‘GEORGIA BUSH’ VELVETBEAN (*Mucuna pruriens*) AND SUNN HEMP (*Crotalaria juncea*): BIOMASS ACCUMULATION AND NUTRIENT CONTENT

by

NICOLE LUCILLE MARTINI

(Under the Direction of Sharad C. Phatak)

ABSTRACT

Velvetbean (*Mucuna spp.*) and sunn hemp (*Crotalaria juncea*) have been used for many years in agricultural systems worldwide. Little information exists on these crops as sources of biomass and nutrients in vegetable production in the U.S. My objective was to determine the best planting and cutting dates for these cover crops. Tifton velvetbean biomass was greatest for the April planting harvested 120 DAP. Watkinsville velvetbean biomass was greatest for the May planting harvested 90 DAP. Tifton sunn hemp biomass was greatest for the July planting harvested 120 DAP; the Watkinsville May planting harvested 120 DAP was greatest. Nitrogen and other nutrients accumulated were substantial in both cover crops at 90-120 DAP in both locations. Biomass production was positively correlated with temperature and rainfall. This study shows sunn hemp and velvetbean can be useful cover crops for growing in rotation with vegetable crops in the Tifton and Watkinsville, GA areas.

INDEX WORDS: *Mucuna, Crotalaria, Cover Crops, Green Manures, Nutrient Analysis, Biomass Accumulation, Cumulative Heat Units*
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SECTION 1
INTRODUCTION

Velvetbean and Sunn Hemp in Vegetable Production

For centuries, people have been growing cover crops as part of an agricultural system to improve the fertility and structural composition of their soil. Today, cover crops are still grown as part of a total agricultural system that promotes sustainability. Some of the long-term benefits obtained from the use of cover crops include weed suppression through competition or allelopathy, shorter fallow periods, possible insect control through rotation, and less monetary input through the decreased use of herbicides, pesticides, and water (Jordan, 1998; Phatak et al., 2002).

Sustainable crop production is achieved through the management of soil fertility and cover crops play a key role in soil fertility through a reduction in synthetic nutrients applied, particularly nitrogen. This reduces the cost of crop production and contamination of the environment (Phatak, 1992). Commonly used as cover crops, legumes are effective in the fixation of nitrogen and can accumulate large amounts of biomass that help to increase the nutrient availability and organic matter in a soil (Phatak, 1992). Organic matter in a soil is important because it improves the composition and texture of the soil. Phatak et al. (2002) note a system that utilizes cover crops, as one part of a whole system that utilizes sustainability will become more sustainable over time (Phatak et al., 2002). Many crops have been used for cover crops, but the choice ultimately depends on climate, cropping systems practiced, and the availability of seed (Pieters, 1927). Cover crops can be incorporated into a vegetable production
The question is when is the optimal time to grow certain cover crops to best fit into rotation with vegetable crops based on accumulated biomass and nutrients.

Velvetbean (*Mucuna spp.*) and sunn hemp (*Crotalaria juncea*) are two tropical legumes in the Fabaceae family that have been used for many years in agriculture and may fit well in a sustainable vegetable production system in the Southeastern Region of the U.S. Traditionally used in agricultural systems in places such as Hawaii, the Philippines, and Meso-America, velvetbean was also once used in the early 1800s in the Southeastern United States. Here it was used as a green manure in orange orchards and in rotation with cotton and corn, because it helped lower external inputs and created a more sustainable system (Buckles et al., 1998; Taylor and Kabana, 1998, 1999). Sunn hemp (*Crotalaria spp*.), also in the Fabaceae family, is one of the earliest, most distinctly named fibers of India; and one of the most widely grown green manure crops throughout the tropics (Cook et al., 1996). Grown usually in rotation with several different crop species, sunn hemp shows promise as a green manure/cover crop for the Southeast region due to its high N content, fast-growing habit and ability to prevent soil erosion (Cook et al., 1996; Mansoer et al., 1997; Marshall et al., 2001; Steinmaier, 2001). In recent years little research has been done on sunn hemp and velvetbean as cover crops in the United States. This results in a lack of information regarding when to grow and when to harvest sunn hemp and velvetbean for the most nutrients and biomass production as part of a sustainable vegetable production system in the United States.

The objective of this study was to determine the most ideal planting and harvesting (or cutting) dates for velvetbean and sunn hemp as green manure/cover crops in a sustainable vegetable production system in the Southeastern United States. The study took place at two locations in Georgia, the U.S.D.A. Phil Campbell, Senior, Natural Resource Conservation Center
on the Piedmont in Watkinsville, Ga., and the University of Georgia Coastal Plain Experiment Station in Tifton, Ga. The two areas represent distinct physiographic regions, both with soils low in organic matter. The Piedmont soils are severely eroded due to a long history of conventional crop production, while the Coastal Plain soils are derived from marine sand deposits and are inherently low in organic matter.

Cumulative Heat Units versus Biomass and Nitrogen Accumulation

Introduction

The growth pattern of plants and insects during the growing season can be estimated using growing degree days (GDDs). As plants develop they require energy from the sun to conduct photosynthesis. However, temperature is also a driving factor because chemical and biological processes generally increase with increases in temperature. Each organism also has a base or threshold temperature below which or above which development will not occur. The rate of development is temperature dependent so GDDs can be useful in predicting crop development and in more efficient management of crops (OMAF 2003).

Heat units can also be used to predict availability of nutrients from crop residues and other amendments. Griffin and Honeycutt (2000) used heat units to predict the availability of N from livestock manures. Previous studies used heat units during the growing season to accurately predict cumulative N mineralization from wastes including bio-solids and plant residues of various compositions.

Ritchie and Nesmith (1991) performed a study on temperature and crop development and suggest optimal biomass production of a crop is a product of the rate of accumulation of mass times the duration of growth. Light is the principal influence on the rate of biomass
accumulation and temperature is directly proportional to the duration of growth for a particular cultivar. This information can be used to help predict or estimate crop growth duration for finding genotypes with particular growth periods that allow farmers to optimize yields. The same concept can be used to predict or estimate amount of biomass accumulation of a cover crop during certain growing durations using cumulative heat units (Ritchie and Nesmith, 1991). In this study we used cumulative heat units and cumulative heat units plus cumulative rainfall to accumulate a model that can be used in the Southeastern Unites States to estimate biomass accumulated by velvetbean and sunn hemp.

**Literature Review of Velvetbean (Mucuna spp.)**

**Introduction**

Velvetbean (velvetbean speciosa) is a tropical legume with agricultural and medicinal uses (Hussain and Manyam, 1997; Buckles and Triomphe, 1999). Velvetbean can be used to improve soil quality and help suppress weeds, decreasing external or off-farm inputs. Velvetbean is a versatile leguminous plant that is used in tropical and subtropical areas to improve field conditions for sustainable, more affordable cultivation of vegetable and cereal crops. Velvetbean is noted for its ability to contribute nitrogen to soil through fixation (Arora et al., 2000; Houngnandan et al., 2000; Ibewiro et al., 2000a), as well as its ability to suppress nematodes (Ibewiro et al., 2000a; McSorley and Frederick, 1999; Taylor and Rodriguez-Kabana, 1999).

**Biology**

Velvetbean is classified in the Leguminosae (Duke, 1981; Capo-chichi, 2001) or Fabaceae family (Buckles et al., 1998; Siddhuraju and Becker, 2001a). Before reaching
maturity, velvetbean sheds large amounts of foliage, which break down gradually and form a layer of litter below the actively growing velvetbean (Buckles et al., 1998). Natural out-crossing of velvetbean is rare because it is a self-pollinator. Approximately twelve velvetbean species are cultivated and found in the tropics; these probably represent a fragmentation from the Asian cultigen (Buckles et al., 1998). The most cited species of velvetbean include *M. deeringiana*, *M. utilis*, *M. pruriens*, *M. cochichenensis*, *M. nivea*, *M. capitala*, *M. hassjoo*, *M. diabolica*, and *M. aterrima*. Buckles et al. (1998) say that some species names may be synonymous because there is confusion regarding the taxonomy of the species. Duke (1981) notes that confusion exists at the genus level as well.

The pubescence on the pod, the color of the seed, and the number of days-to-harvest of the pod are the main differences among species that have been cultivated. The velvetbean with abundant, long stinging hairs on the pod are known as ‘cowitch’ or ‘cowhage’ in English. Contact with the stinging hairs results in an intense itchy dermatitis. The non-stinging types of Velvetbean are velvetbean with soft, silky pubescents (Buckles, 1995). Velvetbean seeds can withstand the cold as far north as Maryland or Kansas (Duke, 1981). This could make velvetbean a useful tool in sustainable agricultural systems in the United States.

