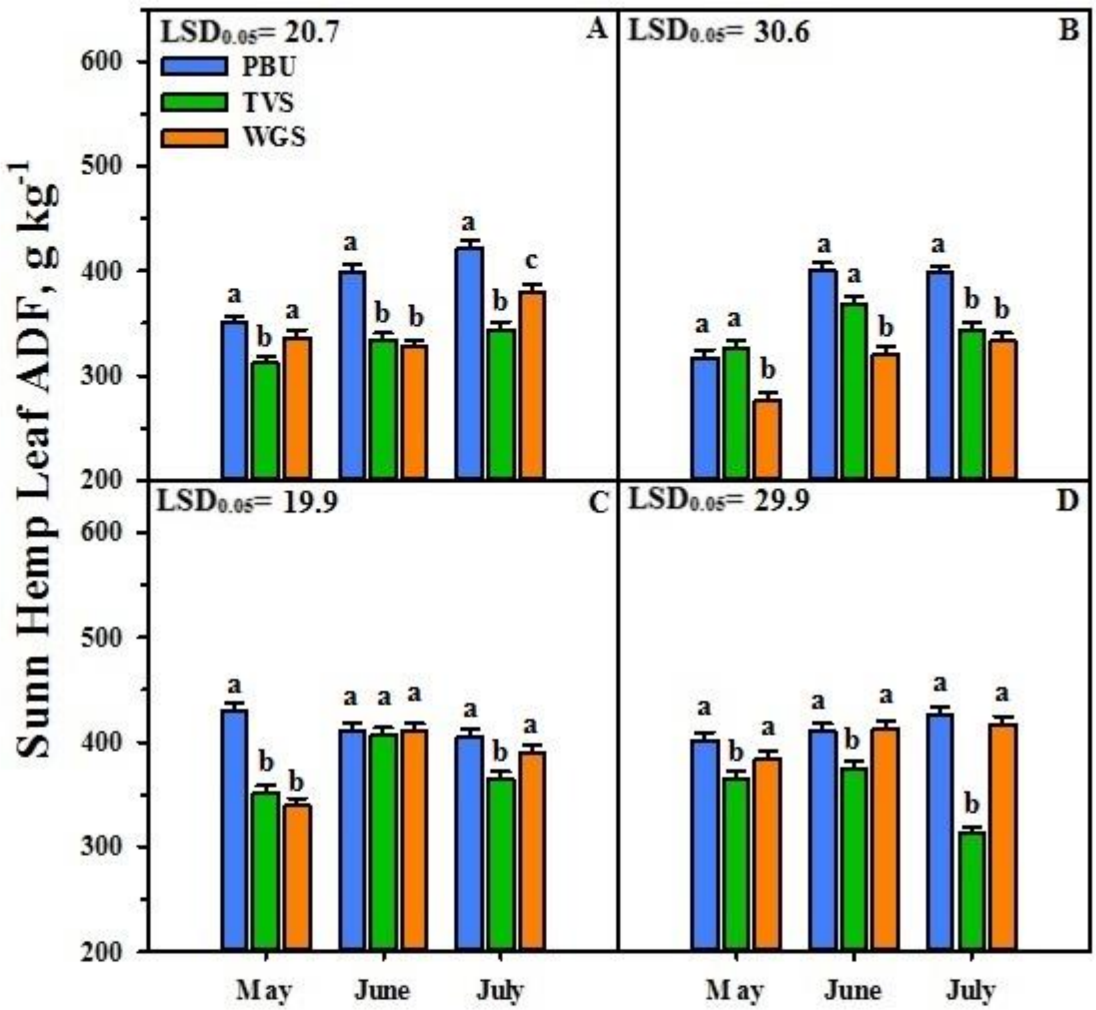

Figure 2.11. Sunn hemp leaf acid detergent fiber (ADF) measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display ADF measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at 50-60 DAP during the 2012 and 2013 growing seasons (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

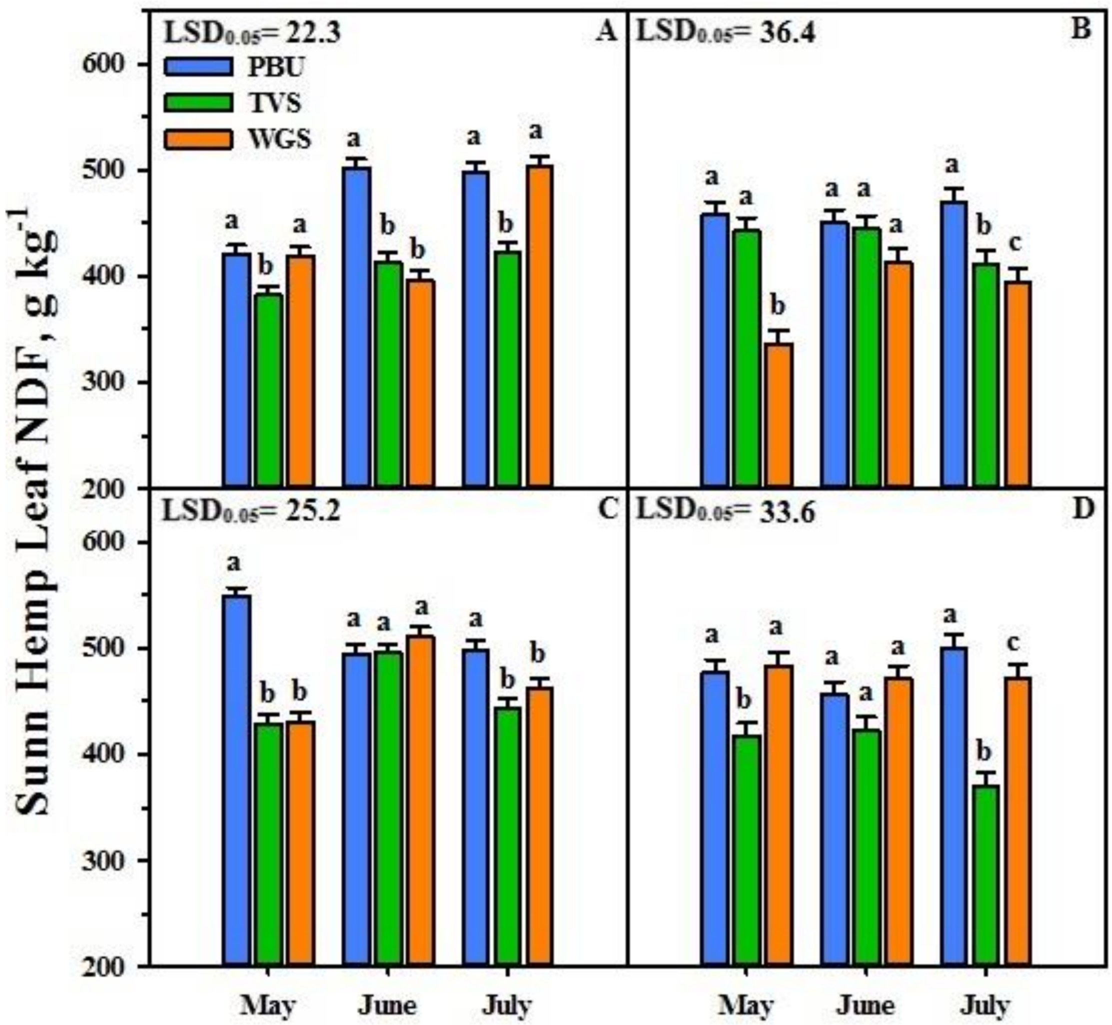

Figure 2.12. Sunn hemp Leaf neutral detergent fiber (NDF) measured across three sunn hemp planting dates at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Graphs display NDF measured at 25-30 days after planting (DAP) during the 2012 and 2013 growing seasons (A and B) and at the 50-60 DAP during the 2012 and 2013 growing season (C and D). Error bars represent the standard error of the mean. The least significant difference ($LSD_{0.05}$) was calculated for the location x planting date interaction means. Means proceeded by a different letter are significantly different across locations within a planting date treatment at *P*>0.05.

III. NITROGEN MINERALIZATION FROM ‘AU GOLDEN’ SUNN HEMP RESIDUE

ABSTRACT

The tropical legume sunn hemp (*Crotalaria juncea*) cultivar, ‘AU Golden’ has the potential to provide a substantial amount of N to subsequent crops through N fixation and subsequent mineralization that could reduce recommended application rates of synthetic N fertilizers. Problems associated with N fertilization by means of legumes are often due to asynchronization between the mineralization of legume N and N uptake by the successive crop. A mineralization field trial was conducted to determine decomposition and N release rates of sunn hemp residue produced during the 2013 growing season at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL. Sunn hemp planted for the months of May, June, and July were terminated after 60 d of biomass accumulation and the mineralization trial was implemented using fresh sunn hemp residue. Nylon mesh bags were used to determine residue decomposition and N release of residue in the field. Bags were collected at allotted time intervals (0, 4, 7, 15, 30, 60, 90, 120 days after termination) that corresponded to the residue decomposition period for each planting date. The decomposition and N release at the WGS location occurred very quickly in comparison to the TVS location as a result of higher temperatures that are typical to the south Alabama region. Sunn hemp decomposed very quickly releasing as much as 65% of its total N in as little as two weeks after termination due to the rapid

decomposition of sunn hemp leaves which contain a majority of total sunn hemp N. Residue from June and July plantings contained more N at the end of decomposition when compared with May, but not enough to reduce fertilizer requirements for a subsequent crop. The climatic conditions of the region must be taken into consideration when managing sunn hemp as a cover crop in order to efficiently optimize its N contributions. As a result of the rapid N release by sunn hemp residue, management decisions must be made when terminating the cover crop in order to create a more synchronous relationship between N mineralization of the residue and N uptake of the succeeding crop. Terminating in closer proximity with the planting of the following crop could better align N release of sunn hemp residue with the crop demand of the beneficiary crop.

INTRODUCTION

Adapted tropical legumes have proven to be superior in performance when compared with traditional warm season legumes utilized in the Southeast (Yadvinder et al., 1992). Legumes in crop rotations have regained attractiveness as conservation efforts look for alternative means of fertilization in order to protect against ecological contamination from chemicals (Holderbaum et al., 1990; Aulakh et al., 1991). Sunn hemp is a tropical legume that serves as a summer annual when grown in the U.S. and is capable of producing large amounts of biomass and symbiotic N in a short period of time (Rotar and Joy, 1983). The amount of N supplemented from legume cover crops is unpredictable and is reliant on synchronization between residue release of N and uptake of N by the beneficiary crop (Mansoer et al., 1997). Decomposition of sunn hemp residue warrants further investigation as a result of multiple factors that contribute to decomposition variability.

Accelerated decomposition of residue can occur as a result of a variety of influences. Legumes typically have a reputation for enhanced decomposition in comparison with nonlegume species as a result of C:N ratios less than 20:1 which contributes to a higher mineralization potential (Cherr et al., 2006). Wide variation in chemical composition of legume residues causes mineralization to vary based on plant part and the stage of maturation (Creamer and Baldwin, 2002). Legume leaves and flowers typically have a high mineralization potential compared to stems (Marshall et al., 2002; Paul and Clark, 1996). The C:N ratio increases in stems of many legume species as the plant matures creating more complex C structures that are more difficult for soil microorganisms to decompose (Krauss et al., 2004). This often discourages N mineralization and encourages N immobilization in microbial biomass (Adams and Attiwill, 1986). Climatic conditions such as high heat and humidity often increase microbial activity in the soil thus increasing rapidity of residue decomposition (Cherr et al., 2006; MacDonald et al., 1995). Previous studies have suggested that high quality legumes will lose anywhere from 50% to 80% of N within in the first two weeks under temperate conditions (Creamer and Baldwin, 2002).

According to the Natural Resource and Conservation Services (NRCS) 'Tropic Sun' sunn hemp is reported to produce 5.6 tons ha^{-1} of dry matter and about 22.7 kg N ton dry $matter^{-1}$ (Valenzuela and Smith, 2002). The majority of sunn hemp N is accumulated in the leaf and flower head fractions which are easily degradable in comparison with the recalcitrant fractions (Marshall et al., 2002). Wang et al., (2011) reported that sunn hemp residue in past studies has broken down in as little as two weeks; therefore, one should expect peak mineralization to occur in the same amount of time. This is most likely due to the rapid decomposition of the highly concentrated leaf and flower divisions (Mansoer et al., 1997). The lack of synchronization between peak mineralization and crop uptake can result in major N losses through denitrification and leaching (Balkcom and Reeves, 2005).

Research surrounding residue decomposition has become a point of interest with the increased popularity of conservation tillage. The adoption of litterbag methodology (Bocock and Gilbert, 1957) has proven to be an effective method of monitoring the rate of decomposition in the field (Isaac et al, 2000; Mansoer et al., 1997; Mulvaney et al., 2010; Wieder and Lang, 1982). Results of litterbag studies are assumed to be characteristic of unconfined decomposing residue exposed to ecological elements as they would be in a representative field situation (Wieder and Lang, 1982). Litterbags that are most commonly made of a nylon mesh material allow for unrestricted decomposition of residue in the field while still keeping it confined for easy collection (Mansoer et al., 1997). Mulvaney et al., (2010) found this to be an effective method for measuring the decomposition of several different high residue organic mulches utilized by no-till vegetable producers.

There have been divisions with regard to proper analyses methods for data from field decomposition studies in the past. Comparisons made by Wieder and Lang (1982) between contrasting statistical analysis approaches found that fitting mathematical models to decomposition data gave a more accurate analysis when the ultimate goal was to determine decomposition rate constants. Isaac et al., (2000) utilized exponential models in order to mirror decomposition of different pruning's taken from hedgerow species. Double exponential decay models are thought to best represent the decomposition of organic residues in the field because they measure labile, as well as recalcitrant portions of residues during decomposition. Labile fractions that consist of sugars, starches, and proteins are readily expended, while recalcitrant fractions made up of cellulose, fats, waxes, lignin, and tannins remain behind and decompose at a slower rate contributing to soil organic matter (SOM) (Wieder and Lang, 1982).

The utilization of 'Tropic Sun' sunn hemp as an N source for succeeding crops has proven beneficial in past research at reducing fertilizer requirements (Balkcom and Reeves, 2005). However, there is little known about the decomposition and mineralization of 'AU Golden' sunn hemp. Sequestration of N from legumes can be inconsistent as a result of numerous contributing factors that affect residue decomposition (Cherr et al., 2006). The determination of best management practices for sunn hemp as a cover crop is essential to efficiently sequester N for fertilization purposes (Mansoer et al., 1997; Vaughan and Evanylo, 1998). Further knowledge is required on the rate of decomposition of 'AU Golden' sunn hemp in order to properly define management guidelines for producers Implementation of a field mineralization trial would be beneficial in determining management strategies to effectively utilize 'AU Golden' as an N source. The objective of this study was to determine the rate of decomposition of 'AU Golden' sunn hemp residue in the field in order to efficiently utilize it as an N source for subsequent crops.