Chapo-chichi et al. (2001) in Alabama sought to determine the relatedness of some velvetbean accessions as well as research velvetbean genetic diversity. Amplified fragment length polymorphism (AFLP) was used to perform the analysis. In the exotic lines of velvetbean, the scientists found greater genetic diversity compared to the U.S. landraces, perhaps due to the greater geographical distribution of the exotics and their large range of origins.
Origins and Early Uses

Velvetbean is thought to have originated in the Far East (China, Malaysia, India, or Indonesia) (Buckles, 1992, 1995). Velvetbean was used as a green manure in the 1600s in Java, Bali and Sumatra where it was grown to recover worn-out ground (Buckles, 1995). It has been grown in Africa, Brazil, the Caribbean, Central America, and the United States for its agricultural attributes for centuries (Buckles et al., 1998).

In the late 1800s, velvetbean was introduced to the Americas (Buckles et al., 1998). Around 1875, velvetbean was introduced into southern agriculture by the U.S.D.A. (Taylor and Rodriguez-Kabana, 1998). In the U.S., it was used for animal fodder and green manure (Buckles et al., 1998). By 1897, in Florida 300 orange growers were planting velvetbean in orchards to improve soil fertility and by the early 1900s, velvetbean acreage expanded rapidly due to the introduction of the shorter-season varieties, a decline in cotton production, recognition of the soil-building attributes of the crop, and the demand for livestock feed and grazing (Buckles et al., 1998; Taylor and Rodriguez-Kabana, 1998). Also in the early 1900s, a farmer from Sumner, GA collected beans from early-maturing plants of the Florida velvetbean. After 1914, the collected seed was distributed and became known as the Georgia velvetbean (Buckles et al., 1998).

By 1915, the area planted to velvetbean reached more than 400,000 ha, and 2 million ha by 1917 (Buckles et al., 1998). Velvetbean acreage in the South peaked at around 1.5 million ha in 1922, and fell to about 607,000 ha in the 1930s. By 1940, production recovered to just over 1 million ha, 80 percent of which was a short-season variety known as the “Alabama velvetbean” (Taylor and Rodriguez-Kabana, 1998). Taylor and Rodriguez-Kabana (1998) state inter-seeding corn with velvetbean was the common practice and after harvesting the corn, the velvetbeans were either harvested or grazed by cattle and hogs. Velvetbean was used for fertilization in
rotation with corn (*Zea mays* L.), cotton, and sugarcane (*Saccharum officinarum* L.) in the southern U.S. However, velvetbean acreage declined and almost disappeared by 1965 due to harvesting difficulties, increasing availability of pesticides, promotion of soybeans, farm programs that encouraged monoculture, and the increased availability and low price of fertilizers (Taylor and Rodriguez-Kabana, 1998).

**Green Manure/Cover Crop**

One of the first reports of velvetbean in the literature is by William E. Carter who describes the use of velvetbean as a mulch in a slash and mulch system in the lowlands of Guatemala by a Maya group, the Kekchi Indians who migrated from the highlands of Guatemala (Thurston, 2004). Velvetbean has been grown for roughly 50 years throughout Mesoamerica, including Belize, Central America and Mexico (Chiapas, Oaxaca, Tabasco, and Veracruz), and in 1996, velvetbean was grown by some 25,000 farmers in this region (Buckles, 1995; Osei-Bonsu et al., 1996).

In southern Veracruz, velvetbean is broadcast over maize fields intended to fallow. In southeastern Oaxaca, velvetbean has been used in rotation with winter maize for many decades and is grown on riverbank hillsides. Winter maize production is ideal in these areas where velvetbean is also grown to smother weeds. After the velvetbean is cut, the mulch helps to conserve the residual moisture from the rainy season (Buckles et al., 1998). In Tabasco velvetbean is used in a slightly different system; the farmers plant velvetbean on a hummock, a small knoll or an insignificantly higher natural area. The velvetbean is slashed and maize and squash are grown in the mulch. This multi-cropping system helps to control pests that would typically have a detrimental impact on maize yields (Buckles et al., 1998).
Velvetbean is also being planted extensively as a green manure crop in Honduras (probably *M. pruriens*) for hillside agriculture where an estimated 66% of hillside farmers rotate velvetbean and dry-season maize (Buckles, 1992). The farmers in Honduras have been developing and adapting creative maize-based cropping methods incorporating velvetbean for more than 25 years, although research regarding velvetbean and its uses only began in 1980 (Buckles, 1992). In northern Honduras, velvetbean is known as *frijol de abono*, the fertilizer bean, and a field of velvetbean eventually became known as an *abonera* (Buckles et al., 1998).

Buckles (1992) mentions that in Honduras velvetbean as a green manure is not without its problems, as intercropping the legume too early before the planting of maize created competition for the maize and reduced yields by 400 kg/ha in (International Maize and Wheat Improvement Center) on-farm trials. In *Adoption of Mucua in the farming systems of northern Honduras*, Buckles and Triomphe (1999) synthesize information gathered through surveys, interviews, and agronomic monitoring of farmers’ fields and on-farm field trials conducted between 1990 and 1995 in more than 40 villages between Tela and Jutiapa in northern Honduras. The synthesis indicated that with continued use of velvetbean, soil conditions improve in porosity, filtration, and organic matter and that maize yields in fields with continuous rotation of velvetbean were on average double those obtained without velvetbean (Buckles and Triomphe, 1999). According to the same article, farmers learned of velvetbean through family members or other farmers and received seed from them as well. Apparently the widespread use of velvetbean in northern Honduras was not due to extension services or outreach programs. In contrast, Horowitz and Cassel (1999), also in Honduras, concluded that velvetbean in rotation with maize did not improve the already excellent soil physical properties present under continuous maize.
Steinmaier (2001) did a similar study in Luapula Province, Zambia to assess the potential of pasture legumes as a green manure, as well as assess farmer adaptation of starter technology by farmer research groups. Across 46 locations the velvetbean mean yield was 1290 kg ha\(^{-1}\) and ranged from 100 to 6500 kg ha\(^{-1}\) (Steinmaier, 2001). Good pod formation resulted, and due to delayed harvest in some areas, low yields were a result of popping pods.

Hartkamp et al. (2002a,b) developed parameters for adaptation of the CROPGRO growth model to velvetbean (\textit{Mucuna pruriens}) for use in Santa Rosa and Tlaltizapan, Mexico. CROPGRO incorporates tools from SOYGRO, PNUTGRO, and BEANGRO (Hartkamp et al., 2002a). Velvetbean’s physiology was like other legume species but had a more variable and indeterminate growth cycle and accumulated large seeds. The CROPGRO model can be used to plan management strategies (plant densities, rotation sequence systems) to optimize biomass (Hartkamp et al., 2002a).

The parameters of CROPGRO were used to analyze velvetbean response to crop management and environmental conditions (Hartkamp et al., 2002b). Sensitivity analysis was conducted to determine the effects of temperature on potential productivity. The data show that plant densities of more than 5 plants m\(^{-2}\) are best for velvetbean. The velvetbean version of CROPGRO worked similar to patterns in observed data, thus the author conclude it could be used to further estimate production of biomass and canopy cover in different soil, management and weather conditions (Hartkamp et al., 2002b).

**Nitrogen and Soil Fertility**

The literature shows velvetbean can contribute significant amounts of N, as well as other important nutrients, to the soil when planted as a cover crop. Buckles et al (1998) report 300 kg N ha\(^{-1}\) in Northern Honduras. In West Africa, researchers note velvetbean can contain from 150-
183 kg N ha\(^{-1}\) (Steinmaier and Ngoliya, 2000). Ibewiro et al. (2000) showed that velvetbean, in in-situ mulch systems, released 154 kg N ha\(^{-1}\) at 28 days. Velvetbean grown in Ghana accumulated 150 kg N ha\(^{-1}\) (Osei-Bonsu et al., 1996)

In the humid forest zone of southeastern Nigeria, Ile et al. (1996) performed a study to determine the N benefits of velvetbean fallow versus natural regrowth with urea fallow, with natural regrowth fallow as a control. The urea plot with natural regrowth resulted in the highest yield of maize biomass. However, velvetbean was second and the authors thus suggest that planting *M. pruriens* var. *utilis* may reduce the need for synthetic N-fertilizer application when it is grown as a relay cover crop with maize (Ile et al., 1996). While in Zambia, Steinmaier and Ngoliya (2001) found velvetbean, along with sunn hemp, to have the greatest green manure potential at zero mineral fertilizer level.

A study in Nigeria sought to estimate realistic equivalencies of N in fallows planted to cover crops in a maize-based system (Carsky et al., 1999). In greenhouse pots, soil total N increased, as well as maize growth, and N accumulation increased when legume residue was incorporated in the soil. Accumulation of N also increased after all leguminous fallows more than the natural fallow and significantly higher following velvetbean. However, response to N fertilizer was greatest after natural fallow and least after velvetbean (Carsky et al., 1999). Total N was maintained for at least 10 years when velvetbean residue was incorporated, but not when it was burned (Carsky et al., 1999).

A study in Cameroon, West Africa sought to assess soil organic matter under three treatments of fallow types. After a nine-month fallow, several biological and chemical components related to soil quality were measured (Koutika et al., 2001) and the plots planted with *M. pruriens* var. *utilis* were slashed, left on the soil surface and then planted with maize.
Velvetbean was reseeded after the maize harvest; the following year the biomass was retained and maize was again planted in the residues. Velvetbean covered the plots completely one year later. By early 1997, velvetbean had virtually disappeared, but it had only been planted in 1993 and 1994. The study found that under velvetbean, except for exchangeable Mg$^{2+}$, exchangeable cations and available P concentration were higher than under natural regrowth or under *Pueraria phaseoloides*, another commonly grown legume in West Africa, known as tropical kudzu. Effective cation exchange capacity (ECEC) was higher under velvetbean than under natural regrowth and pueraria. Particulate organic matter (POM) was found to be higher in plots planted with the legumes, pueraria showing a slightly more significant increase in POM than in natural fallow and as compared to velvetbean. The authors concluded that fallow (e.g. pueraria and velvetbean) can be used by small farmers to improve soil organic matter quality in southern Cameroon (Koutika et al., 2001).

Residues left on a field grown in velvetbean were analyzed and measured to determine the nitrogen contributions of such decomposing crops that are affordable supplements to or substitutes of mineral fertilizers on the derived savanna of Ibadan, Nigeria (Ibewiro et al., 2000b, 2000c). The scientists found that velvetbean had the largest contribution, in terms of residual N, to maize when compared to lablab (*Lablab purpureus* (L.) Sweet) and imperata (*Imperata cylindrical* (L.) Raueschel) for the first 84 days after planting (Ibewiro et al., 2000b). Ibewiro et al. (2000c) report 69 percent of soil mineral N in velvetbean was derived from the added residues after 168 days, representing 4-8 percent of residue N. Herbaceous legumes decompose quickly, mineralizing N faster than cereals because of their low C:N ratios (Iberwiro et al., 2000b, 2000c). Hairiah et al. (1993) report that *Mucuna pruriens* var. *utilis* accumulates good biomass and exhibits fast growth on acid soils.
Versteeg and Koudokpon (1993) collected and analyzed data from farmers who tested four low external input technologies meant to address the decline in soil fertility in Mono Province (Benin). The farmers planted *Mucuna pruriens* var. *utilis* in relay with maize one month after sowing the first-season maize. The velvetbean accumulated a dense cover during the second growing season. The mulch is then used to fertilize the succeeding first-season maize crop after the dry season and the velvetbean cover have died. Soil regeneration is the objective of such land management (Versteeg and Koudokpon, 1993). Apparently, the increase in maize yields when planted in relay with velvetbean after only one year were so impressive that only a few farmers chose the agroforestry option of this study (Versteeg and Koudokpon, 1993). The authors also suggest that using agroforestry techniques, the same results may take a minimum of 3-4 years to accumulate.

Another study in Benin sought to assess soil factors that limit growth and establishment of velvetbean in farmers’ fields in the derived savanna (Hougnandan et al., 2001). Velvetbean had poor establishment in some farmers’ fields per observations, probably due to velvetbean having poor symbiotic effectiveness on the N fixing bacteria associated with it or because its poor nutrition from soil mineral deficiencies. The most limiting nutrient next to N was P, which is required for nodule development and optimum plant growth (Hougnandan et al., 2001). The authors conclude that improvements in growth and establishment of velvetbean could be made through selection and use of effective micro-symbiotic bacteria (Hougnandan et al., 2001).

Tian et al. (1995, 2000) proposed indices for evaluating the residues of certain plants, as well as their effects on soil and crop in Ibadan, Nigeria at the International Institute of Tropical Agriculture (IITA) headquarters. Tian et al. (2000) sought to develop an index of legume cover
crops and N fertilizer replacement in the derived savanna of West Africa. The authors report that *M. pruriens* could potentially save 50 to 100 kg of urea N ha$^{-1}$ for maize crops (Tian et al., 2000).

In the 1995 study, the researchers evaluated the leaves of velvetbean and compared them to several types of grass species including maize stover (*Zea mays*) and rice straw (*Oryza sativa*). They developed an equation that calculates a plant residue quality index (PRQI) using the C:N ratio and lignin and polyphenol concentration of plant residues (Tian et al., 1995). Through knowledge of the C:N ratio, and lignin and polyphenol concentration of plant residues, one may estimate the rates of decomposition of residue and their effects on soil microclimate and soil fauna density to assess their effects on crop performance (Tian et al., 1995).

Low amounts of available P are common to the soils of the moist savanna of tropical Ibadan Nigeria in West Africa (Tian et al., 1995), so P fertilization is necessary for legumes to accumulate high biomass. Tian et al. (1995) note the velvetbean (from white seed) responded substantially to the applied P. Tian and Kang (1998) performed a study on soil fertility and fertilizer application effects on biomass and chemical compositions of leguminous cover crops including velvetbean. High quality plant residue often contains lignins and polyphenols and has low C:N ratios. Generally, in soils with low fertility a high root percentage was obtained relative to high fertility soil, which indicated fertilizer application can improve residue quality (Tian and Kang, 1998). An increase in lignin content of the legumes in this study was a result of high levels of N and will slow residue decomposition time. *M. pruriens* had a higher nitrogen concentration in its roots than shoots (Tian and Kang, 1998).
Literature Review of Sunn Hemp (*Crotalaria spp.*)

**Introduction**

Sunn hemp (*Crotalaria juncea*) is a tropical legume grown in India, Bangladesh, and Brazil as a green manure crop and for the bast fibers, which can be manufactured into cordage and high quality paper (Cook et al., 1996). Sunn hemp is used for fodder, as well, and the FAO (2002) mentions sunn hemp is used as fresh forage or hay (Cook and White, 1996). Sunn hemp is also grown extensively in Hawaii in rotation with vegetable and ornamental crops where it can accumulate more than 5,600 kg dry matter ha⁻¹ and 134.4 kg N ha⁻¹ in 9 to 12 weeks and is reported as being one of the most widely grown green manure crops throughout the tropics (Cook and White, 1996; Reeves, 1998).

**Biology**

A rapidly growing tropical legume native to India, sunn hemp like velvetbean, is a member of the Fabaceae (pea) family (Fahrney et al., 1987; Reeves, 1998). Sunn hemp is an erect shrubby annual, generally 1 to 4 m in height. Flowering is indeterminate, photoperiod-sensitive and responds to short days. Cross-pollination is extensive in sunn hemp and self-pollination takes place after the stigmatic surface has been insect or mechanically stimulated.

Sunn hemp seeds and leaves contain alkaloids that are poisonous to livestock (Cook and White, 1996; Reeves, 1998; Russell et al., 2002). In a joint project between The University of Hawaii and USDA-NRCS (Natural Resource Conservation Service) a variety of sunn hemp low in alkaloids called “Tropic Sun” was accumulated (Reeves, 1998).

*Crotalaria juncea* is also known for its ability to suppress root-knot nematodes (*Meloidogyne* spp.) and reniform nematodes (*Rotylenchulus reniformis*) (Cook and White, 1996;
Reeves, 1998; Rupper, 2003). Rotar and Joy (1983) suggest that the resistance is because sunn hemp is not a suitable host.

**Green Manure/Cover Crop and Soil Fertility**

Originally grown as a source of fiber for the production of twine and cord, sunn hemp (*Crotolaria juncea*) also shows potential for use in the pulp and paper industry due to its high percentage of soft lignified fibers (Cook and White, 1996). Sunn hemp grows in marginal soils, such as poor, clays soils, and is resistant to drought (Cook and White, 1996; Reeves, 1998).

In south Alabama, sunn hemp sown before September 1st and after a corn crop can create 128.8 kg N ha⁻¹ on average by December 1st (Reeves, 1998). Seeding rate recommended is 44.8-56 kg ha⁻¹ and Reeves suggests using a cowpea-type inoculant. A major drawback with sunn hemp is that seed is expensive, roughly $4.96/kg, making it less feasible for large scale farm operations. The seed is imported by specialty seed companies and only accumulated in tropical areas such as Hawaii (Reeves, 1998).