MATERIALS AND METHODS

A field decomposition study was conducted at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL (34˚4' N, 86˚53' W) on a Decatur and Dewey silt loams (Fine, kaolinitic, thermic Plinthic Typic Kandiudults) and at the Wiregrass Research and Extension Center (WGS) in Headland, AL (31°30' N, 85°17' W) on a Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) for the 2013 sunn hemp growing season utilizing litterbag methodology (Bocock and Gilbert, 1957). The field study was imposed into an existing experimental design, which was a randomized complete block with main treatments being the sunn hemp planting dates (May, June, and July) with four replications at each location. Individual plot dimensions were 3.0 m wide and 12.2 m long at the TVS location and 3.6 m wide and 12.2 m long at the WGS location with 4.6 m alleys between plots. Sunn hemp was planted at 34 kg ha^{-1} with a 3.0 m wide John Deere® conventional drill at TVS and a 3.6 m wide Great Plains® (GP) drill at WGS between the 10th and 20th of each corresponding month (Table 3.01). Biomass was only allowed to accumulate for 60 d after which sunn hemp was rolled down utilizing a cover crop roller and crimper (Ashford and Reeves, 2003). An application of glyphosate (*N*-(phosphonomethyl) glycine) was then applied to the rolled down sunn hemp to ensure complete termination.

Residue collection and sampling

A designated plot was chosen to correspond with each sunn hemp planting date within each replication to impose the mineralization field trial (Table 3.02). Prior to termination of each corresponding sunn hemp planting date, a 0.25 m^2 of fresh sunn hemp residue was collected in addition to the 0.25 m^2 biomass samples taken at 50-60 days after planting (DAP). Nylon mesh bags measuring 10 x 20 cm were utilized in the field to contain the sunn hemp residue designated for observation. Residue amounts for the litter bags were estimated based on the dry weight of biomass collected from the 2012 sunn hemp crop and moisture percentages from a previous study because fresh weights were not collected in 2012. Litterbags contained a designated amount of residue for each planting date based on equivalent rates of sunn hemp biomass produced from the previous growing season (Table 3.02). Fresh residue biomass was calculated using a sunn hemp moisture content of 220 g kg^{-1} and then adjusted to equivalent rates in g bag^{-1}. Fresh weights of the sunn hemp biomass collected for the 2013 growing season were taken at both locations, prior to the separation of the leaf and stem fractions to determine the correct moisture percentage and weights were adjusted accordingly. The appropriate amount of residue was then placed into the litterbags, sealed, and pinned to the soil surface in the designated plot for the designated planting date for the four replications.

Bags were retrieved from the field at 0, 4, 7, 15, 30, 60, 90, and 120 days after sunn hemp termination (Table 3.03). Due to the different planting dates and termination times, there were a different number of litterbags assigned to each planting date treatment to correspond to the number of days between sunn hemp termination and anticipated wheat planting. May litterbags decomposed for 120 days, June litterbags decomposed for 90 days, and July litterbags decomposed for 60 days at both locations. Once collected from the field, bags were cleaned of any soil and the remaining residue within each bag was oven dried at 55˚ C for a minimum of 72 hours, weighed, and ground to pass a 0.5 mm screen with a Cyclone sample mill (Thomas Scientific, Swedesboro, NJ). Total C and N content of the residue was determined through dry combustion using the LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI). Approximately 0.5 g of material from each litterbag sample was ashed in a muffle furnace at 400˚ C for 12 hours. Data was converted to an ash-free dry weight (AFDW) basis to account for possible soil contamination that might have occurred while in the field (Cochran, 1991).

Statistical analysis

Means, standard errors, and statistical significance for mineralization data were determined using the Proc Glimmix procedure (SAS Institute, 2012). Classification variables were location, planting date, and sampling times. Analysis of variance was performed for the percent of mass, N, and C remaining. Non-linear models were also fitted using SigmaPlot® 12 software (Systat Software, 2010). Equations were single or double exponential models chosen based on their R^2 value. The model that had the highest value was considered the best fit and was utilized in all cases. The following equation represents the double exponential decay model:

$$Y = Ae^{-k_1 t} + Be^{-k_2 t} \text{ (Equation 1).}$$

Variables embodied in this equation are as follows: Y= the nutrient or mass remaining, A= labile portion, B= recalcitrant portion, k_1 and k_2 are rate constants fitted to the data, and t= time in days after termination (Wieder and Lang, 1982).

RESULTS AND DISCUSSION

Different aspects of sunn hemp residue decomposition and nutrient release were affected by location, planting date, sample time, and their interactions (Table 3.04). Double and single exponential decay models (Equation 1) functioned as the foundation for comparison of percent mass, N, and C remaining after decomposition and were considered significant for mass and N remaining across three planting dates at both locations. Comparisons between k_1 and k_2 values represented in exponential decay models (Table 3.05) indicated that labile leaf fractions of sunn hemp residue decomposed at a quicker rate when compared with recalcitrant stem fractions. The k_1 value representing the fixed decomposition rate of labile portions was consistently higher than k_2 values for percent mass, N, and C remaining across planting dates and locations (Table 3.05). Single decay exponential models formed in several instances as a result of a small k_2 value which is indicative of a near linear response that causes the double exponential decay model to collapse into a single exponential model (Table 3.05).

Residue decomposition

The decomposition of sunn hemp residue in the field in regards to mass was significantly affected by location, planting, date, sample time, and all interactions (Table 3.04). The percent of sunn hemp residue remaining after decomposition across the three sunn hemp planting dates at the WGS location was less than the amount remaining at TVS demonstrating a more complete deterioration of sunn hemp residue (Figure 3.01).

A strong location by planting date by sample time interactions (p = 0.0005) was observed for mass remaining (Table 3.04). A more rapid decomposition at WGS particularly within the first two weeks after sunn hemp decomposition is evident by the steeper slope for the planting dates of May and June in comparison with TVS (Figure 3.01A and Figure 3.01B). During the month of July, the initial slope was steeper for TVS, but quickly leveled out into a gradual decomposition while WGS continued to decrease in mass (Figure 3.01C). Over the decomposition period, labile portions decompose, which increases the amount of recalcitrant portions thus decreasing the overall rate of decomposition (Wieder and Lang, 1982). Climatic conditions typical to more southern locations of the state could also explain the accelerated decomposition compared to locations in north Alabama where the overall rate of decomposition was slower. Higher amounts of microbial activity are often typical in environments with high temperatures such as south Alabama, particularly in regards to legume residues that have high amounts of N and low C: N ratio (Biederbeck and Campbell, 1973; MacDonald et al., 1995) (Table 3.06). Additionally, May and July planting dates at the TVS location contained larger amounts of stems (*B*) in comparison to WGS while larger amounts of leaves (*A*) were present at WGS (Table 3.05). This would also contributes to the rate of decomposition because stems decompose at a slower rate having a C:N ratio > 20:1 (Table 3.06). (Mansoer et al., 1997). July was only allowed to decompose for 60 d and therefore lost the least amount of residue between sunn hemp termination and planting of the subsequent crop. Peak mass loss was observed during the month of June at TVS with losses at 53% while WGS lost as much as 62% during the month of May (Figure 3.01B). May residue equivalent rates were much smaller compared to June and July and were allotted 120 days for decomposition; however, June sunn hemp lost more mass in comparison to May across both locations which could be attributed to higher temperatures (Figure 3.01B). July contained greater amounts of initial sunn hemp residue and therefore had higher percentage remaining at each sampling time (Figure 3.01C).

Nitrogen release

Nitrogen release from sunn hemp residue was significantly affected by location, sample time, a location by sample time interaction, and a planting date by sample time interaction (Table 3.04). Differences between k_1 values at WGS and TVS revealed a faster release of N from May sunn hemp at WGS than at TVS (Table 3.05). The final litterbags collected from the field had a higher percentage of N remaining (Table 3.06) when compared with residue from WGS for the May planting date while June and July had comparable percentages across locations (Figure 3.02A, Figure 3.02B, and Figure 3.02C).

May sunn hemp residue N release at the WGS location occurred rapidly with 64% being released within two weeks before leveling out indicating complete decomposition of labile fractions (Figure 3.02A). Additionally, higher amounts of leaf fractions indicated by the high (*A)* value for May corresponds to the initial rapid release of a large percentage of sunn hemp N (Figure 3.05). The majority of sunn hemp N is concentrated in the leaf fractions whose rapid decomposition can release as much as 50% of its total N in as little as 4 wks (Mansoer et al.,1997) (Table 3.06). These reports were associated with overwintering residue decomposition; therefore, higher amounts of N could be lost in a shorter period of time due to increase microbial activity at higher temperatures.

June N release was comparable across both locations resulting in a near linear decomposition rate (Figure 3.02B). Similar values were observed for both single exponential models with a slightly higher *k* value at WGS (Table 3.04). The speed of decomposition can be determined by whether the model corresponds to a single or double decay exponential model. Often, accelerated decomposition results in a single decay model due to an almost linear response of the recalcitrant fractions causing the k_2 rate constant to become very small (Mulvaney et al., 2010).

The initial slope of July sunn hemp N release at TVS was steeper indicating rapid N release, but quickly leveled out into a gradual decline while N release at WGS resulted in a linear response decreasing at a consistent rate (Figure 3.02C). The majority of sunn hemp N was lost from the May residue at WGS while June and July lost 50 and 39% (Table 3.06) (Figure 3.02). The N release at TVS occurred slowly in comparison with WGS. A majority of N release occurred in as little as two weeks after termination with as much as 87% being released at WGS and over 20% at TVS. Leaf and flower heads of ‘Tropic Sun’ sunn hemp contain 80.6% of sunn hemp N and decompose quickly in comparison to stem fractions that have low N value and are high in lignin and cellulose (Marshall et al., 2002). Similar values were seen for ‘AU Golden’ sunn hemp where leaf and flower head fractions contained 73-75% of sunn hemp total N across the three planting date treatments. These recalcitrant fractions often encourage immobilization and reduce mineralization (Mansoer et al. 1997). In order to take advantage of the N contributions of sunn hemp, planting of the subsequent crop would need to be synchronized with the N release of labile fractions that contain the majority of the N. Sunn hemp that is allowed to fully decompose prior to planting wheat appears to have little N left to contribute.

Carbon release

The decomposition of C from sunn hemp residue was affected by planting date, sample time, and a planting date by sample time interaction (Table 3.04). The release of C was comparable for May and June and slightly higher at TVS for the month of July. Exponential decay models were not considered significant for C remaining (%) for June and July at TVS nor for June at WGS. Rate constant k_1 was higher for May and July at the TVS location and for June at the WGS location (Table 3.05). Carbon was released at a quicker rate at TVS for May and June residue in comparison with July (Figure 3.03 A, Figure 3.03B, Figure 3.03C). July residue appeared to be more resistant to decay as a result of a higher amount of recalcitrant (*B*) fractions in comparison with labile fractions and C was released at a gradual rate (Table 3.06) (Figure 3.03C). May sunn hemp residue released C at a quicker rate than June and July which is evident by the higher rate constant (k_1) and single decay model indicating rapid decomposition (Figure 3.03A). There was a decrease in C release with later sunn hemp planting dates (Table 3.06). At TVS, 54% loss of C was observed for May residue in comparison with only 26% for July sunn hemp residue while WGS May sunn hemp experienced a loss of 39% and July only 12%. Observations were indicative of a steady decline of C over the period of residue decomposition. After the rapid decomposition of labile fractions, the recalcitrant stems of sunn hemp decompose slowly, releasing C at a gradual rate.

CONCLUSION

A two pooled exponential decay model showed that sunn hemp leaves are readily decomposed by soil microbes in comparison to stems which are more resilient against decomposition. Leaf fractions went through full decomposition by the end of the mineralization field trial leaving only sunn hemp stems. Residue from the May planting experienced greater losses than later plantings in residue and N with complete dissolution occurring in some instances. As much as 87% of N was lost for May sunn hemp at WGS while June and July losses were between 40-50%. July planting dates terminated in September not only had more initial residue, but also had less time to decompose. Cooler temperatures later on in the season could also account for a reduced rate of decomposition. There was a greater loss of residue and N at the WGS location in comparison to the TVS location indicated by steeper slopes and greater k_1 values. Decomposition and N release were most likely accelerated by higher temperatures and greater amounts of precipitation that occurred at the southern location. A more gradual slope was observed for C release across both locations for the three sunn hemp planting dates. June sunn hemp at WGS and July sunn hemp at TVS exhibited steeper slopes beginning decomposition before shifting into a gradual decline which could be attributed to C release from rapidly decomposing labile fractions. May showed the largest amount of C loss when compared with June and July, but this was due to more allotted time for decomposition.

Decomposition, N, and C release occurred at different rates for the different sunn hemp planting dates. This is most likely due to the different ratios of stem and leaf fractions which decompose at different rates. Sunn hemp residue C:N ratios oscillated above >20:1 after labile fractions had decomposed and only stems remained. The decomposition of N rich components of sunn hemp took place very rapidly after termination. Forming a synchronous relationship between N release of sunn hemp residue and N uptake of subsequent crops is essential in effectively utilizing sunn hemp as a fertilizer source (Dabney et al., 2001). Termination of a sunn hemp cover crop should occur near planting of the following crop in rotation so that N released from rapidly decomposing leaf and flower fractions are not lost. Although sunn hemp stems do not serve as a primary N source for subsequent crops, they still contribute to soil surface protection as well as soil organic matter (SOM) which can benefit crop production in the long run.

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Table 3.01. Sunn hemp field calendar for 2013 at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland AL.

Sunn Hemp Data	TVS			WGS		
	May	June	July	May	June	July
	---------------2013 Sunn Hemp Growing Season---------------					
Planting Date	24-May	25-Jun	26-Jul	13-May	11-Jun	9-Jul
Termination Date	26-Jul	20-Aug	12-Sep	9-Jul	8-Aug	5-Sep

Table 3.02. Sunn hemp residue amounts and designated plots for three sunn hemp planting dates at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the growing season of 2013.

	TVS			WGS		
	May	June	July	May	June	July
Plots†	103	114	108	113	108	111
	215	201	205	211	207	216
	308	316	311	307	311	304
	404	414	408	408	413	402
	$g\ bag^{-1}$					
Residue Amount	8.72	20.62	18.69	9.35	15.97	18.84
	$Mg\ ha^{-1}$					
Equivalent Rates‡	4.4	10.3	9.3	4.7	8.0	9.4

† One plot from each replication within each planting date at both locations chosen for mineralization trial.

‡ Residue amount for decomposition bags was based on equivalent biomass rates of planting date at each location from the previous sunn hemp growing season.

Table 3.03. Mineralization field calendar for the growing season of 2013 at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL.

	May		June		July	
Location	Collection Date	DAT†	Collection Date	DAT	Collection Date	DAT
TVS	26-Jul	—	20-Aug	—	19-Sep	—
	30-Jul	4	24-Aug	4	23-Sep	4
	2-Aug	7	27-Aug	7	26-Sep	7
	10-Aug	15	4-Sep	15	3-Oct	15
	25-Aug	30	19-Sep	30	18-Oct	30
	24-Sep	60	19-Oct	60	18-Nov	60
	24-Oct	90	18-Nov	90		
	23-Nov	120				
WGS	9-Jul	—	8-Aug	—	5-Sep	—
	13-Jul	4	12-Aug	4	9-Sep	4
	16-Jul	7	15-Aug	7	12-Sep	7
	24-Jul	15	23-Aug	15	20-Sep	15
	8-Aug	30	9-Sep	30	7-Oct	30
	9-Sep	60	10-Oct	60	6-Nov	60
	10-Oct	90	9-Nov	90		
	9-Nov	120				

† Days after termination.

Table 3.04. Analysis of variance for sunn hemp residue decomposition measuring percent mass, N, and C remaining and C:N ratio across three locations (LOC) and three sunn hemp planting dates (PD) at various sample times (ST) during sunn hemp decomposition for the growing season of 2013.

	Mass Remaining		N Remaining		C Remaining		C:N Ratio	
	F value	P value	F value	P value	F value	P value	F value	P value
Location	84.27	<.0001	11.48	0.0029	0.76	0.3914	1.07	0.3081
Planting Date	6.66	0.0051	0.30	0.7436	31.52	<.0001	4.33	0.0247
LOC X PD	35.10	<.0001	3.06	0.0696	2.46	0.1108	7.64	0.0057
Sample Time	231.52	<.0001	70.76	<.0001	267.09	<.0001	7.20	0.0000
LOC X ST	6.23	<.0001	2.20	0.0388	1.10	0.3670	1.21	0.3046
PD X ST	13.69	<.0001	12.43	<.0001	49.14	<.0001	3.07	0.0004
LOC X PD X ST	3.01	0.0005	1.21	0.2785	1.01	0.4433	1.24	0.2560

Table 3.05. Double and single exponential decay equations regressed on time (days) for mass, C, and N remaining from sunn hemp decomposing under field conditions. Residue was obtained from sunn hemp grown for three sunn hemp planting dates (May, June, and July) at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for the growing season of 2013. Double and single exponential decay equations are in the form of $Y= Ae^{-k_1 t} + Ce^{-k_2 t}$ and $Y= Ae^{-k_1 t}$, where Y= mass, C, and N remaining (%), A= the labile portion, C= the recalcitrant portion, k_1 and k_2 are the labile and recalcitrant rate constants, and *t*= time in days.

Location/PD†	Equations	R^2	P>F‡	S_{yx}§
TVS	Mass Remaining (%)			
May	$Y= 25.9\ e^{-0.105t} + 78.3\ e^{-0.003t}$	0.8004	0.0234	8.4
June	$Y= 51.3\ e^{-0.036t} + 44.2\ e^{-1.177^{-019t}}$	0.9248	0.0122	5.4
July	$Y= 23.8\ e^{-0.231t} + 76.2\ e^{-0.004t}$	0.9957	0.0026	1.0
	N Remaining (%)			
May	$Y= 62.9\ e^{-0.038t} + 44.8\ e^{-1.43^{-018t}}$	0.7545	0.0351	13.3
June	$Y=99.2\ e^{-0.010t}$	0.9795	<0.0001	3.2
July	$Y= 18.2\ e^{-0.36t} + 81.9\ e^{-0.003t}$	0.9369	0.0376	2.7
	C Remaining (%)			
May	$Y= 99.2\ e^{-0.007t}$	0.9549	<0.0001	4.5
June	$Y= 97.8\ e^{-0.004t}$	0.9532	0.1111	7.4
July	$Y= 18.4\ e^{-0.531t} + 81.6\ e^{-0.002t}$	0.9120	0.0523	2.8
WGS	Mass Remaining (%)			
May	$Y= 67.1\ e^{-0.073t} + 35.0\ e^{-4.42^{-019t}}$	0.8984	0.0062	8.6
June	$Y= 56.8\ e^{-0.096t} + 44.6\ e^{-0.002t}$	0.9394	0.0089	5.9
July	$Y= 51.6\ e^{-0.0559t} + 49.1\ e^{-5.86^{-019t}}$	0.9582	0.0250	3.9
	N Remaining (%)			
May	$Y= 73.0\ e^{-0.192t} + 27.0\ e^{-0.003t}$	0.9779	0.0003	4.2
June	$Y= 96.4\ e^{-0.0087t}$	0.7100	0.0107	11.9
July	$Y= 94.3\ e^{-0.007t}$	0.6589	0.0310	8.3
	C Remaining (%)			
May	$Y= 94.6\ e^{-0.005t}$	0.7746	0.0024	8.3
June	$Y= 26.1\ e^{-0.113t} + 74.8\ e^{-0.003t}$	0.6915	0.0979	9.4
July	$Y= 94.3\ e^{-0.007t}$	0.6589	0.0309	8.3

† Planting date.

‡ Significance of regression.

§ Standard error of the estimate Y on X.

Table 3.06. Carbon, nitrogen, and the C/N ratio of sunn hemp residue measured across a period of decomposition for three sunn hemp planting dates at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the year of 2013.

		TVS			WGS		
Planting Date	Time†	C	N	C/N Ratio	C	N	C/N Ratio
	days	$g\ kg^{-1}$					
May	0	448.9	17.8	26.8	442.3	47.9	9.3
	4	417.1	19.0	22.8	402.0	29.9	14.7
	7	419.1	14.3	31.4	407.5	19.5	25.9
	15	399.3	15.0	27.0	181.0	5.8	31.6
	30	294.8	9.0	33.6	389.6	11.1	36.3
	60	314.3	8.6	37.6	87.7	3.5	24.3
	90	222.3	8.9	25.5	165.1	6.2	26.2
	120	205.5	8.5	25.0	21.0	1.2	17.7
$LSD_{0.05}$		120.0	5.9	12.7	143.7	10.0	16.8
June	0	457.2	25.8	17.8	458.2	20.0	23.2
	4	415.4	27.5	15.1	419.6	23.0	18.4
	7	416.2	22.5	18.9	403.0	20.1	20.4
	15	414.6	21.7	19.4	314.5	12.3	25.3
	30	391.0	19.0	21.0	283.2	10.5	26.3
	60	307.9	14.0	21.8	245.5	11.2	21.4
	90	239.3	10.7	22.4	283.2	10.0	27.0
$LSD_{0.05}$		53.4	3.8	4.0	168.8	5.9	10.9
July	0	474.6	23.9	20.7	455.1	26.2	17.5
	4	398.3	19.8	20.2	425.3	19.9	48.7
	7	375.1	18.8	20.0	425.0	25.6	17.1
	15	390.3	18.5	21.2	421.1	21.8	19.6
	30	358.6	16.3	22.3	426.5	20.5	20.8
	60	350.0	15.9	22.1	400.0	16.0	25.2
$LSD_{0.05}$		42.3	4.2	4.3	44.6	8.1	38.7

† Days after bags were placed in the field; day 0 corresponds to the day the bags were placed in the field.

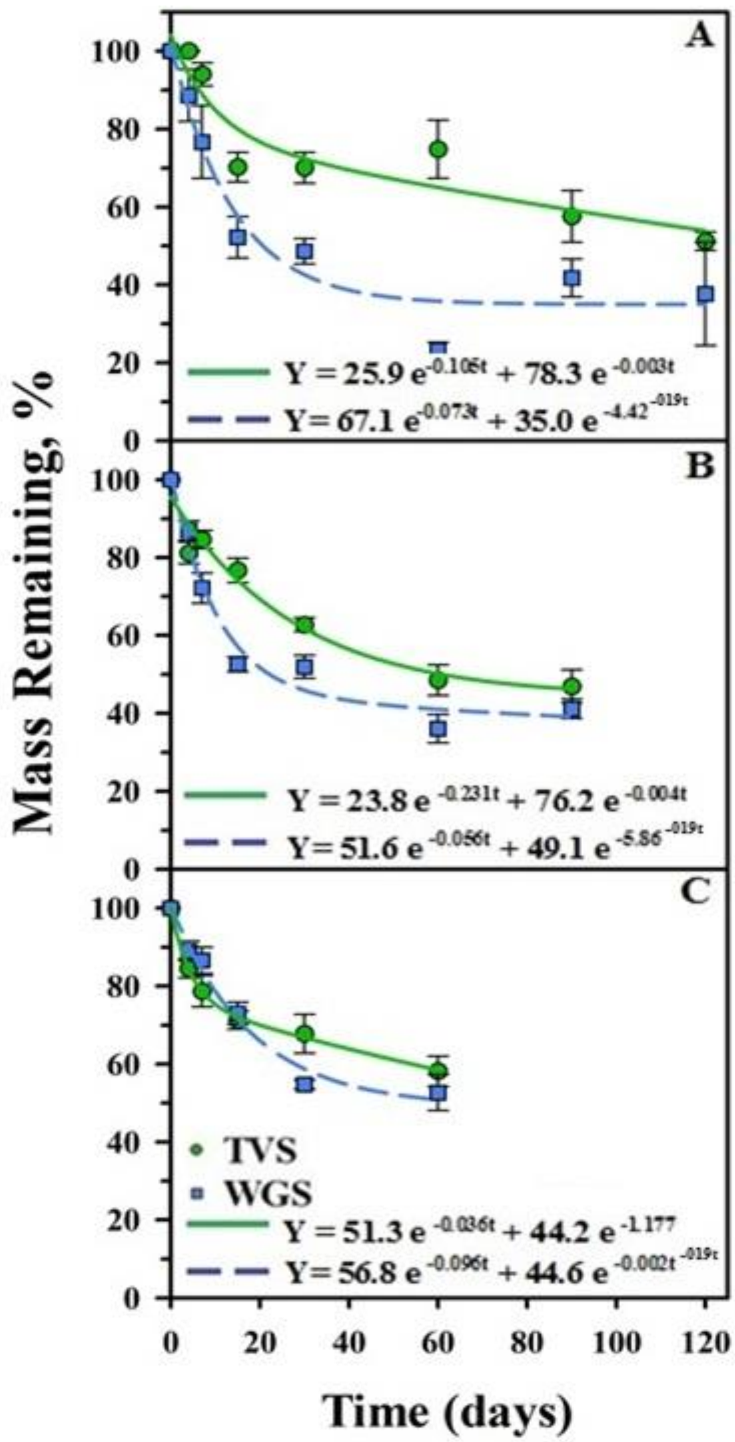

Figure 3.01. Location comparisons at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL comparing the exponential decay of sunn hemp residue over seven sample time (days) for sunn hemp planting dates May (A), June (B), and July (C) during the 2013 growing season.

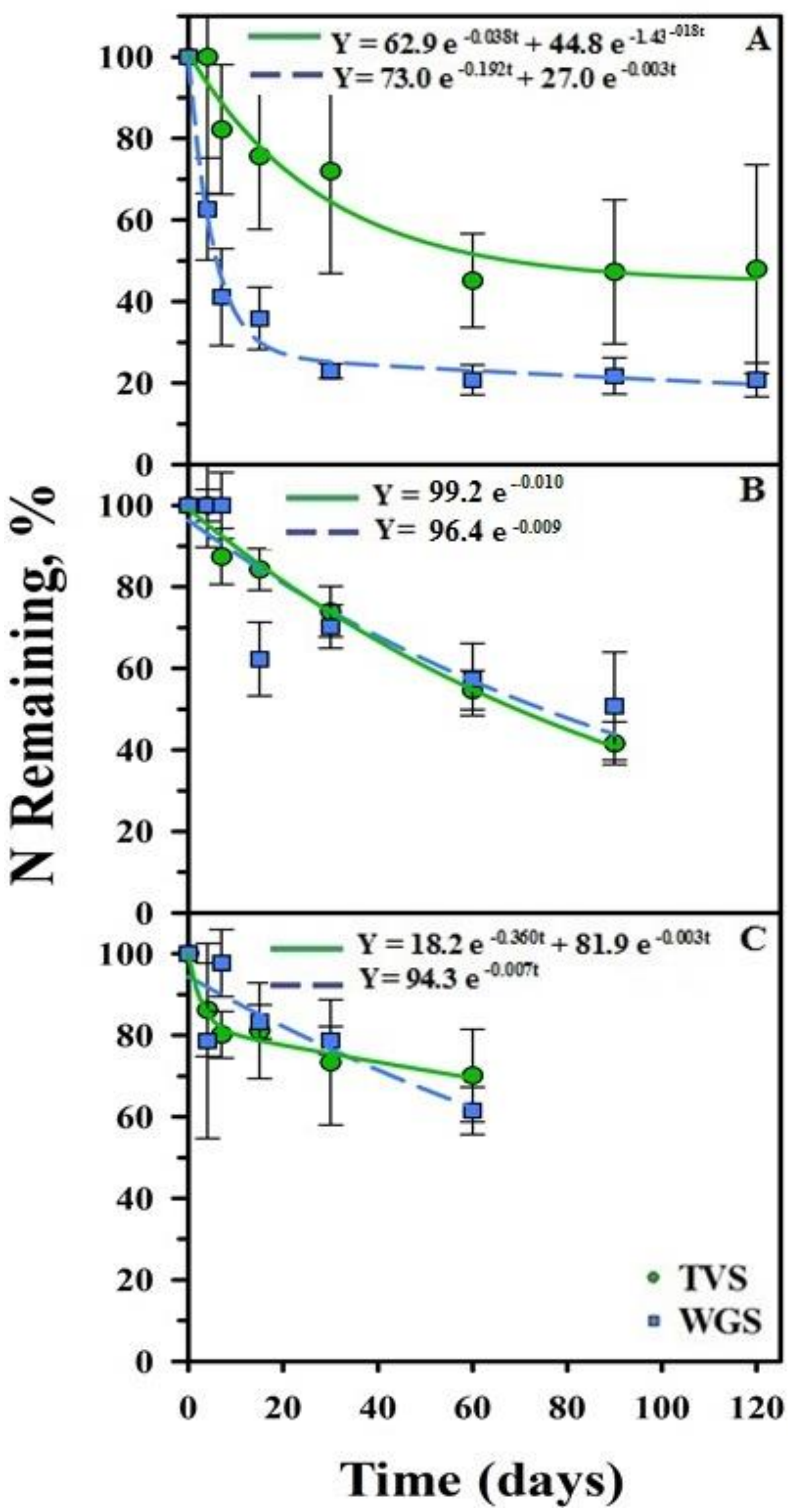

Figure 3.02. Location comparisons at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL comparing the release of N from sunn hemp residue over seven sample time (days) for sunn hemp planting dates May (A), June (B), and July (C) during the 2013 growing season.