Steinmaier (2001) conducted a study north of Zambia with small-scale farmers as part of the Low-External Input and Sustainable Agriculture (LEISA) program instituted by the Luapula Livelihood and Food Security Programme (LLFSP). The on-farm experiments showed an increased use of *Crotalaria zanzibarica* as a green manure crop and averaged a yield of 531 kg ha⁻¹ with a range of 100 to 1500 kg ha⁻¹. Green manure had a positive impact on maize grain yields in 14 trials. The resultant maize crop stands included taller plants, a more rigorous growth habit, and a more intense green color, as well as larger numbers of cobs per plant which made *Crotolaria zanzibarica* favorable to farmers (Steinmaier, 2001).

In Florida, Marshall et al. (2001) evaluated systems for organic and inorganic nitrogen management of seven vegetables. One of the treatments used sunn hemp (*Crotalaria juncea* L.)
at 100 kg N ha\(^{-1}\) (Marshall et al., 2001). The study found there was no difference in plant nitrogen concentration or plant growth between those vegetables fertilized with ammonium nitrate and those fertilized with sunn hemp. Sunn hemp may, however, further benefit vegetable plants with an increase in soil organic matter and a redistribution of macro and micronutrients as the plant tissue decays. Inorganic N would be unable to provide the same benefits (Marshall et al., 2001). Rupper (2001) reported sunn hemp accumulated 162.4 kg ha\(^{-1}\) and 6.72 Mg ha\(^{-1}\) following broadcast seeding at a rate of 50.2 to 75.3 kg ha\(^{-1}\) and 60 days after planting (DAP). Marshall et al. (2001) report similar results, showing sunn hemp could accumulate 110 to 140 kg N ha\(^{-1}\). Rotar and Joy (1983) report \textit{Crotalaria juncea} (cv. Tropic Sun) can add 150 to 165 kg N to the soil in 60 days. Fahrney et al. (1987) write that sunn hemp can provide full coverage of soil in 5 weeks and accumulate 98.6 kg N ha\(^{-1}\) in above-ground nitrogen.

Sunn hemp has been shown to have low nitrogen fertilizer requirements and is a nitrogen fixer (Reeves 1998). Tian and Kang (1998) found that the application of fertilizer increased shoot biomass of sunn hemp (\textit{Crotalaria verrucosa}) and the effect was stronger in low fertility soils than in high fertility soils. In high fertility soils, \textit{C. verrucosa} had the largest decrease in root percentage and the biggest increase in shoot percentage from fertilizer application.

Mansoer et al. (1997) determined the dry-matter production, chemical composition, and N release from sunn hemp (\textit{Crotalaria juncea} L.) residue under conventional and no-tillage systems in a summer grain production system. Nitrogen concentration reached a maximum at 3 weeks after planting (WAP), ranging from 33.5 to 57.6 g kg\(^{-1}\) in leaves and 18.1 to 34.3 g kg\(^{-1}\) in stems. The concentration of N decreased with age 3 WAP. Concentrations of N ranged from 39.6 to 46.8 g kg\(^{-1}\) in leaves and from 11.3 to 15.7 g kg\(^{-1}\) in stems at 9 WAP (Mansoer et al., 1997). Total accumulation of N at 12 WAP was 136 kg ha\(^{-1}\) in one Alabama location and 120 kg
ha$^{-1}$ at 9 WAP in the other location. Sunn hemp accumulated more leaf than stem dry matter during the first 3 weeks. At 6 WAP total dry matter ranged from 1.2 to 3.5 Mg ha$^{-1}$. Sunn hemp grew rapidly until 9 WAP (late October) and then slowed as temperatures declined. They concluded sunn hemp could provide an alternative to winter cover crops. Dry matter production during the fall season averaged 5.9 Mg ha$^{-1}$ at 9-12 WAP and coverage of the soil surface was rapid, helping to protect against erosion. Mineralization was rapid in the mowed residue and occurred during the winter (Mansoer et al., 1997). The authors mention, however, that when sunn hemp is followed with a winter cereal a synchronous N use pattern would occur, helping to reduce or eliminate this loss of N (Mansoer et al., 1997).

Plenty of literature suggests velvetbean and sunn hemp can provide ample biomass and nutrients to soil. The objective of this study is to help establish an idea of the best planting and harvesting dates based on the accumulated biomass and nutrient content of sunn hemp and velvetbean planted at two locations in Georgia. The next three sections will discuss the materials and methods, as well as the results and discussions of biomass accumulation and nutrient content of velvetbean and sunn hemp. The relationship between DAP, cumulative heat units (CHU), CHU plus cumulative rainfall units (CRU) and how these relationships may help develop models that can be used in the U.S. to help estimate biomass and nitrogen accumulation is explored. A discussion of all the findings concludes the thesis in Section 5.
SECTION 2

MATERIALS AND METHODS

Biomass Accumulation

This study took place in Watkinsville, GA at the U.S.D.A. Agricultural Research Service Station on a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) and at the Coastal Plain Experiment Station on a Tifton sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) in Tifton, Georgia. One plot of velvetbean and one plot of sunn hemp were planted on (within two days) four different dates, including 15 Apr., 15 May, 15 Jun., and 15 Jul. in the summer of 2002. Reeves (1998) recommends a seeding rate of 45-56 kg ha\(^{-1}\) for sunn hemp, however, sunn hemp seed is costly relative to other cover crop seed so the seeding rate used for sunn hemp in this experiment was reduced to 13 kg ha\(^{-1}\) with an in-row spacing of 30-39 seed/meter in Watkinsville and 36-46 seed/meter in Tifton. Velvetbean seed was planted at 36 kg ha\(^{-1}\) with an in-row spacing of 5.6 seed/meter in Watkinsville and 6.6 seed/meter in Tifton. In Tifton 91 cm row spacing (between rows) was used and in Watkinsville 76 cm row spacing (between rows) was used due to the difference in planters available for use at each site.

In Watkinsville all plots were irrigated approximately 1.3 cm shortly after planting. Ammonium nitrate was applied to each plot at the rate of 16.8 kg ha\(^{-1}\) shortly after planting. During the second week of May, glyphosate was sprayed on the April plot of velvetbean between rows due to an abundance of grassy weeds. Metolachlor and pendimethalin were also sprayed in the middle of May on the plots (Velvetbean and Sunn hemp) to be planted at a later date (June and July plots) to control weeds. Round up was again sprayed in the April plot of velvetbean in
late June for weed control. The July plots were sprayed again with metolachlor and pendimethalin just prior to planting. In July all plots were irrigated approximately 5.1 cm. All plots were irrigated approximately 5.1 cm in August, as well.

Weed control was done by hand, otherwise, throughout the month of July with about six hours of labor (for one person). Weeds were mostly a problem on the outer edges of the plots, in between the plots and in the bare spaces resulting from harvesting. The harvest dates included 30, 60, 90, and 120 days after planting (DAP). Four replicates of each treatment were collected as defined by areas previously randomly selected and mapped accordingly (see diagrams 1 and 2). In Watkinsville, biomass samples were collected by cutting the plants at the base in .91 linear meters per row, harvesting two rows per sample so each sample contained 1.8 linear meters. In Tifton 1.8 linear meters were harvested, as well. The fresh weight of each sample was recorded shortly after harvesting and each sample was placed in an oven at 66 degrees C for at least 72 h to dry. Dry weights were then recorded for each biomass sample.

The data were analyzed using The GLM Procedure and Duncan’s Multiple Range Test with an alpha value of 0.05. The mean weight of each (16) planting/harvest date was compared among each month of planting (April-July) using 64 observations except in Watkinsville for velvetbean, which is discussed later in this paper. A comparison of each planting/harvesting date was made among and within each month. A comparison of each planting and harvesting date, for example among the mean weights for all samples that were collected 30 DAP was also analyzed for differences in significance.

**Nutrient Content**

For tissue nutrient analysis, at each harvest one to two plants (depending on the size of the plant) were collected directly adjacent to the biomass collection area. Four repetitions of
each planting and harvesting date were used. Sampled plants (whole excluding the roots) were ground through a Wiley Mill with a 2 mm screen to be prepared for analysis. The sample was stirred to insure the analysis would most closely resemble the true nutrient content of entire plants (such as what would be found in a field situation). The samples were then sent for processing to the soil testing laboratory at The University of Georgia, Horticulture Department in Tifton, GA.