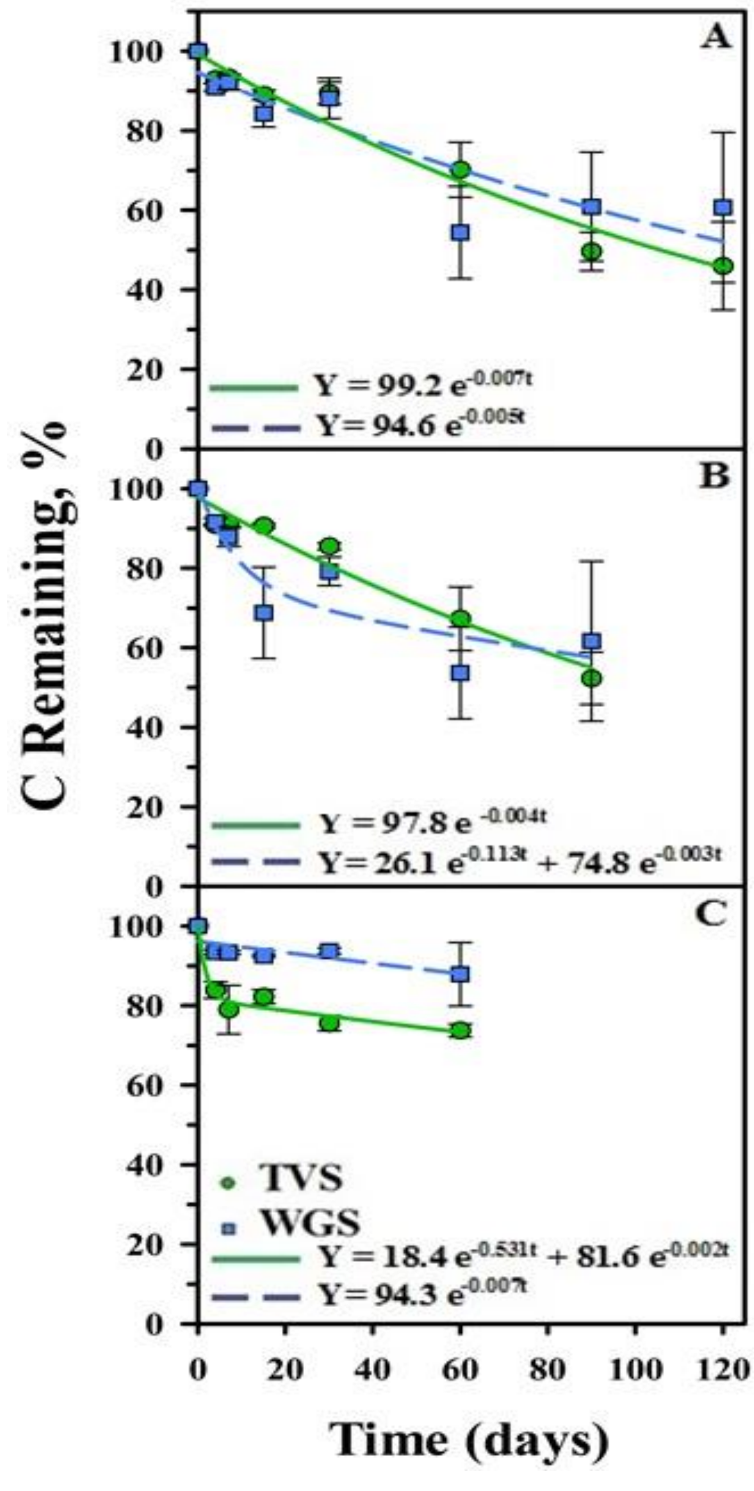

Figure 3.03. Location comparisons at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL and at the Wiregrass Research and Extension Center (WGS) in Headland, AL comparing the release of C from sunn hemp residue over seven sample time (days) for sunn hemp planting dates May (A), June (B), and July (C) during the 2013 growing season.

IV. WHEAT N RESPONSE TO 'AU GOLDEN' IN ALABAMA

ABSTRACT

Winter legumes are frequently utilized within crop rotations to enhance soil productivity and provide nitrogen (N) to ensuing cash crops in order to offset the cost of synthetic fertilizers. Biomass and N accumulation are often restricted as a result of time limitations between previous crops in rotation, which does not allow for optimum production. Sunn hemp (*Crotalaria juncea* L.) is a tropical legume adapted to the temperate climates of the U.S. as a fast growing summer annual. The rapidity of sunn hemp's biomass and N production has prompted further research utilizing the crop as a warm season cover crop. Recently, the sunn hemp cultivar, 'AU Golden' was developed by plant breeders at Auburn University to allow for consistent and affordable domestic seed production above 28˚ N latitude, which would improve seed availability to producers in the Southeast. A two year experiment was conducted at three locations across Alabama from 2012-2014 to determine the effectiveness of 'AU Golden' sunn hemp at reducing N fertilizer requirements for winter wheat (*Triticum aestivum* L.). Treatments were arranged in a strip- plot configuration with plots vertically corresponding to the three sunn hemp planting dates (May, June, and July) and a fallow area while plots horizontally corresponded to four N application rates applied as urea ammonium nitrate (UAN) liquid solution to winter wheat in fall and spring combinations. The sunn hemp cover crop contributed little to no N to the subsequent wheat crop for the

2013 and 2014 growing seasons. Two of the three locations showed no differences in wheat grain yields during the 2013 growing season between fallow and sunn hemp plots. However, at the Tennessee Valley Research and Extension Center (TVS) location yields following a fallow area were 30% higher averaging 6.1 Mg ha^{-1} compared with yields following sunn hemp which only averaged 4.7 Mg ha^{-1} across the three planting date treatments. Overall, wheat responded best during the 2013 growing season when fertilized with the fallow rate of 22 kg N ha^{-1} in the fall and 78 kg N ha^{-1} in the spring, but there were not differences in yields across planting date treatments for the four N treatments. Wheat yields for 2014 were comparable across planting dates; however, the PBU location yielded significantly lower compared to the remaining locations. Wheat grain N concentrations were not affected by N treatments for either growing season, but interactions were observed between location and planting date with comparable values across sunn hemp and fallow plots. Current results fail to show that N from sunn hemp was successful in reducing fertilizer requirements for winter wheat. Further investigation on the utilization of sunn hemp N is warranted in order to make efficient use as a beneficial cover crop.

INTRODUCTION

Before the introduction of synthetic fertilizers, producers relied on biological sources of N for crop fertilization (Reeves, 1994). Synthetic fertilizers led to a period of heavy dependence on chemical usage for N supplementation (Horrigan et al., 2002). As food demands increase to accommodate the growing population, crop fertilization has become a costly expenditure as a result of the volatile prices of synthetic fertilizers (Kassam et al., 2009). Sustainable agriculture that strives to prevent the exhaustion of natural resources and maintain productivity of arable lands has impelled producers to return back to traditional legume rotations for N contributions to cash crops (Reeves, 1994).

Legumes' N_2 fixing capabilities makes them a desirable cover crop option for producers looking to decrease overhead expenses often inflated by the reliance on chemical applications (Holderbaum et al., 1990). Traditional legumes utilized in the temperate climates of the Southeast are often limited in biomass production due to time restraints surrounding harvest and planting schedules of contiguous crops in rotation (Mansoer et al., 1997). The growth habits of temperate legumes are not often conducive for peak production within short intervals often seen between planting of cash crops (Balkcom et al., 2011). Legume cover crop performance is optimized when allowed to accumulate maximum top growth, which typically results in higher N percentages (Decker et al., 1987). Traditional winter legumes often utilized in the Southeast have little time in the fall for biomass accumulation before the onset of cool temperatures due to harvest obligations of previous crops in rotation. Accumulation is also limited in the spring by the earliness of spring planting. Adequate time must be allotted in order for moisture to be restored to the soil before planting of cash crops so optimum germination can occur (Balkcom and Reeves, 2005). Tropical legumes have gained attention in the U.S. as a warm season cover crop because of the haste in which peak biomass and N production is reached (Yadvinder et al., 1992). Prior investigations have found that tropical legumes are capable of producing 10 Mg ha^{-1} of biomass and 200 kg N ha^{-1} during a summer growth period (Reddy et al., 1986). The ability of tropical legumes to produce substantial residue in a short period of time could have greater effects on maximizing crop yields and improving soil properties than a low residue cover crop. Tropical legumes are commonly used as green manure crops in their native countries to enhance the productivity of depleted soils (Chaudhury et al., 1978). The high amounts of residue produced provide soil protection and contributes organic matter back to the soil increasing soil fertility. Additionally the large amounts of N fixed by tropical legumes can contribute to fertilization of following crops (Cherr et al., 2006).

Sunn hemp is a tropical legume that has generated interest in the U.S. since the 1930's (Cook and White, 1996). Although native to tropical regions, sunn hemp is capable of performing as a summer annual in the warm temperatures of the Southeast (Rotar and Joy, 1983). 'Tropic Sun' sunn hemp released for utilization in 1983 has proven vigorous in our climate by producing 7.6 Mg ha^{-1} at 14 weeks after planting (WAP) in south Alabama (Balkcom and Reeves, 2005). Sunn hemp production was superior to the average minimum requirement of 4.5 Mg ha^{-1} for a high residue cereal cover crop and was comparable to dry matter production for several traditional winter legumes utilized across the Southeast (Reiter et al., 2003; Hoyt and Hargrove, 1986). Similar performance was seen in the N production of sunn hemp with results equating to and sometimes exceeding values for crimson clover and hairy vetch, which are considered standards in the Southeast

(Reeves, 1994). Sunn hemp, utilized as an alternative cover crop in rotations, could eliminate management challenges that are often associated with temperate climate legumes because it can produce sufficient ground cover and N within a condensed time frame.

Despite all of sunn hemp's valuable qualities, there are still management issues that could reduce the efficiency of its performance as a cover crop. The use of legumes as an N source is commonly accompanied by synchronicity complications. Improper management of sunn hemp can cause asynchronization between peak N mineralization of residue and N sequestration of the recipient crop (Dabney et al., 2001). Recovery of cover crop N is highly variable and influenced by climate, the amount of N in residue, as well as initial soil fertility (Doran and Smith, 1991). Prior examinations for sunn hemp preceding a corn (*Zea mays* L.) crop found that N available in the spring was reduced due to possible denitrification and leaching during the winter months. However, spring corn still received a fertilizer equivalent of 58 kg ha^{-1} from sunn hemp residue despite winter losses and corn yields were increase by 1.2 Mg ha^{-1} compared to fallow plots. Recommendations were made for incorporation of a winter cereal into the crop rotation to reduce N loss as well as increase residue cover for the subsequent corn crop (Balkcom and Reeves, 2005; Humberto et al., 2012).

Winter cereals are valuable high residue crops that are efficient at nutrient recycling. Winter wheat often serves as a winter cover crop in rotations in addition to being produced for grain because of its capabilities at producing high amounts of residue and cleaning the soil of residual N (Schomberg et al., 2007). The dense rooting system of cereal grains is established quickly and can reach anywhere from 80 to 150 cm allowing for more resource scavenging in comparison with legume cover crops (Sainju et al., 1998; Frye et al., 1985). Increased N uptake by wheat was observed following a high residue legume cover crop in a study conducted in New Delhi (Sharma and Behera, 2008). A wheat crop following a sunn hemp cover crop could benefit from residue N released during decomposition and sunn hemp could potentially reduce N fertilizer requirements for the growing season.

There has been little information gathered on the N contributions of sunn hemp selection ‘AU Golden’ recently developed by Auburn University. Sunn hemp cultivar ‘Tropic Sun’ proved to be an adequate 3:1:2 fertilizer containing 123-42-80 of N-P_2O_5-K_2O in a study conducted by Marshall et al., (2002). ‘AU Golden’ planted prior to a winter wheat crop could prove equally as beneficial in serving as a biological nutrient source thereby decreasing overhead expenses for producers and aiding in ecological preservation by reducing synthetic fertilizer use. The objective of this study was to determine if ‘AU Golden’ sunn hemp was efficient in reducing N fertilizer requirements for a subsequent winter wheat crop.

MATERIAL AND METHODS

‘AU Golden’ sunn hemp’s efficiency at reducing N fertilizer requirements for winter wheat was evaluated during the 2013 and 2014 growing seasons. The experiment was conducted at the Plant Breeding Unit (PBU) in Tallassee, AL (32˚32’ N, 85˚53’ W), the Wiregrass Research and Extension Center (WGS) in Headland, AL (31°30' N, 85°17' W), and at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL (34˚4’ N, 86˚53’ W). Soil types included Wickham sandy loam (PBU), Dothan fine sandy loam (WGS), and Decatur and Dewey silt loams (TVS). Experimental design was a strip plot configuration with plots vertically consistent with three sunn hemp planting dates and a fallow area while plots were horizontally represented by four N application rates (Table 4.01) applied as 28% urea ammonium nitrate (UAN) to winter wheat in fall and spring application combinations. The designated area for the experimental site was relocated the second year and planting date treatments were re-randomized. Individual plot dimensions were 3.6 m wide and 12.2 m long at the WGS location and 3.0 m wide and 12.2 m long at the PBU and TVS location with 4.6 m alleys between plots. Ignite (glufosinate ammonium) and Roundup (glyphosate) was used for burn down of the initial weed population and for weed control in fallow areas.

Soil Sampling

Soil inorganic N and fertility requirements were determined prior to wheat planting using a 1.9 cm diameter probe by compositing 10-12 cores to a depth of 0-15 and 15-30 cm within each planting date for four replications at the three locations for the 2012-2013 growing season. Soils were extracted at the USDA-ARS National Soil Dynamics Laboratory (NSDL) for NH_4-N and NO_3-N by extracting 10 g of each soil with 50 mL of 2 M KCl and filtering the soil solution through Whatman no. 42 filter paper (GE Healthcare Ltd, Little Chalfont, UK) and measuring spectrophotometrically (Kenney and Nelson, 1982).