**Cumulative Heat Units**

Heat Units were determined for each day using the following formula:

\[
\frac{(\text{Daily maximum temperature (T)} + \text{Daily minimum T})}{2} - 16
\]

(OMAF, 2003; Ball, 2003; Nielson, 2001). Cotton’s base temperature, or the temperature at which cotton will not grow, is 16°C (Ball, 2003). For this reason, 16°C has been chosen as the base temperature for Sunn hemp for the purpose of this section of the study. Heat units were summed between each planting and harvest date and these values were used similar to DAP to fit regressions for biomass and N accumulation for the Tifton and Watkinsville locations. All weather related data was taken from “The Georgia Automated Environmental Monitoring Network” website (www.GeorgiaWeather.net, 2003). Regression equations were developed for each location and cover crop using the REG procedure in SAS with no intercept in the model, for example no biomass at 0 DAP. The resulting regression equations were then combined for one model per cover crop. Equations were fit using all data points, except extreme outliers; which excluded the June planting in Tifton harvested 120 DAP.
SECTION 3

‘GEORGIA BUSH’ VELVETBEAN (MUCUNA PRURIENS)

Biomass Accumulation

Introduction

Velvetbean is noted for its ability to accumulate large amounts of biomass. Buckles et al. (1998) note aboveground biomass production of velvetbean ranges from 5 to 12 Mg of dry matter ha\(^{-1}\) and in Ghana Osei-Bonsu et al. (1996) report up to 9 Mg ha\(^{-1}\). Planting date has a significant effect on the biomass production of a cover crop. This study will help determine how cover crops like velvetbean and sunn hemp can fit into rotation with vegetable crops. The objective of this study was to determine the most effective planting and harvesting dates for velvetbean for the Coastal Plain and Piedmont areas of Georgia. The most successful dates will be considered the ones that accumulate the largest amount of biomass.

Dry Weight - Tifton

Biomass harvested 120 DAP had the maximum mean DW of 8.6±5.3 Mg ha\(^{-1}\), velvetbean harvested 90 DAP accumulated a mean DW of 6.0±2.9 Mg ha\(^{-1}\), velvetbean harvested 60 DAP had a mean DW of 3.0±1.7 Mg ha\(^{-1}\) and velvetbean harvested 30 DAP accumulated a mean DW of 0.4±0.3 Mg ha\(^{-1}\). The maximum biomass for velvetbean in Tifton was 65.6 Mg ha\(^{-1}\) (fresh weight) harvested 120 DAP from the May planting, however the standard error for this mean is 38 Mg ha\(^{-1}\). The maximum DW was harvested 120 DAP from the April planting (12.0±2.3 Mg ha\(^{-1}\)), which was not significantly more than the May and July plantings with 10.8±6.6 Mg ha\(^{-1}\) and 9.6±2.1 Mg ha\(^{-1}\) DW accumulated respectively. The June planting harvested 120 DAP
accumulated a significantly smaller amount of biomass with a DW of 1.8±0.7 Mg ha⁻¹ probably as previously mentioned, due to a viral infection. The minimum fresh and DWs recorded for velvetbean in Tifton were 1.1±0.4 Mg ha⁻¹ for the June planting and 0.3±0.1 Mg ha⁻¹ for the April planting, respectively, both harvested 30 DAP.

Velvetbean biomass harvested 60 DAP from each planting date accumulated from 1.0±0.9 Mg ha⁻¹ for the June planting to 4.9±0.9 Mg ha⁻¹ for the May planting. However, no significant difference occurred between the May planting (4.9±0.9 Mg ha⁻¹) and the April planting (3.4±1.1 Mg ha⁻¹). The biomass harvested 60 DAP from the July planting (2.8±1.0 Mg ha⁻¹) was not significantly less than the April planting harvested 60 DAP, which accumulated 3.4±1.1 Mg ha⁻¹.

Velvetbean biomass harvested 90 DAP accumulated DWs from 2.8±1.4 Mg ha⁻¹ for the June planting to 9.5±2.0 Mg ha⁻¹ for the May planting. At 90 DAP there was a significant difference between the April and May plantings with weights of 7.0±1.2 Mg ha⁻¹ and 9.5±2.0 Mg ha⁻¹ respectively. Biomass harvested 90 DAP from the July planting (4.7±0.9 Mg ha⁻¹) proved not to be significantly greater than the 2.8±1.4 Mg ha⁻¹ of biomass harvested from the June planting (Figure 3.1).
Figure 3.1 DW (± SE) of ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 days after planting (DAP).

**Dry Weight - Watkinsville**

In Watkinsville herbivore by deer was a problem for the velvetbean. For the first five months of the experiment deer were not a problem. They did go into the velvetbean plots during this time, however, they tended to only feed on the plants on the outer edge of the plots. The plot planted in July suffered slightly more damage from deer, probably because it had stunted growth probably due to a virus, which kept the leaves small, tender, and more palatable to the deer. In early September, however, deer went into the velvetbean plots and completely defoliated all the plants.
Unfortunately, due to the damage from the deer, collection of September samples of velvetbean plots was not possible. To determine the possibility of velvetbean recovering from the severe damage done by the deer, Milorganite™ nitrogen fertilizer containing human waste was put down on the perimeter of both the sunn hemp and velvetbean plots to deter the deer. The velvetbean began to put on new growth, however, in the middle of October either the fall army worm or the velvetbean caterpillar managed to completely defoliate the sparsely existing foliage that remained or had grown back from the damage done by the deer.

A comparison among harvesting times (30, 60, 90, and 120 DAP) shows that velvetbean harvested 120 DAP accumulated the maximum DW of 6.6±1.2 Mg ha⁻¹, unfortunately only four samples were taken for this treatment of time due to damage to the velvetbean plantings as mentioned earlier. Velvetbean harvested 90 DAP accumulated a mean (of 8 samples) DW of 5.7±1.9 Mg ha⁻¹. The mean (of 12 samples) DW of velvetbean harvested 60 DAP accumulated 2.8±1.2 Mg ha⁻¹ and the biomass collected 30 DAP accumulated a mean (of 12 samples) of 0.6±0.6 Mg ha⁻¹.

The DW of 16 samples from the April planting, 12 samples from the May planting and 8 samples from the June planting included four repetitions of each 30, 60, 90 and 120 DAP harvest time. At 30 DAP the June planting accumulated the most DW biomass with 1.2±0.7 Mg ha⁻¹, while the April and May plantings accumulated significantly less biomass (0.2±0.04 Mg ha⁻¹ and 0.3±0.04 Mg ha⁻¹ respectively) than the June planting.

Velvetbean biomass harvested 60 DAP from the May planting had the largest DW of biomass (3.5±0.8 Mg ha⁻¹) with the June planting producing an amount not significantly different of 3.4±0.8 Mg ha⁻¹. The April planting accumulated the least amount after 60 DAP (1.5 Mg
Biomass harvested 90 DAP was only recorded for the April and May plantings. The May planting accumulated significantly more biomass (7.3±0.8 Mg ha\(^{-1}\)) than the April planting (3.0 ±0.3 Mg ha\(^{-1}\)). No data were collected for the July plot (Figure 3.2).

**Figure 3.2** DW (± SE) of ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP. Data are incomplete due to damage from a virus and damage from deer browsing and caterpillar feeding.
Days After Planting, Cumulative Heat Units, Cumulative Heat Units Plus Cumulative Rainfall Units, and Biomass Accumulation

Days After Planting and Biomass Accumulation - Velvetbean

The model for velvetbean biomass accumulation versus DAP shows that as expected more biomass is accumulated the longer velvetbean is allowed to grow, however the variability increases later in time, such as at 120 DAP. The combined model for both locations is \( \hat{Y} = 0.054 \times \text{DAP} \) where \( \hat{Y} \) is equal to the biomass accumulated in Mg ha\(^{-1}\) and \( r^2 = 0.88 \). The April, May, and June plantings in Tifton show a specific trend of more biomass accumulated 120 DAP. The June planting did not perform as might be expected based on the data from the other plantings, however, the suspected virus is probably the reason. Data are incomplete for velvetbean in Watkinsville due to pest damage (Figure 3.3).

Cumulative Heat Units and Biomass Accumulation - Velvetbean

When expressed on a heat units (HU) basis, the combined model for velvetbean at both locations is \( \hat{Y} = 0.004 \times \text{CHU} \) where \( \hat{Y} \) is equal to the biomass accumulated in Mg ha\(^{-1}\) and \( r^2 = 0.93 \). Cumulative heat units better described biomass accumulation than cumulative heat units plus cumulative rainfall. Variability among data points is small, except for the June plantings in Tifton; which are outliers due to viral damage to the planting. However, the linear pattern of the data points suggests an effective model at estimating potential biomass accumulation based on cumulative heat units (Figure 3.4).
Figure 3.3 Biomass accumulation of velvetbean in dry weight (DW) as a function of days after planting (DAP). Data points are mean of four observations. Data are incomplete for Watkinsville.
Figure 3.4 Biomass accumulation of velvetbean in dry weight (DW) as a function of cumulative heat units (CHU). Data points are mean of four observations. Data are incomplete for Watkinsville.

Cumulative Heat Units Plus Cumulative Rainfall Units and Biomass Accumulation - Velvetbean

The combined (including each location) equation \( \hat{Y} = 0.005 \times (\text{CHU} + \text{CRU}) \), where \( \hat{Y} \) equals the amount of DW biomass accumulated in Mg ha\(^{-1}\) and \( r^2=0.829 \). The scatter plot shows large variability regarding DWs, especially with increased cumulative rainfall and heat units. This model does not fit as linear a pattern as the models for DAP versus cumulative biomass and
CHU versus biomass. Intermittent rainfall and velvetbean’s dependence on water may account for some of the variability seen in this plot (Figure 3.5).

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**Figure 3.5** Biomass accumulation of velvetbean in dry weights (DW) as a function of cumulative heat units (CHU) plus cumulative rainfall units (CRU). Data points are mean of four observations. Data are incomplete for Watkinsville.

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**Nutrient Content**

**Introduction**

Velvetbean is known for its nitrogen content and nitrogen fixing abilities. In northern Honduras it has come to be known as *frijol de abono*, “the fertilizer bean” (Buckles et al. 1998). In Zambia, Steinmaier and Ngoliya (2001) found velvetbean, along with sunn hemp has great green manure potential with no fertilizer application. There, velvetbean (*Mucuna pruriens* cv.
NIRS 16) contained 183 kg N ha\(^{-1}\), 41 kg P ha\(^{-1}\), and 112 kg K ha\(^{-1}\). Buckles et al. (1998) found 300 kg N ha\(^{-1}\), 20 kg P ha\(^{-1}\), 100 kg K ha\(^{-1}\), 140 kg Ca ha\(^{-1}\), 26 kg Mg ha\(^{-1}\) in the above ground biomass of velvetbean in northern Honduras. Velvetbean grown in Ghana accumulated 150 kg N ha\(^{-1}\) (Osei-Bonsu et al., 1996). The objective of this study was to determine approximate target dates for planting velvetbean and cutting, rolling, or planting into the cover crop according to the nutrient content found in the tissue of the whole plant.

**Nitrogen - Tifton**

The velvetbean harvested 30 DAP from each planting only showed significant differences in N accumulation among the April and June plantings when compared to the July planting. Values ranged from a maximum 22.1±10.1 kg N ha\(^{-1}\) for the July planting to a minimum 8.6±3.2 kg N ha\(^{-1}\) for the June planting. Again, the low results for the June planting are probably due to a virus infection that stunted the growth of the velvetbean in this planting. Velvetbean planted in April and harvested 30 DAP accumulated 10.1±5.7 kg N ha\(^{-1}\) and velvetbean planted in May accumulated an amount (17.2±4.7 kg N ha\(^{-1}\)) not significantly different from the N accumulated by the July planting (22.1±10.1 kg N ha\(^{-1}\)).

Velvetbean harvested 60 DAP only showed a significant difference between nitrogen accumulated in the May and June plantings. The May planting accumulated the most N with 170.8±61.2 kg N ha\(^{-1}\). There was no significant difference between N in the April planting 128.3±90.8 kg N ha\(^{-1}\) and the July planting (89.1±24.1 kg N ha\(^{-1}\)). There was no significant difference between the July planting and the April and May plantings. The N production for the June planting at 60 DAP was minimal, 23.1±12.2 N kg ha\(^{-1}\).

Velvetbean harvested 90 DAP accumulated a maximum of 303.1±85.6 kg N ha\(^{-1}\) for the May planting and a minimum of 77.4 kg ha\(^{-1}\) for the June planting. There was no significant
difference between nitrogen accumulated by the June planting and N accumulated by the July planting (134.1±49.3 kg N ha\(^{-1}\)). The April and May planting accumulated significantly more N (259.3±56.4 kg ha\(^{-1}\) and 303±85.6 kg ha\(^{-1}\) respectively) than the June and July plantings. Nitrogen content of velvetbean harvested 120 DAP showed a significant difference between the April and June plantings with 421.8±128.2 kg N ha\(^{-1}\) and 64.4±18.5 kg N ha\(^{-1}\) accumulated respectively. However, the velvetbean harvested 120 DAP and planted in May and July accumulated 407.3±269.2 kg N ha\(^{-1}\) and 337.6±105.9 kg N ha\(^{-1}\) respectively, neither significantly less than that accumulated in the April planting (Figure 3.6).

**Figure 3.6** Nitrogen (± SE) for ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.
Phosphorus - Tifton

Maximum P production was in the April planting of velvetbean harvested 120 DAP (50.7±11.6 kg ha⁻¹). At 30 DAP no significant difference existed among treatments (months). At 60 DAP no significant difference existed among plantings either, the May planting accumulated the maximum P at 18.8 kg ha⁻¹ and the June planting accumulated the least (3.87 kg ha⁻¹ P). The June planting of velvetbean in Tifton suffered severely stunted growth probably due to what appeared to be a virus. This is probably why nutrient content for the June planting was always much lower than for each other planting (at 30, 60, 90, and 120 DAP). The April and May plantings consistently accumulated more P than the other plantings at each DAP (Figure 3.7).
Figure 3.7 Phosphorus (± SE) for ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Potassium - Tifton**

Maximum K was accumulated in the April planting of velvetbean harvested 120 DAP (339.8±107.8 kg K ha⁻¹), although this amount was not significantly more than the amount accumulated by the May and July plantings (256.6±156.7 kg K ha⁻¹ and 207.1±78.8 kg K ha⁻¹ respectively). At 30 DAP the July and May plantings accumulated the maximum K at 12.5±5.5 kg ha⁻¹ and 12.5±2.9 kg ha⁻¹ respectively, although neither of these weights were significantly more than the amount accumulated by the April planting at 8.3±4.8 kg ha⁻¹. No significant difference occurred in the amount of K accumulated by each planting at 60 DAP with maximum being for the May planting (125.1±20.7 kg K ha⁻¹) and the minimum being for the June planting...
(19.1±16.0 kg K ha⁻¹). At 90 DAP the May planting performed best accumulating 266.5±94.8 kg K ha⁻¹, although not significantly more K than the April planting (207.4±24.1 kg K ha⁻¹), both plantings accumulated significantly more than the June and July plantings (54.6±33.6 kg K ha⁻¹ and 96.6±22.4 kg K ha⁻¹ respectively) (Figure 3.8).

**Figure 3.8** Potassium (± SE) for ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.
Other Nutrients – Tifton

Copper, iron, manganese and zinc accumulation overall was minimal. The highest calcium content was 142.7±73.5 kg Ca ha\(^{-1}\) for the April planting harvested 120 DAP, significantly more than the other plantings, except for the July planting which was similar with 84.29 kg Ca ha\(^{-1}\). Magnesium content at 120 DAP was similar for the April, May, and July plantings. The April planting accumulated the most Mg with 36.9±11.9 kg Mg ha\(^{-1}\) while the June planting accumulated significantly less than the other plantings (Table 2.1).
Table 3.1 Other Nutrients in ‘GA Bush’ Velvetbean in Tifton (±SE) in kg ha\(^{-1}\)