Soil sampling prior to the 2013- 2014 wheat planting was modified to check for residual N deeper in the soil profile that could potentially contribute to higher wheat yields in fallow plots. Composite samples of 5 cores were taken using a 3.8 cm probe attached to a Giddings Probe (Giddings Machine Company, Inc.) to a depth of 60 or more cm and split up into five depths at 15 cm increments for each planting date treatment. Soil samples were extracted for NH_4-N and NO_3-N performing the same procedure utilized for previous soil samples. Soil extractable nutrients (P, K, Mg, and Ca) fluctuated from medium to very high across all three locations; the pH ranged from 5.8-6.7. Recommendations from Auburn University Soil Testing Laboratory were adhered to and 44 kg P_2O_5 ha^{-1} was broadcast prior to wheat planting at the TVS location for the 2013 and 2014 growing season and at the WGS location prior to 2013 wheat growing season (Table 4.02).

Plant and Tissue Samples

Wheat cultivar 'AGS 2035' was planted during the month of November for the 2013 and 2014 growing seasons (Table 4.03). Non-inversion tillage was performed at the PBU and WGS locations with a KMC sub-soiler leveler prior to wheat planting; TVS did not receive any tillage. Fall UAN was applied shortly after wheat planting and spring UAN was applied at Feekes 4 stage of wheat growth according to fall and spring application combinations (Table 4.01 and Table 4.03). Feekes 4 tissue samples were collected by extracting whole plant samples from 0.093 m^2 area from each plot. A second sampling took place at the Feekes 6 stage of wheat growth by removing all of the above ground plant material from the same size area. Tillering density was determined for the samples collected at Feekes 4 by counting tillers with three or more leaves on them. Samples collected at both stages of wheat growth were oven-dried at 55˚ C for 72 hours and weighed before being ground to pass a 1-mm screen size with a Wiley mill and a Cyclone sample mill (Thomas Scientific, Swedesboro, NJ). Analysis for total carbon (C) and N was conducted for all tissue samples through dry combustion using a LECO CHN-600 analyzer (Leco Corp., St. Joseph, MI).

Harvest

The center two rows of each plot were harvested with a small plot combine, and yields were adjusted to 13.5% moisture. Test weights were determined using a 151 filling hopper after sieving a portion of the grain sample collected from each plot. Moisture of each grain sample was also determined using a Burrows Moisture Tester (Seedburo Equipment Co., Chicago, Illinois). Grain samples were then ground using a Cyclone sample Mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen size and analyzed for C and N performing the same procedure utilized for the tissue samples.

Daily precipitation were obtained from the AWIS Weather Services Inc., monitoring stations located near the experimental sites in Belle Mina, AL, Headland, AL, and Tallassee, AL (Alabama Mesonet Weather Data, 2012). A 63 year average was calculated for each location to determine precipitation for a "normal" growing season utilizing data from 1950 to 2013. Monthly precipitation measured during the wheat growing seasons was below normal at the PBU location and above the normal at the TVS and WGS locations during the 2013 growing season (Table 4.04). During the 2014 growing season, monthly precipitation averaged above the normal at the PBU and WGS location, but below the normal at the TVS location (Table 4.04). Insufficient data could be the result of monthly precipitation averaging below the normal at the WGS location because growing conditions were excessively wet during the 2014 growing season compared to the 2013 growing season. Maximum precipitation well above the normal was exhibited during January and February during 2013 across the three locations. April exhibited the highest amount of rainfall during the 2014 growing season at the PBU and WGS locations while June averaged the highest above the normal at TVS (Table 4.04).

Statistical Analysis

Wheat tissue and grain data was analyzed by growing season using the GLIMMIX procedure in Statistical Analysis System (SAS) software (SAS Inst., Cary, NC). Among classification variables, replication was considered random and location, planting date, treatments, and interactions were fixed. Analysis variables measured at Feekes 4 and Feekes 6 stage of growth included wheat tillering density, wheat tissue biomass and N concentration, and wheat grain yields and N concentration. Treatment means were compared when the F-test was significant ($P \leq 0.05$) by determining least significant differences (LSD) at 5% probability ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Soil samples

Differences for NH_4-N were only observed at the WGS location at 0-15 cm where July levels were significantly different than May and fallow levels (Table 4.05). Highest levels of NO_3^--N were observed at PBU. The PBU location had elevated NO_3-N at 0-15 and 15-30 cm with similar levels observed for May, June, and fallow plots compared to July plots for the 2013 growing season (Table 4.05). Nitrate levels for fallow plots at TVS were also significantly higher when compared to July plots at 15-30 cm while levels at the WGS locations were not significantly different across planting dates. Maximum NO_3-N levels were measured at PBU with levels up to 18.16 mg kg^{-1}.

Soil samples were collected to a depth of 60 + cm prior to wheat planting for the 2013-2014 growing season to account for possible leaching of soil NO_3-N. Soil NH_4-N levels were not significantly different across planting date treatments or depths at the three locations (Table 4.06). Soil NO_3-N levels were the highest at the TVS location for May and fallow plots ranging from 11.51-17.73 mg kg^{-1} at 0-15 cm (Table 4.06). Nitrate levels at subsequent depths were not as high across the three locations. Levels for May and June plots consistently averaged higher in comparison with July and fallow plots in the majority of circumstances, but did not reach the levels observed at TVS (Table 4.06). Although NO_3- N was elevated within fallow plots at PBU during the 2013 growing season and at TVS during the 2014 growing season, levels were not substantial enough to fulfill fertilizer requirements that would sustain a wheat crop in Alabama.

Wheat tissue development

Wheat tiller density and dry matter production measured at Feekes 4 growth stage was impacted by location and planting date effects for the 2013 and 2014 growing seasons with the exception of dry matter production during 2013 which was only impacted by location (Table 4.07). Tiller densities compared across the three locations during the 2013 growing season were all significantly different with maximum density averaging 1277.9 tillers m^2 at WGS (Table 4.08). Tiller density was reduced during the 2014 growing season with comparable values at PBU and WGS (Table 4.08). Tiller densities at the TVS locations were consistently lower across the 2013 and 2014 growing seasons which could be attributed to cooler temperatures in conjunction with later planting dates (Table 4.08). Comparisons made among planting date treatments revealed similar tiller densities during the 2013 growing season with the exception of June which was significantly lower than the other three planting dates (Table 4.08). During the 2014 growing season, similar densities were observed for June and July with densities up to 429.4 tillers m^2 (Table 4.08). May and fallow tiller densities during 2014 were the lowest averaging 347.7 tillers m^2 (Table 4.08). Weisz et al., (2001) identified tiller density measuring at 550 tillers m^{-2} to be the critical threshold, and densities measuring lower would require additional N fertilization at growth stage (GS) 25 (tillering) in order to optimize wheat yields.

Dry matter production corresponded to tiller density across locations during 2013 with maximum accumulation averaging 1.7 Mg ha^{-1} at WGS while production during 2014 at PBU and WGS were significantly different than production at TVS (Table 4.08). When measured across planting date treatments during the 2014 growing season, wheat dry matter production following fallow plots averaged the highest at 0.6 Mg ha^{-1}, but only differed significantly from July as May and June had comparable production (Table 4.08). Low tiller densities and dry matter production that occurred during the 2014 growing season could be explained by the delay of wheat planting due to unfavorable field conditions. Studies conducted on wheat production in Alabama, determined that yields decreased as a result of delayed planting because of reduced tiller production (Ortiz et al., 2012; Shah et al., 1994). The formation of fall tillers is important to wheat grain yields because fall tillers have been found to typically have stronger root systems and contribute 60 to 80 percent of the number of harvestable heads (Ortiz et al., 2012; Weisz et al., 2001). Tiller production can also vary across a field as a result of weather conditions, changing soil characteristics, drainage issues, and problems planting (Flowers et al., 2001).

Nitrogen concentration measured during early wheat production was significantly affected by location, planting date, N treatment, and a location x treatment interaction during the 2013 growing season and by location, planting date, a location x planting date interaction, and a treatment x location interaction (Table 4.07). Wheat tissue N concentrations were similar at PBU and TVS averaging 33.9 g N kg^{-1} while concentrations at WGS only averaged 31.7 g N kg^{-1} during the 2013 growing season (Table 4.08). Differences observed across planting date treatments during 2013 were for fallow plots which averaged significantly higher than June and July concentrations at 34.1 g N kg^{-1} (Table 4.08).

A location x planting date interaction was observed during the 2014 growing season for tissue N concentration measured at Feekes 4 stage of growth. Concentrations at the TVS location were significantly higher compared to PBU and WGS particularly for wheat tissue following fallow plots (Figure 4.01). Changes across planting date treatments were not observed at PBU, but WGS showed a decrease in N concentration for wheat tissue following fallow plots which could indicate a small contribution from sunn hemp residue at this location (Figure 4.01). Interactions across locations and N treatments were observed during the 2013 and 2014 growing season. Nitrogen concentrations at PBU were at their peak when applied with 22 kg ha^{-1} soon after planting which is a recommended rate of fall N for wheat production in Alabama (Table 4.09) (Ortiz et al., 2012). At TVS and WGS there was an increase in N concentration for fallow plots when applied with 44 or 67 kg N ha^{-1} in the fall (Table 4.09). Significant differences were not observed between N treatments in the majority of cases for sunn hemp plots (Table 4.09). Wheat in north Alabama often is slower in development due to cooler temperatures typical to the region. This could explain the positive response to higher N rates that were available to contribute to wheat growth during this time period (Ortiz et al., 2012). Overall, there was little enhancement of wheat N concentration attributed to sunn hemp contributions as similar values were observed between sunn hemp and fallow plots across the three N treatments at the three locations (Table 4.09).

Nitrogen concentrations were reduced at the PBU and WGS locations during the 2014 growing season with comparable values seen for fallow and sunn hemp plots across the four N treatments (Table 4.09). Notable differences were observed at the TVS location between sunn hemp and fallow plots with maximum N concentration seen for wheat tissue following fallow plots across the four N treatments (Table 4.09). In the majority of cases, significant differences were not observed for N treatments compared across the three locations nor among N treatments (Table 2.09). There was little contribution to wheat N concentration at Feekes 4 from sunn hemp as in several instances, fallow concentrations were numerically higher than sunn hemp concentrations. Heavy precipitation that occurred on these Coastal Plain soils could have resulted in leaching of soil NO_3-N leaving little N to contribute to wheat development.

Nitrogen treatments had a greater effect on wheat dry matter production at Feekes 6 stage of development during the 2013 and 2014 growing season following the spring application of N. Location, planting date, N treatment, and various interactions significantly contributed to wheat dry matter production at this stage of growth (Table 4.10). Wheat dry matter production during 2013 corresponded to tiller density and dry matter production at Feekes 4 with TVS averaging the lowest compared to PBU and WGS and fallow plots averaging significantly higher compared to June and July plots (Table 4.10). Dry matter production measured across the four N treatments responded best to fertilization of 22 kg N ha^{-1} or higher during the 2013 and 2014 growing season in comparison with a treatment of zero fall N (Table 4.11). A location by planting date interaction was observed during the 2014 growing season with peak dry matter production observed at the TVS location for fallow plots (Figure 4.02). Production at

WGS responded positively for July and fallow plots in comparison with May and June plots. Residual NO_3-N that was elevated at the TVS location within the first 15 cm of soil could have contributed to higher dry matter production, but sunn hemp N did not appear to contribute to wheat development as fallow plots typically compared to or exceeded sunn hemp plot production (Table 4.06).

Nitrogen concentrations were affected by planting date and a location by treatment interaction during the 2013 growing seasons with fallow plots averaging over concentrations for June and July (Table 4.10 and Table 4.11). Nitrogen fertilization treatments were significant to wheat N concentration at Feekes 6 stage of growth across both growing seasons (p= <.0001) (Table 4.10). A location by treatment interaction during the 2014 growing season showed that wheat N concentration responded best to a split application of 22 kg N ha^{-1} in the fall and 78 kg N ha^{-1} at Feekes 6 across the three locations (Table 4.12). These results agree with similar findings conducted on wheat production in Alabama as stated previously (Ortiz et al., 2012). Sunn hemp residue did not contribute in enhancing wheat tissue N concentrations during this stage as is evident by the similar concentrations between sunn hemp and fallow plots (Table 4.12). Similar results were observed during the 2014 growing season where treatment significantly affected wheat N concentrations with treatment 2 being the optimum rate that averaged the highest N concentration (Table 4.11). Concentrations during the 2014 growing season affected by a location by planting date interaction showed variable results with TVS and WGS displaying peak wheat N concentrations following fallow plots compared to PBU (Figure 4.03). Concentrations at TVS and WGS similarly averaged higher following May plots while WGS averaged the highest for the June planting date (Figure

4.03). The N concentrations at PBU were comparable across planting date treatments with only a slight decrease following fallow plots indicating that there was little benefit contributing to wheat production (Figure 4.03).

Wheat grain yields

Wheat yield was significantly affected by planting date, location × planting date interaction, treatment, and a planting date × treatment interaction during 2013 and by location and a location × treatment interaction during 2014 (Table 4.13). Wheat grain yields for the 2013 growing season were comparable at PBU and WGS across sunn hemp planting date treatments, but showed significant differences at TVS where grain yields following fallow plots were 30% higher than sunn hemp plots averaging 6.1 Mg ha^{-1} ($p = 0.0056$) (Table 4.13) (Figure 4.04). Planting date by treatment interactions revealed that wheat following a fallow area responded best when fertilized with 22 kg N ha^{-1} in the fall and 78 kg N ha^{-1} or with 44 kg N ha^{-1} in the fall and 56 kg N ha^{-1} in the spring which corresponds to wheat response at Feekes 6 stage of growth; however, there was no differences seen across planting date treatments across the four N treatments indicating that sunn hemp N contributions were minimal and did not enhance wheat yields over fallow plots (Figure 4.05). In the majority of cases, fallow yields were comparable to May yields across N treatments and often were numerically superior (Figure 4.05). Differences in wheat grain yields for the 2014 growing season were not significantly affected by sunn hemp planting date treatments, but location was significant with TVS and WGS averaging 32% higher than PBU grain yields at 4.4 Mg ha^{-1} (Table 4.13 and Table 4.14). The location by treatment interactions was significant for grain yield ($p = .0388$) during 2014 showing variable results across locations (Table 4.15). Wheat yielded the lowest at PBU across the four N treatments compared to TVS and WGS (Table 4.15). Yields compared between fallow and sunn hemp plots were not significantly different, although, fallow plots had a slight advantage numerically (Table 4.15). Yields were higher at the TVS and WGS location but differences between sunn hemp and fallow plots across the four N treatments were not observed indicating that wheat yields were not benefiting from the presence of sunn hemp residue (Table 4.15). These results contradict previous findings that observed superior corn grain yields following a sunn hemp cover crop compared with a fallow area (Balkcom and Reeves, 2005). Research done on crop fertilization via legume N indicated that there are several contributing factors that make synchronization between N supply of legume residue and N demand of the subsequent crop a difficult task to achieve (Cherr, et al., 2006). The mobility of N in the soil makes it easily transformed which increases the potential for loss of legume N accumulated in barren soils (Crews and Peoples, 2005). Potential loss of accumulated sunn hemp N in the soil could have attributed to the lack of impact that sunn hemp had on wheat fertilization requirements.