<table>
<thead>
<tr>
<th>Planted Harvested</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>3.6±2.7</td>
<td>1.1±0.7</td>
</tr>
<tr>
<td>April 60</td>
<td>0.0±0.0</td>
<td>0.5±0.3</td>
<td>0.3±0.1</td>
<td>0.2±0.1</td>
<td>34.7±22.9</td>
<td>9.9±4.1</td>
</tr>
<tr>
<td>April 90</td>
<td>0.1±0.0</td>
<td>1.0±0.3</td>
<td>0.5±0.1</td>
<td>0.5±0.0</td>
<td>83.7±15.9</td>
<td>25.6±4.4</td>
</tr>
<tr>
<td>April 120</td>
<td>0.1±0.0</td>
<td>1.8±0.6</td>
<td>1.2±0.8</td>
<td>0.8±0.2</td>
<td>142.7±73.5</td>
<td>36.9±11.9</td>
</tr>
<tr>
<td>May 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>2.8±2.1</td>
<td>1.3±0.5</td>
</tr>
<tr>
<td>May 60</td>
<td>0.1±0.0</td>
<td>0.6±0.2</td>
<td>0.1±0.1</td>
<td>0.2±0.0</td>
<td>22.4±7.5</td>
<td>11.7±3.6</td>
</tr>
<tr>
<td>May 90</td>
<td>0.2±0.0</td>
<td>1.3±0.4</td>
<td>0.2±0.1</td>
<td>0.4±0.1</td>
<td>54.5±20.4</td>
<td>24.3±6.5</td>
</tr>
<tr>
<td>May 120</td>
<td>0.2±0.1</td>
<td>1.4±1.1</td>
<td>0.3±0.4</td>
<td>0.5±0.3</td>
<td>51.8±30.4</td>
<td>25.8±14.5</td>
</tr>
<tr>
<td>June 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>1.7±0.7</td>
<td>0.7±0.3</td>
</tr>
<tr>
<td>June 60</td>
<td>0.0±0.0</td>
<td>0.3±0.3</td>
<td>0.1±0.0</td>
<td>0.1±0.0</td>
<td>4.0±2.5</td>
<td>2.3±1.3</td>
</tr>
<tr>
<td>June 90</td>
<td>0.0±0.0</td>
<td>1.0±0.7</td>
<td>0.2±0.1</td>
<td>0.2±0.1</td>
<td>17.1±11.6</td>
<td>6.7±2.9</td>
</tr>
<tr>
<td>June 120</td>
<td>0.0±0.0</td>
<td>0.3±0.1</td>
<td>0.1±0.0</td>
<td>0.1±0.0</td>
<td>9.5±6.3</td>
<td>4.6±3.1</td>
</tr>
<tr>
<td>July 30</td>
<td>0.0±0.0</td>
<td>0.3±0.2</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>4.8±2.5</td>
<td>1.8±1.1</td>
</tr>
<tr>
<td>July 60</td>
<td>0.0±0.0</td>
<td>0.8±0.4</td>
<td>0.2±0.3</td>
<td>0.2±0.2</td>
<td>0.2±0.1</td>
<td>21.8±9.9</td>
</tr>
<tr>
<td>July 90</td>
<td>0.0±0.0</td>
<td>1.2±0.5</td>
<td>0.3±0.1</td>
<td>0.3±0.1</td>
<td>40.9±16.0</td>
<td>10.5±2.5</td>
</tr>
<tr>
<td>July 120</td>
<td>0.0±0.0</td>
<td>3.9±3.2</td>
<td>0.8±0.3</td>
<td>0.6±0.2</td>
<td>84.3±44.5</td>
<td>25.6±9.3</td>
</tr>
</tbody>
</table>

**Nitrogen - Watkinsville**

Velvetbean grown 120 days contained the largest amount of N with a mean value (of 4 samples) of 217.3±37.1 kg N ha\(^{-1}\). At 90 DAP velvetbean contained (of 8 samples) of 172.7±41.3 kg N ha\(^{-1}\) and 60 DAP velvetbean contained (of 12 samples) 93.9±39.6 kg N ha\(^{-1}\). As might be expected, velvetbean harvested 30 DAP contained the least N at 16.8±17.6 kg ha\(^{-1}\). For velvetbean harvested 30 DAP the June planting accumulated the most N at 34.2±22.7 kg ha\(^{-1}\).
ha\textsuperscript{-1}. The April and May plantings harvested 30 DAP accumulated similar quantities of N at 6.5±2.1 kg ha\textsuperscript{-1} and 9.9±2.2 kg ha\textsuperscript{-1} respectively.

The May and June plantings harvested 60 DAP accumulated 124.6±29.0 kg N ha\textsuperscript{-1} and 107.4±22.9 kg N ha\textsuperscript{-1} respectively, not significantly different values. The April planting harvested 60 DAP accumulated significantly less N (49.8 kg ha\textsuperscript{-1}). The May planting accumulated the most N (202.0±34.7 kg ha\textsuperscript{-1}) for velvetbean harvested 90 DAP, however data were only available for the April and May plantings due to problems in the field and so only four samples of velvetbean grown 120 DAP were available for the April planting, which accumulated 217.3±37.1 kg ha\textsuperscript{-1}. The April planting harvested 90 DAP accumulated 143.4±22.0 kg ha\textsuperscript{-1} N while the mean value of 4 samples for the May planting harvested 90 DAP accumulated significantly more at 202.0±34.7 kg ha\textsuperscript{-1} (Figure 3.9).
Figure 3.9 Nitrogen (± SE) content of ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP. Data are incomplete.

**Phosphorus - Watkinsville**

Maximum P in velvetbean harvested 120 DAP was for the April planting harvested 120 DAP (19.0 kg P ha⁻¹), this was the only sampling for 120 DAP due pest damage. The mean P in velvetbean harvested 90 DAP was 15.0 kg P ha⁻¹. Velvetbean harvested 30 and 60 DAP contained little P (1.6 and 8.1 kg ha⁻¹ respectively). At 30 DAP the June planting contained 3.0 kg P ha⁻¹, significantly more than the April and May plantings (0.9 kg P ha⁻¹ and 0.8 kg P ha⁻¹).

The May planting accumulated more P at 60 DAP than the other months, however, not
significantly more than the P from the June planting (9.4 kg ha\(^{-1}\)). The April planting accumulated significantly less (4.0 kg ha\(^{-1}\)) than both months at 60 DAP. The May planting accumulated significantly more P (17.7 kg ha\(^{-1}\)) than the April planting (12.2) at 90 DAP (Figure 3.10).

**Figure 3.10** Phosphorus (± SE) content of ‘Georgia Bush’ velvetbean (*Mucuna pruriens*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP. Data are incomplete.
Potassium - Watkinsville

At 30 DAP the June planting accumulated significantly more K than the other plantings (41.8 kg ha\(^{-1}\)), while May and April only accumulated 10.4 kg K ha\(^{-1}\) and 5.0 kg K ha\(^{-1}\), respectively. At 60 DAP the May and June plantings were similar, accumulating 121.2 kg K ha\(^{-1}\) and 126.5 kg K ha\(^{-1}\) respectively, while the April planting accumulated significantly less (44.1 kg K ha\(^{-1}\)). At 90 DAP the May planting accumulated significantly more K at 247.4 kg K ha\(^{-1}\) than the April planting (126.0 kg K ha\(^{-1}\)), the only other sample taken at 90 DAP (Figure 3.11).

Figure 3.11 Potassium (± SE) content of ‘Georgia Bush’ velvetbean (\textit{Mucuna pruriens}) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP. Data are incomplete.
Other Nutrients - Watkinsville

No significant difference occurred among plantings of velvetbean for each nutrient analyzed: copper, magnesium, manganese, iron, and zinc. Calcium, however, showed a significant difference between the May and June plantings with the June planting containing the most Ca (38.6 kg ha\(^{-1}\)) and the May planting containing the least (25.5 kg ha\(^{-1}\) P). The Ca from the April planting (34.9 kg ha\(^{-1}\)) was not significantly different from the other two plantings. The nutrient content for each planting and harvesting date shows a pattern of increasing until 90 DAP and then dropping or decreasing to 120 DAP (Table 3.2).

<table>
<thead>
<tr>
<th>Planted Harvested</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.0±7.7</td>
<td>0.0±0.0</td>
<td>1.5±0.5</td>
<td>0.4±0.1</td>
</tr>
<tr>
<td>April 60</td>
<td>0.0±0.0</td>
<td>0.4±0.2</td>
<td>0.3±0.2</td>
<td>0.1±0.0</td>
<td>14.2±7.7</td>
<td>3.8±0.1</td>
</tr>
<tr>
<td>April 90</td>
<td>0.1±0.0</td>
<td>1.8±0.1</td>
<td>1.1±0.2</td>
<td>0.3±0.0</td>
<td>43.7±7.9</td>
<td>10.6±1.9</td>
</tr>
<tr>
<td>April 120</td>
<td>0.1±0.0</td>
<td>1.1±0.3</td>
<td>1.8±1.5</td>
<td>0.5±0.1</td>
<td>80.2±9.0</td>
<td>19.5±1.9</td>
</tr>
<tr>
<td>May 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>3.2±0.8</td>
<td>0.7±0.2</td>
</tr>
<tr>
<td>May 60</td>
<td>0.1±0.0</td>
<td>1.1±0.1</td>
<td>1.1±0.22</td>
<td>0.3±0.1</td>
<td>32.8±14.7</td>
<td>8.4±1.2</td>
</tr>
<tr>
<td>May 90</td>
<td>0.1±0.0</td>
<td>1.3±0.2</td>
<td>1.7±0.8</td>
<td>0.7±0.1</td>
<td>56.3±24.1</td>
<td>16.4±3.8</td>
</tr>
<tr>
<td>June 30</td>
<td>0.0±0.0</td>
<td>0.2±0.1</td>
<td>0.2±0.1</td>
<td>0.1±0.1</td>
<td>9.7±5.3</td>
<td>2.5±1.6</td>
</tr>
</tbody>
</table>

Data are incomplete due to damage from deer and fall armyworm or velvetbean caterpillar.
Days After Planting, Cumulative Heat Units, Cumulative Heat Units Plus Cumulative Rainfall Units, and Nitrogen Accumulation

For velvetbean, the relationship between DAP and nitrogen accumulation was examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in velvetbean as a result of DAP. The model developed is \( \hat{Y} = 2.26 \times \text{DAP} \), where \( \hat{Y} \) is equal to the amount of N in kg ha\(^{-1}\) and \( r^2 = 0.844 \). The scatter plot shows more variability in N accumulated with an increase in time or DAP (Figure 3.12).