Grain N concentration

A location by planting effect was observed for grain N concentration during the 2013 growing season, but was affected only by location during 2014 (Table 4.13). Planting date effects were minimal with grain N concentrations showing comparable values across the three locations (Figure 4.06). There were a few cases where grain N concentrations following sunn hemp had a slight advantage over fallow plots, but contributions were minimal and inconsistent (Figure 4.06). Grain N concentration did not appear to correspond with wheat yields during the 2014 growing season. Nitrogen concentrations measured across locations revealed higher grain N concentrations at PBU despite low yields (Table 4.14). Although N treatments impacted grain yield, grain N concentrations was not influenced by the different N rates for the growing season of 2013 and 2014. Grain N content did correspond to both N fertilization treatments and yields during the 2013 and 2014 growing seasons similar to findings by Balkcom and Reeves, (2005) that saw a positive correlation between corn grain yields and increasing N rates.

CONCLUSION

Comparisons made between wheat following sunn hemp and wheat following a fallow area revealed that there was little to no N contributed to wheat by the sunn hemp in order to fund N fertilizer reduction. Differences among planting date treatments were not observed for the first growing season except for at TVS where fallow plots yielded 30% higher. During the second growing season, heavy precipitation was the cause of poor performance at the PBU which yielded 26% less than the other two locations. Differences among sunn hemp plots were non-existent with fallow plots often exhibiting greater performance which indicates that there was little to no N received from sunn hemp to impact fertilizer requirements for winter wheat.

Wheat yields responded best to a split application of 22 kg N ha^{-1} in the fall and 78 kg N ha^{-1} in the spring for fallow plots with equivalent rate for sunn hemp plots without a fall application. There was minimal contribution to grain N concentration across the two growing seasons. Grain N concentration during the 2013 growing season fluctuated across planting dates at the three locations with fallow plots and sunn hemp plots having comparable concentrations.

Overall, wheat yields were superior for the first growing season in comparison with the first. Sunn hemp N is not attributed with contributing to wheat performance as higher yields were often observed within fallow plots with little to no difference being observed among sunn hemp plots. The formation of a synchronous relationship between N release of a cover crop and N uptake of the subsequent crop is an important factor that determines how much N can be utilized by a legume source. The lack of N contributions from sunn hemp residue to wheat indicates asynchronization resulted in N loss before wheat planting could takes place. Synchronization between N release of sunn hemp and N uptake of a winter cereal warrants further study in order reduce fertilizer requirements for winter wheat.

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Table 4.01. Urea ammonium nitrate (UAN) fertilization of winter wheat applied at four different rates in fall and spring combinations at three locations in Alabama for the growing seasons of 2013 and 2014.

	Fallow			Sunn Hemp		
Trt #	Total N	Fall	Spring	Total N	Fall	Spring
	------------------------------kg ha $^{-1}$------------------------------					
1	0	0	0	0	0	0
2	100	22	78	78	0	78
3	100	44	56	56	0	56
4	100	67	34	34	0	34

Table 4.02. Soil pH, and soil recommendations (N, P_2O_5, K_2O) for soil samples taken to a depth of 15 cm per replication at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2013 and 2014 growing seasons.

		2013				2014			
Location		pH	N	P_2O_5	K_2O	pH	N	P_2O_5	K_2O
	Rep		--------kg ha^{-1}--------				--------kg ha^{-1}--------		
PBU	1	6.3	90	0	0	5.8	90	0	0
	2	6.4	90	0	0	6.0	90	0	0
	3	6.5	90	0	0	5.9	90	0	0
	4	6.1	90	0	0	6.0	90	0	0
WGS	1	6.1	90	44	0	6.6	90	0	44
	2	6.1	90	44	0	6.2	90	44	0
	3	5.8	90	78	0	6.3	90	67	0
	4	5.8	90	56	0	6.3	90	44	0
TVS	1	6.5	90	0	0	6.0	90	44	0
	2	6.2	90	44	0	6.1	90	0	0
	3	6.7	90	0	0	6.2	90	0	0
	4	6.5	90	0	0	5.9	90	0	0

Table 4.03. Wheat field calendars at the Plant Breeding Unit (PBU) in Tallassee, AL; the Tennessee Valley Research and Extension (TVS) Center in Belle Mina, AL; and the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2013 and 2014 growing seasons.

	2012-2013			2013-2014		
Wheat Data	PBU	TVS	WGS	PBU	TVS	WGS
Planting date	9-Nov	16-Nov	7-Nov	20-Nov	21-Nov	22-Nov
Fertilization date						
Fall	28-Nov	19-Dec	30-Nov	12-Dec	18-Dec	11-Dec
Spring	21-Feb	27-Mar	20-Feb	23-Mar	10-Apr	20-Mar
Harvest date	29-May	25-June	23-May	10-June	18-June	3-June

Table 4.04. Monthly precipitation measured at the Plant Breeding Unit (PBU), Tallassee, AL, at the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL, and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2013 and 2014 growing seasons.

Location	Month	2013	2014	Normal†
		-------------------------mm‡	-------------------------	
PBU	Nov.§	18.7	32.8	78.9
	Dec.	176.4	169.5	137.9
	Jan.	87.7	66.4	123.1
	Feb.	320.0	122.6	135.5
	Mar.	71.3	149.5	164.5
	Apr.	97.4	225.4	121.0
	May	51.8	114.4	101.6
	June¶	—	60.0	30.6
	Total	823.3	940.6	893.1
TVS	Nov.	3.1	50.8	61.9
	Dec.	143.1	136.9	142.5
	Jan.	207.9	67.2	135.5
	Feb.	72.1	138.5	120.1
	Mar.	128.5	62.1	149.7
	Apr.	137.7	148.5	121.6
	May	166.7	61.8	116.8
	June	83.1	106.9	79.0
	Total	942.2	772.7	927.1
WGS	Nov.	25.9	46.4	74.1
	Dec.	105.6	214.1	121.7
	Jan.	35.1	—#	129.8
	Feb.	430.5	—#	130.4
	Mar.	95.1	123.3#	136.3
	Apr.	121.3	327.7	103.7
	May	29.0	102.1	96.5
	June	—	8.5	9.9
	Total	842.5	822.1	802.4

† 1950-2013 means. The normal for the months of November was calculated based on the earliest planting date and the normal for May and June were calculated based on the latest harvest date between the 2012 and 2013 growing seasons.

‡ Alabama Mesonet Weather Data.

§ November corresponds to the 7 November, 2012 and the 20 November, 2013.

¶ June corresponds to the 25 June, 2013 and the 18 June, 2014.

Data for January, February, and prior to 3 March, 2014 not available at this location.

Table 4.05. Measurements of NH_4-N and NO_3-N taken before wheat planting for three sunn hemp planting dates and a fallow area at two depths. Located at the Plant Breeding Unit (PBU) in Tallassee, AL, the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL, and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for the 2012-2013 growing season.

	PBU				TVS				WGS			
	0-15cm		15-30cm		0-15cm		15-30cm		0-15cm		15-30cm	
PD†	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
	mg kg^{-1}											
May	3.5	12.3	2.6	18.2	5.7	10.6	3.6	6.8	2.1	2.4	2.4	3.0
June	3.6	9.9	3.9	17.4	5.5	5.6	3.9	7.1	2.5	2.4	2.7	3.9
July	3.7	7.0	3.1	5.0	5.3	6.9	4.8	3.5	3.1	3.6	3.1	4.0
Fallow	2.1	15.0	4.3	13.2	4.9	6.6	3.9	11.6	2.2	2.2	2.5	3.0
$LSD_{0.05}$	2.0	6.3	4.9	12.1	4.4	7.2	2.5	5.4	0.6	1.4	1.4	1.3

† Planting date.

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Table 4.06. Measurement of soil NO_3-N and NH_4-N taken prior to wheat planting for three different planting dates and a fallow area at five depths. Located at the Plant Breeding Unit (PBU) in Tallassee, AL, the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL, and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for the growing season of 2013-2014.

		0-15cm		15-30cm		30-45cm		45-60cm		60+cm	
Location	PD[†]	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
PBU		-----	-----	-----	-----	mg kg^{-1}	-----	-----	-----	-----	-----
	May	5.6	4.7	1.5	3.5	0.9	4.3	1.0	5.7	1.0	3.8
	June	4.4	4.9	1.3	4.1	1.0	4.4	1.0	5.4	1.0	6.2
	July	4.8	6.4	1.4	3.5	1.0	2.6	1.0	4.1	1.1	4.6
	Fallow	5.0	2.9	1.5	2.0	1.0	2.3	1.2	3.2	1.1	4.8
	$LSD_{0.05}$	3.3	3.0	0.3	1.4	0.3	1.4	0.5	2.9	0.4	1.8
TVS											
	May	3.7	11.5	1.9	6.3	1.5	6.5	1.4	5.7	1.4	4.5
	June	4.1	7.7	1.9	6.7	1.4	4.4	1.3	3.0	1.2	5.0
	July	3.4	6.6	1.8	3.2	1.7	2.5	1.3	2.3	1.2	4.7
	Fallow	3.2	17.7	1.9	5.2	1.4	4.7	1.3	4.4	1.3	5.1
	$LSD_{0.05}$	0.8	7.5	0.4	1.6	0.4	1.6	0.4	1.6	0.3	3.0
WGS											
	May	3.6	7.2	2.1	5.9	1.9	8.0	1.8	6.5	1.8	7.5
	June	4.0	8.2	2.2	7.3	2.0	10.0	1.7	7.5	1.6	7.3
	July	4.1	9.4	2.2	7.3	1.9	7.9	1.9	4.6	1.8	5.1
	Fallow	3.5	6.7	2.1	5.5	1.9	6.3	1.8	5.7	1.6	5.9
	$LSD_{0.05}$	1.5	1.9	0.5	1.8	0.5	2.8	0.4	2.0	0.5	2.5

[†] Planting date.

Table 4.07. Analysis of variance for wheat tissues samples taken at Feekes 4 measured for tiller density, dry matter production, and N concentration across three sunn hemp planting dates (PD) at three locations (LOC) in Alabama that were fertilized with four urea ammonium nitrate (UAN) treatments (TRT) during the 2013 and 2014 growing season.

Year	Effect		Tiller density		Dry matter		N concentration	
		df	F value	P value	F value	P value	F value	P value
2013								
	LOC	2	111.67	< 0.0001	206.81	< 0.0001	11.49	< 0.0001
	PD	3	3.37	0.0205	2.67	0.0498	3.69	0.0134
	LOC x PD	6	0.80	0.5740	1.15	0.3353	1.78	0.1063
	TRT	3	0.35	0.7879	0.21	0.8867	3.10	0.0287
	LOC x TRT	6	0.69	0.6614	0.99	0.4365	3.30	0.0046
	PD x TRT	9	0.82	0.6000	0.71	0.6959	0.68	0.7291
	LOC x PD x TRT	18	0.78	0.7241	0.91	0.5716	0.80	0.6953
2014								
	LOC	2	43.82	< 0.0001	62.35	< 0.0001	523.68	< 0.0001
	PD	3	5.60	0.0012	5.47	0.0014	2.76	0.0445
	LOC x PD	6	1.31	0.2548	0.98	0.4413	9.19	< 0.0001
	TRT	3	0.71	0.5500	0.05	0.9844	1.62	0.1885
	LOC x TRT	6	0.21	0.9742	0.78	0.5844	2.24	0.0423
	PD x TRT	9	0.73	0.6766	0.86	0.5598	0.56	0.8263
	LOC x PD x TRT	18	0.66	0.8468	0.95	0.5259	0.72	0.7876

Table 4.08. Wheat tiller density, dry matter production, and N concentration measured at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for three sunn hemp planting dates during the 2013 and 2014 growing seasons.

	Tiller density		Dry matter		N concentration
Treatment	2013	2014	2013	2014	2013
	-----Tillers m^{2}†----		-----Mg ha^{-1}-----		-----g kg^{-1}-----
Location					
PBU	1097.5	455.4	1.4	0.5	33.8
TVS	728.9	262.2	0.4	0.3	33.9
WGS	1277.9	419.9	1.7	0.6	31.7
$LSD_{0.05}$	76.3	44.5	0.1	0.1	1.2
Planting Date					
May	1036.4	366.7	1.1	0.5	33.4
June	976.3	429.4	1.1	0.5	32.5
July	1016.2	392.0	1.2	0.4	32.5
Fallow	1110.1	328.6	1.3	0.6	34.1
$LSD_{0.05}$	126.7	59.9	0.3‡	0.1	1.4

† Row width was 7.5 inches at PBU and TVS and 8 inches at WGS.

‡ Indicates effect was not significant.

Table 4.09. Nitrogen concentration for wheat tissue measured at the Feekes 4 stage of growth measured across four N treatments at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 (A) and 2014 (B) growing seasons. Treatments were arranged in fall and spring application combinations with the fall application differing between sunn hemp and fallow plots.

			Wheat N Concentration			
Year	CC† Trt	N Trt	PBU	TVS	WGS	$LSD_{0.05}$§
			---------------g kg^{-1}---------------			
2013	Sunn hemp	0/0‡	33.0	32.4	32.8	2.4
		0/78	34.1	33.3	29.1	2.5
		0/56	33.0	33.8	32.1	2.4
		0/34	33.3	33.4	33.4	3.0
	$LSD_{0.05}$		2.9	2.4	2.4	—
	Fallow	0/0	33.7	33.3	31.9	7.0
		22/78	36.1	33.0	29.1	5.1
		44/56	35.5	37.4	32.2	4.0
		67/34	34.7	40.5	32.6	4.6
	$LSD_{0.05}$		4.5	6.2	4.4	—
2014	Sunn hemp	0/0	24.7	40.2	29.0	2.6
		0/78	25.4	40.1	27.5	2.5
		0/56	24.6	40.5	29.6	2.6
		0/34	27.3	39.2	29.2	2.4
	$LSD_{0.05}$		2.9	2.7	1.8	—
	Fallow	0/0	24.0	46.3	27.4	6.5
		22/78	24.3	45.6	27.1	6.5
		44/56	25.9	45.7	24.1	5.3
		67/34	30.5	44.6	27.9	4.9
	$LSD_{0.05}$		6.1	6.6	4.2	—

†Cover crop.

‡Nitrogen treatments were applied in fall/spring combinations at all three locations for both growing seasons.

§Represents the least significant difference (LSD) for wheat N concentrations between the three locations for each N treatment.

Table 4.10. Analysis of variance for wheat tissue samples taken at Feekes 6 measured for dry matter production and N concentration across three sunn hemp planting dates (PD) at three locations (LOC) in Alabama that were fertilized with four urea ammonium nitrate (UAN) treatments (TRT) during the 2013 and 2014 growing season.

Year	Effect		Dry matter		N concentration	
		df	F value	P value	F value	P value
2013						
	LOC	2	65.10	< 0.0001	1.39	0.2525
	PD	3	11.81	< 0.0001	16.26	< 0.0001
	LOC x PD	6	1.74	0.1161	1.46	0.1969
	TRT	3	3.44	0.0186	22.67	< 0.0001
	LOC x TRT	6	2.05	0.0629	3.37	0.0039
	PD x TRT	9	1.89	0.0580	0.29	0.9752
	LOC x PD x TRT	18	0.63	0.8712	0.66	0.8474
2014						
	LOC	2	50.19	< 0.0001	13.24	< 0.0001
	PD	3	6.13	0.0006	0.42	0.7402
	LOC x PD	6	2.97	0.0093	4.05	0.0009
	TRT	3	21.83	< 0.0001	7.60	< 0.0001
	LOC x TRT	6	1.58	0.1567	1.89	0.0863
	PD x TRT	9	1.76	0.0818	0.50	0.8753
	LOC x PD x TRT	18	0.39	0.9879	0.65	0.8541

Table 4.11. Wheat tissue samples collected at Feekes 6 measured for dry matter production and N concentration at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL for three sunn hemp planting dates across four N treatments.

			Dry matter	N concentration
			--------2013 Wheat Growing Season--------	
			---Mg ha^{-1}---	---g kg^{-1}---
Location				
		PBU	1.5	23.0
		TVS	0.9	23.0
		WGS	1.5	22.4
		$LSD_{0.05}$	0.1	1.1†
Planting Date				
		May	1.3	23.5
		June	1.2	22.1
		July	1.2	21.3
		Fallow	1.5	24.5
		$LSD_{0.05}$	0.2	1.1
UAN rate (kg ha^{-1})				
	Sunn hemp	Fallow		
1	0/0	0/0	1.2	21.1
2	0/78	22/78	1.4	25.1
3	0/56	44/56	1.3	22.8
4	0/34	67/34	1.4	22.3
		$LSD_{0.05}$	0.2	1.1
			--------2014 Wheat Growing Season-------	
UAN rate (kg ha^{-1})				
	Sunn hemp	Fallow		
1	0/0	0/0	2.0	20.8
2	0/78	22/78	3.2	22.6
3	0/56	44/56	2.8	20.5
4	0/34	67/34	2.8	20.1
		$LSD_{0.05}$	0.4	1.2

† Indicates effect was not significant or that an interaction occurred with this effect.

Table 4.12. Nitrogen concentration for wheat tissue collected at Feekes 6 stage of growth across four treatments at Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season. Treatments were arranged in fall and spring application combinations with the fall application differing between sunn hemp and fallow plots.

		Wheat N Concentration			
CC† Trt	N Trt	PBU	TVS	WGS	$LSD_{0.05}$§
		--------------------g kg^{-1}--------------------			
Sunn hemp	0/0‡	20.4	21.4	19.8	2.0
	0/78	25.2	24.6	24.1	2.3
	0/56	22.6	23.1	21.1	2.0
	0/34	22.6	19.8	22.8	1.8
$LSD_{0.05}$		1.9	1.9	2.2	—
Fallow	0/0	20.5	24.2	23.4	3.8
	22/78	27.4	27.7	25.0	5.9
	44/56	23.5	26.5	23.6	5.2
	67/34	25.0	23.7	23.5	4.2
$LSD_{0.05}$		4.4	5.0	4.6	—

†Cover crop.

‡Nitrogen treatments were applied in fall/spring combinations at all three locations for both growing seasons.

§Represents the least significant difference (LSD) for wheat N concentrations between the three locations for each N treatment.

Table 4.13. Analysis of variance for wheat yields and grain N concentration across three sunn hemp planting dates (PD) at three locations (LOC) in Alabama that were fertilized with four N treatments (TRT) during the 2013 and 2014 growing season.

Year	Effect		Wheat grain yield		Grain N concentration	
		df	F value	P value	F value	P value
2013						
	LOC	2	0.53	0.6071	11.40	< 0.0001
	PD	3	13.10	0.0000	3.94	0.0097
	LOC x PD	6	4.13	0.0056	8.88	< 0.0001
	TRT	3	21.23	< 0.0001	1.88	0.1361
	LOC x TRT	6	1.22	0.3268	0.18	0.9811
	PD x TRT	9	2.36	0.0206	0.29	0.9759
	LOC x PD x TRT	18	0.23	0.9995	0.59	0.9001
2014						
	LOC	2	41.15	< 0.0001	310.07	< 0.0001
	PD	3	0.49	0.6916	0.61	0.6125
	LOC x PD	6	1.14	0.3418	0.89	0.5036
	TRT	3	1.50	0.2166	0.96	0.4134
	LOC x TRT	6	2.29	0.0388	0.90	0.4955
	PD x TRT	9	0.29	0.9775	0.32	0.9659
	LOC x PD x TRT	18	0.24	0.9995	0.42	0.9814

Table 4.14. Wheat grain yields and grain N concentration measured at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL across four N treatments during the 2014 growing season.

Location	Wheat grain yield	Grain N concentration
	---Mg ha^{-1}---	---g kg^{-1}---
PBU	3.2	21.0
TVS	4.3	17.3
WGS	4.4	17.2
$LSD_{0.05}$	0.3	0.4

Table 4.15. Wheat grain yields measured across four treatments at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2014 growing season. Treatments were arranged in fall and spring application combinations with the fall application differing between sunn hemp and fallow plots.

		Wheat Yields			
CC† Trt	N Trt	PBU	TVS	WGS	$LSD_{0.05}$§
		---------------Mg ha^{-1}---------------			
Sunn hemp	0/0‡	2.9	3.8	4.3	0.8
	0/78	3.0	4.8	4.3	0.6
	0/56	3.3	3.9	4.7	0.7
	0/34	3.2	4.6	4.3	0.6
$LSD_{0.05}$		0.6	0.7	0.7	—
Fallow	0/0	3.3	4.1	4.2	1.3
	22/78	3.2	4.5	3.8	1.5
	44/56	3.5	4.1	4.8	1.3
	67/34	3.5	4.8	4.4	1.7
$LSD_{0.05}$		1.6	1.3	1.3	—

†Cover crop.
‡Nitrogen treatments were applied in fall/spring combinations at all three locations for both growing seasons.
§Represents the least significant difference (LSD) for wheat N concentrations between the three locations for each N treatment.

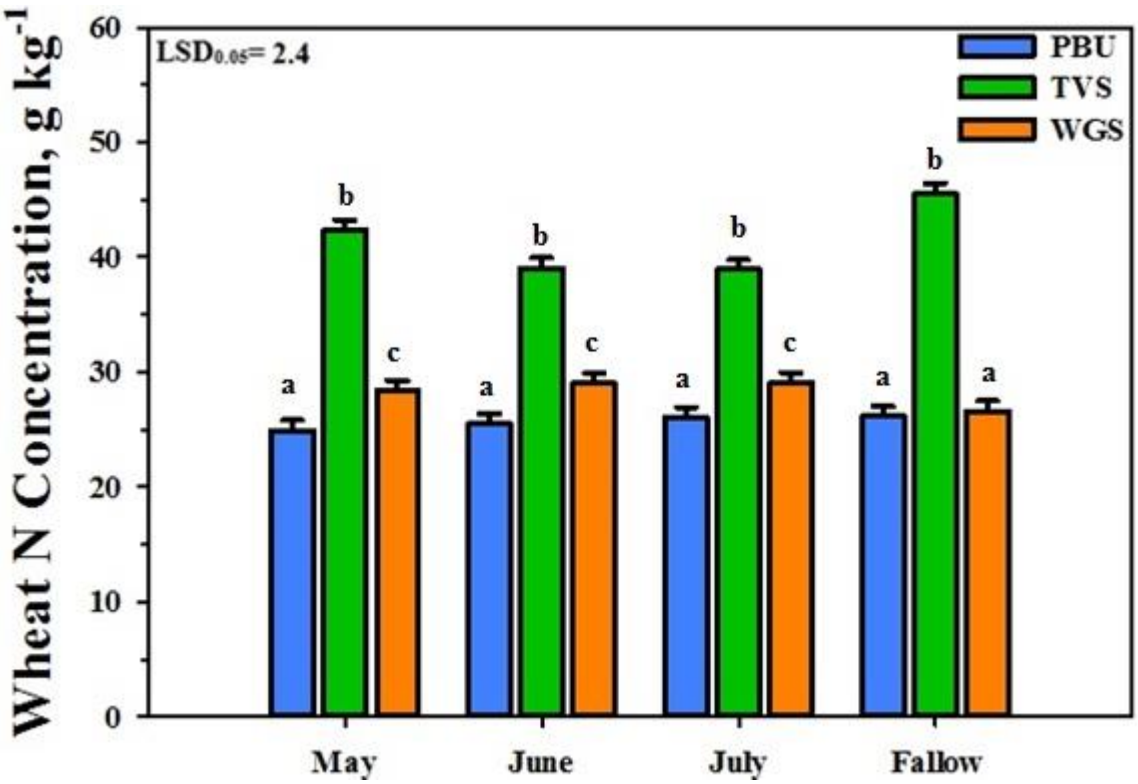

Figure 4.01. Nitrogen concentration for wheat tissue collected at Feekes 4 stage of growth across three sunn hemp planting dates and a fallow area at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2014 growing season.

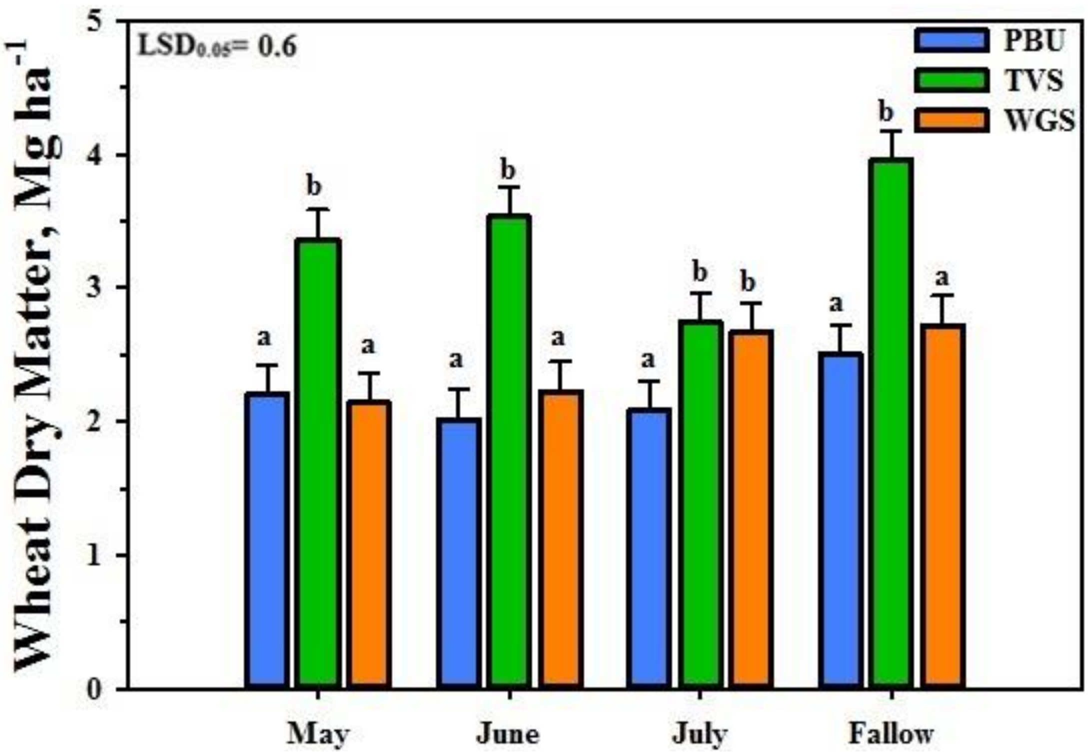

Figure 4.02. Wheat dry matter measured at Feekes 6 stage of growth across three sunn hemp planting dates and a fallow area at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2014 growing season.

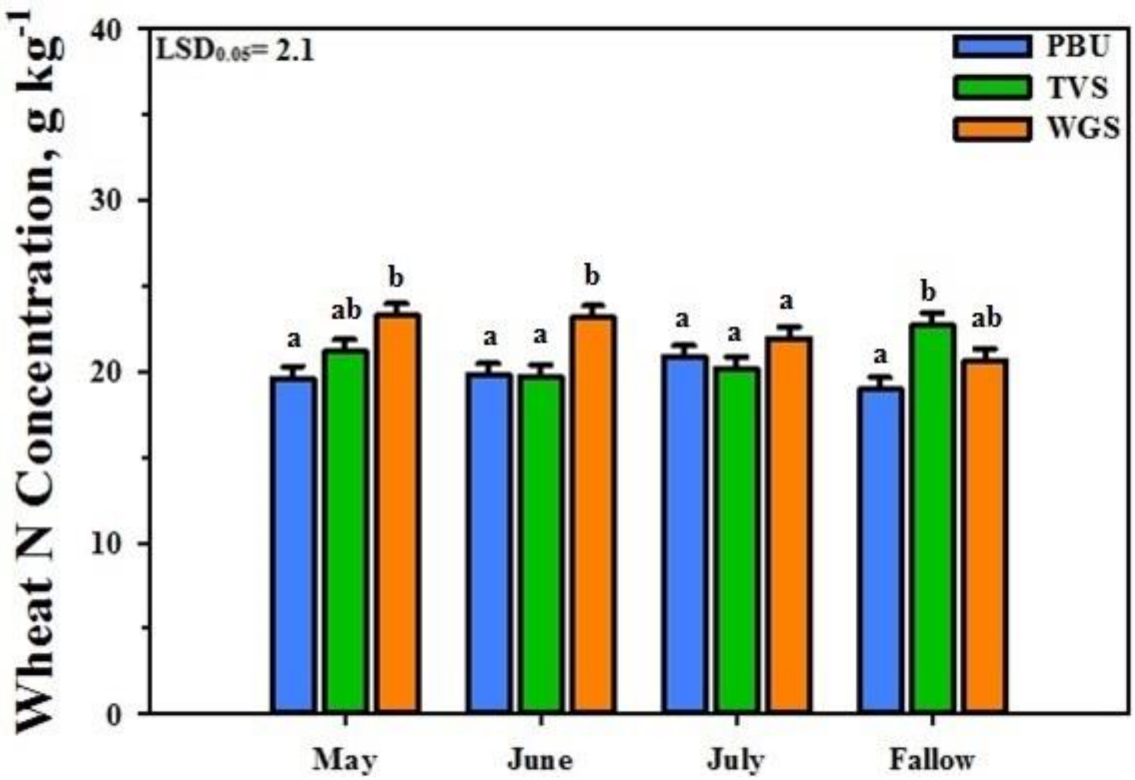

Figure 4.03. Nitrogen concentration of wheat tissue collected at Feekes 6 stage of growth measured across three sunn hemp planting dates and a fallow area at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2014 growing season.

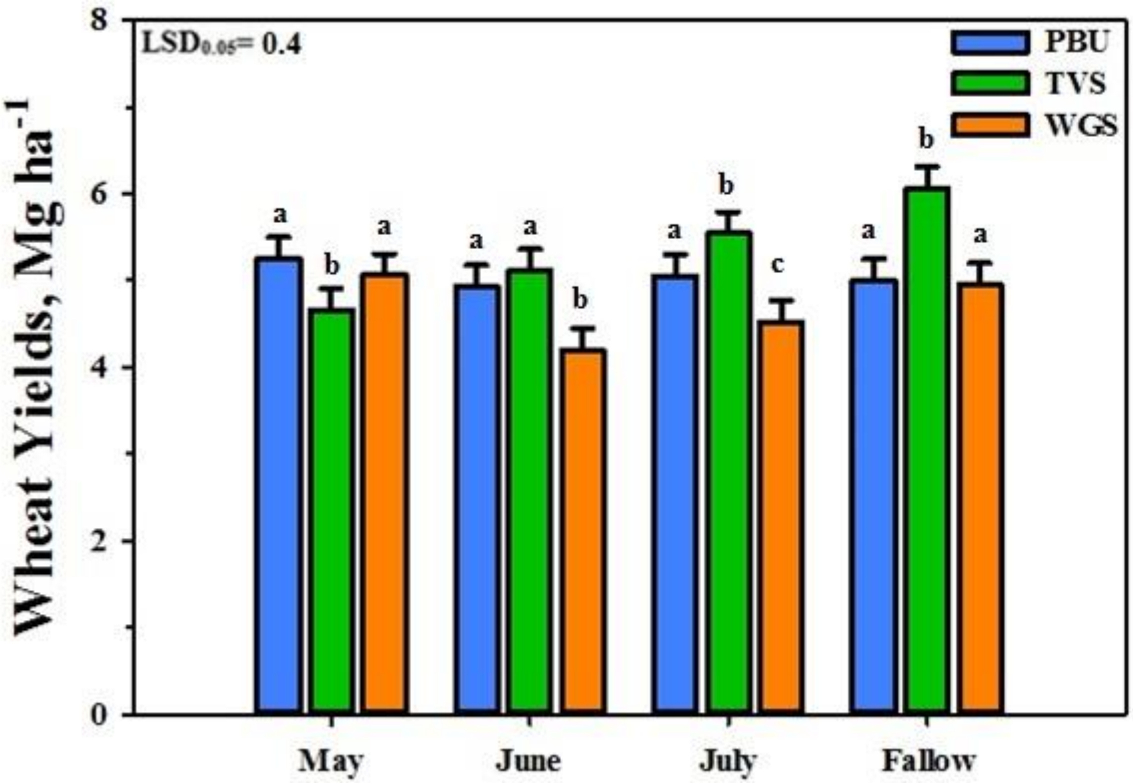

Figure 4.04. Wheat grain yields measured across three sunn hemp planting dates and a fallow area at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season.

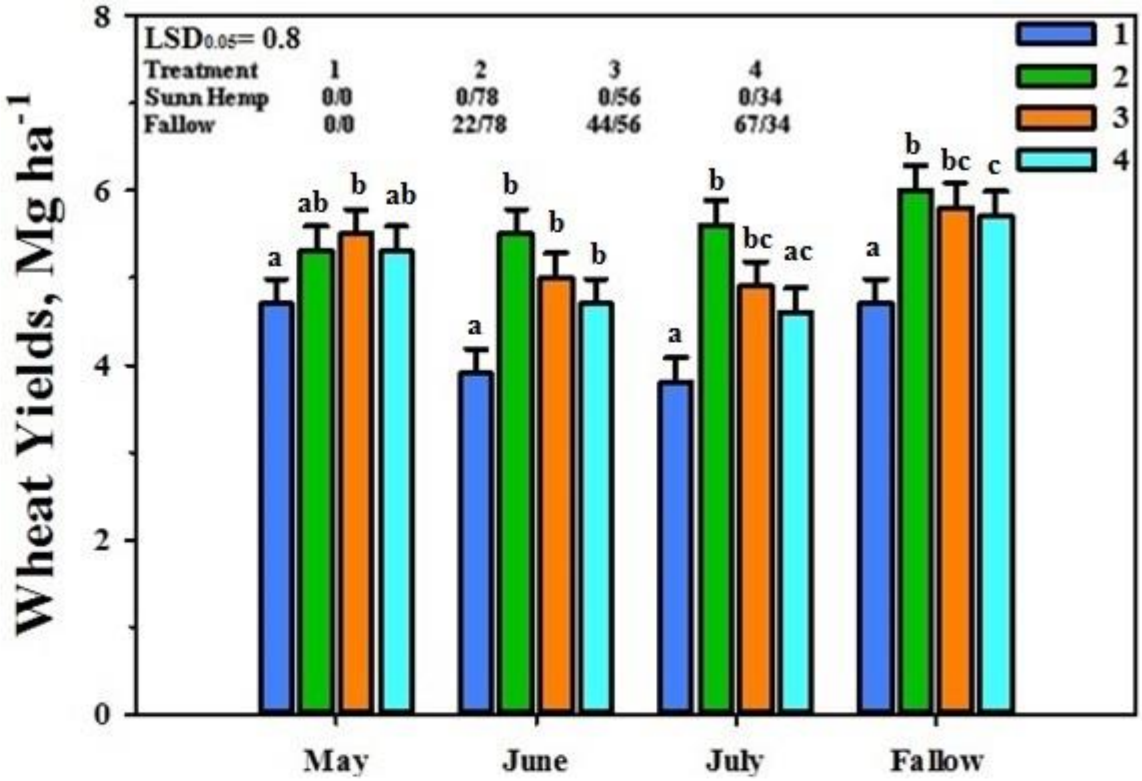

Figure 4.05. Wheat grain yields measured across three sunn hemp planting dates and a fallow area across four N treatments during the 2013 growing season. Treatments were arranged in fall and spring application combinations with the fall application differing between sunn hemp and fallow plots.

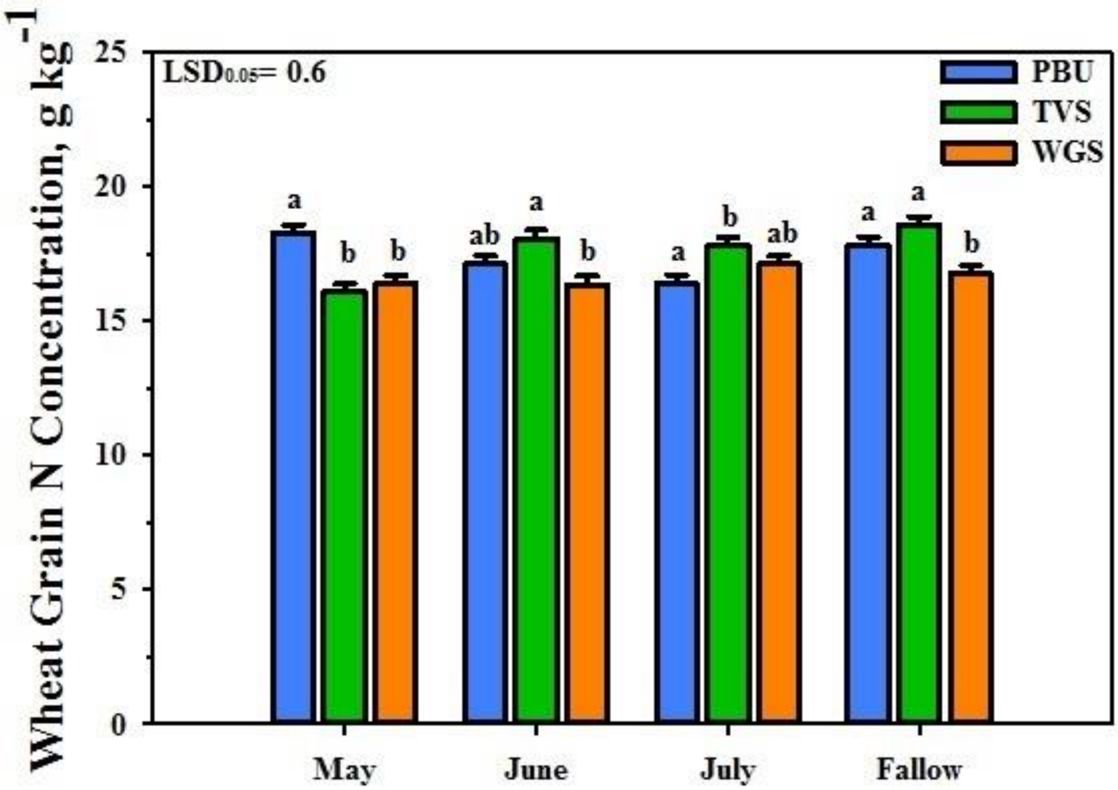

Figure 4.06. Wheat grain N concentration measured across three sunn hemp planting dates and a fallow are at the Plant Breeding Unit (PBU) in Tallassee, AL; at the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL; and at the Wiregrass Research and Extension Center (WGS) in Headland, AL during the 2013 growing season.

V. SUMMARY AND CONCLUSION

Optimum sunn hemp production occurred for June and July planting dates across the three locations during the 2012 growing season, but the response was not consistent across growing seasons due to climatic fluctuations that occurred during the 2013 growing season. 'AU Golden' performance was maximized under favorable weather conditions during the first growing season, but proved to be sensitive to the climatic fluctuations and heavy rainfall that occurred during the second growing season. Heavy precipitation resulted in flooding that limited overall biomass production across the three planting dates during the second growing season, particularly at the PBU location. Although sunn hemp can perform well in a variety of depleted soil types, it cannot tolerate waterlogged soils (Chaudhury et al., 1978). According to previous studies, periods of frost free warm weather with adequate moisture are ideal (Monsoer et al., 1997).

Sunn hemp N concentration was inversely related to biomass population while N content corresponded to biomass production. Sunn hemp N concentration decreased with sunn hemp maturity while N content increased with biomass accumulation. These results are consistent with previous studies evaluating 'AU Golden' sunn hemp as a cover crop for a winter cereal (Balkcom et al., 2011). Nitrogen production was also negatively impacted by excessive precipitation during the 2013 growing season with decreased N concentration and N content. Despite performance reductions due to unfavorable growing conditions, ‘AU Golden’ still provided adequate biomass and N to be considered a suitable cover crop in the Southeast.

Sunn hemp grown for the full term of 60 d was not considered an appropriate quality forage for ruminant livestock due to the high NDF and ADF values of sunn hemp stems. Sunn hemp stems at early maturity are indigestible for livestock and become less palatable as maturation is reached. Sunn hemp leaf fractions demonstrated quality attributes particularly during the first 30 d of sunn hemp production with a high percentage of CP which is a valued supplement in livestock diets (Chaudhury et al. 1978). Observations made across sunn hemp planting dates concluded that forage quality begins to decrease with the later planting dates as well as with maturity in leaf and stem fractions. Sunn hemp utilized as a feed source should be planted early and harvested or grazed early during maturation in order to maintain a high quality forage.

Sunn hemp residue decomposition occurred rapidly after termination particularly at the southern location. Decomposition was more complete and accelerated at the WGS location in regards to N release and dry matter decay where as much as 65% of dry matter and 87% of N was lost within in the first 2 wks after termination. Exponential decay models revealed an accelerated decomposition of leaf and flower fractions in comparison with recalcitrant fractions. The majority of sunn hemp N was lost as a result of the quick decay of sunn hemp leaves and flower heads shortly after termination leaving only sunn hemp stems which contain little N and decompose slowly. Similar results were reported by Mansoer et al., (1997) who found that the majority of the N is concentrated in sunn hemp leaves which decomposed within a few weeks after termination. The sunn hemp residue that remained on the soil surface at wheat planting was sufficient in providing adequate soil protection, but had little to no N to contribute to a subsequent crop.

'AU Golden' sunn hemp did not prove to be proficient in reducing fertilizer requirements for a subsequent wheat crop for the growing seasons of 2012-2013 and 2013-2014. Differences observed among wheat yields were either greater for fallow plots in comparison with sunn hemp plots or not significantly different at all. Wheat yield response to N fertilizer was successful when applied at a rate that is recommended for wheat production in Alabama; however, no N was received from sunn hemp residue to contribute to wheat production (Ortiz et al., 2013). As a result of the rapid decomposition of sunn hemp residue between sunn hemp termination and wheat planting, there was little to no N available for wheat uptake. Excessive amounts of N not sequestered by a crop could lead to environmental detriments of different forms. Leaching or runoff of excess N could lead to contamination of ground water as well as surface water causing high NO_3- levels in drinking water as well as eutrophication in rivers, lakes, and ponds (Carpenter et al., 1998). Nitrogen released in the form of N_2 through denitrification has also been attributed with global warming along with several other greenhouse gases (Vitousek et al., 1997). In order to form a more synchronous relationship between residue N release and wheat uptake, sunn hemp should be terminated in closer proximity with wheat planting to avoid N loss. Later plantings of sunn hemp have proven to still provide adequate biomass and N despite its short day photoperiodism (Balkcom and Reeves, 2005). Further examination of sunn hemp management and N synchronization is warranted in order for sunn hemp to be beneficial as an N source in the Southeast.