The relationship between CHU and nitrogen accumulation was also examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in velvetbean as a result of CHU. The model developed is \( \hat{Y} = 0.181 \times \text{CHU} \), where \( \hat{Y} \) is equal to the amount of N in kg ha\(^{-1}\) and \( r^2 = 0.760 \). The scatter plot shows more variability in N accumulated with an increase in time or CHU and nitrogen accumulation appears to be more positively affected by CHU in Tifton than in Watkinsville (Figure 3.13).

The relationship between CHU + CRU and nitrogen accumulation was also examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in velvetbean as a result of CHU. The model developed is \( \hat{Y} = 0.167 \times (\text{CHU} + \text{CRU}) \), where \( \hat{Y} \) is equal to the amount of N in kg ha\(^{-1}\) and \( r^2 = 0.791 \). The scatter plot shows increased variability in N accumulated with an increase in time or CHU + CRU and nitrogen accumulation appears to be more positively affected by CHU + CRU in Tifton than in Watkinsville. Overall, when regression analyses were used to determine the above relationships, more variability is seen in N accumulation than in biomass accumulation (Figure 3.14).
Figure 3.12 Nitrogen accumulation in velvetbean as a function of days after planting (DAP).

Data points are mean of four observations. Data are incomplete for Watkinsville.
Figure 3.13 Nitrogen accumulation in velvetbean as a function of cumulative heat units (CHU).

Data points are mean of four observations. Data are incomplete for Watkinsville.
Figure 3.14 Nitrogen accumulation in velvetbean as a function of cumulative heat units (CHU) plus cumulative rainfall units (CRU). Data points are mean of four observations. Data are incomplete for Watkinsville.

Conclusions

Velvetbean planted in Tifton in April accumulated the most biomass at 120 DAP, however this biomass was similar to that accumulated in the May and July plantings. The May planting harvested 90 DAP was similar to the April, May and July plantings harvested 120 DAP. It appears that to receive soil-improving benefits from velvetbean when grown in Tifton, allowing 120 days for the velvetbean to grow will provide the most benefit when it’s planted in April, May, or July. Results for velvetbean planted in June would probably generally be as good, however, for this study the results from the June planting were poor, most likely due to a virus
infection as mentioned previously. If a grower needed a shorter growing period for velvetbean, according to this study, planting in May and cutting 60-90 DAP or planting in July and cutting 90-120 DAP, would also provide significant biomass. This provides two windows of opportunity for growing velvetbean in early or late summer as a short-fallow rotational crop in South Georgia.

At 90 DAP, the May planting of velvetbean grown in Watkinsville accumulated more biomass than the April planting. The April planting harvested 120 DAP accumulated less biomass than the May planting harvested 90 DAP. The data show a trend of increasing biomass accumulation with later planting dates. The May and June plantings were similar at 60 DAP, both producing average biomass. The biomass accumulated in the June planting at 30 DAP was similar to that produced in the April planting at 60 DAP. This data may suggest planting velvetbean after April is better for biomass accumulation in the Watkinsville, GA area.

Nitrogen content for velvetbean grown in Tifton was highest for the April planting at 120 DAP; which was similar to the May and July plantings at 120 DAP. However, N accumulation was also substantial for the April and May plantings of velvetbean at 90 DAP and at 60 DAP for the April, May and July plantings. For P the April and May plantings consistently accumulated more P than the other plantings at each DAP, the same was true for K. Although for K, the July planting was similar to the April and May plantings. The June plantings contained the least nutrients overall due to a presumed virus. Overall, for the other nutrients examined (Cu, Fe, Mn, Zn, Ca, and Mg), only significant amounts of Ca and Mg were accumulated. The April planting was generally similar to the July planting in accumulation of other nutrients. This would allow a grower to fit velvetbean into an early summer or fall vegetable production system as a short-fallow rotation crop in Georgia.
In Watkinsville, the April planting of velvetbean at 120 DAP accumulated the most N, however, the May planting harvested 90 DAP accumulated a similar amount of N. The other nutrients analyzed increased until 90 DAP and then declined to 120 DAP. Phosphorus accumulation followed the same pattern as N accumulation. However, overall K accumulation was greatest for the May planting at 90 DAP.

Literature shows velvetbean N content ranging from 150 kg N ha\(^{-1}\) to 183 kg N ha\(^{-1}\) with P content ranging from 20±7 kg P ha\(^{-1}\) to 41 kg P ha\(^{-1}\), and K ranging from 100±24 kg K ha\(^{-1}\) to 112 kg K ha\(^{-1}\) (Buckles et al., 1998; Osei-Bonsu et al., 1996; Steinmaier and Ngoliya, 2001). Buckles et al., (1998) also note Mg content at 26±7 kg Mg ha\(^{-1}\) in above ground velvetbean biomass. This research shows some of these amounts can be seen growing velvetbean for only 60 to 90 days. This suggests velvetbean may work well as a green/manure cover crop grown in rotation with vegetable crops in Georgia because velvetbean can be grown late spring/early summer or late summer/early fall based on its biomass and nutrient accumulation at 60-120 DAP.

**Problems and Observations**

In Watkinsville velvetbean germination was low after the first (April) planting. Approximately ten days after the first planting, a stand count was taken and seed were sown by hand to reach the desired planting specifications. A second stand count was taken and considered acceptable after germination of the seed sown by hand.

Wild plantain, a grassy weed was a problem in the April velvetbean planting due to the small size of the velvetbean and its minimal soil coverage. However, the weeds were controlled through two applications of glyphosate spaced two weeks apart and two attempts at weeding by
hand. Redroot pigweed (*Amaranthus retroflexus*) became a problem in the May planting of velvetbean, however, the weeds were removed manually.

In early June wild plantain (*Heliconia bihai*) was a major pest in the April planting and in early July, redroot pigweed (*Amaranthus retroflexus*) and sicklepod (*Senna obtusifolia*) were major problems in the May and June velvetbean plantings. Weeds, however, were mostly controlled by hand. In late June, pigweed and sicklepod became problems in nearly all the velvetbean plantings. In late June, deer began to graze the velvetbean severely damaging plants on the edges of the plots.

In early September, deer came into the velvetbean plots and completely defoliated all the plants. Possibly a major food source for the deer was harvested or somehow otherwise made unavailable which motivated the deer to consume in entirety the velvetbean plots. However, due to the damage from the deer, collection of September samples of velvetbean plots was not possible. To determine the possibility of velvetbean recovering from the severe damage done by the deer, Milorganite™ nitrogen fertilizer was put down on the perimeter of both sunn hemp and velvetbean plots to deter the deer. The velvetbean began to put on new growth, however, in the middle of October either the fall armyworm or the velvetbean caterpillar completely defoliate the sparsely existing foliage that remained or had grown back from the damage by the deer.

Due to the damage caused by the deer in Watkinsville, the researchers recommend farmers use a preventive approach by managing for deer by mid-summer. Farmers could put a deer fence around their plots, if their plots are small enough. Otherwise, spreading a fertilizer containing human wastes on the outside boundary of the plots might also keep the deer out, as experienced in this study. Another approach, that would also require a small planting area, would be for farmers to put a netting type of fabric over the plants. When sizing the netting,
considering the amount needed at plant maturity is important. Deer were only a problem in the velvetbean plots and only a major problem in the beginning of September.

Deer also fed on a small amount of sunn hemp, but the damage was considerably minor, unlike as occurred with velvetbean. The damage occurred only to the sunn hemp plants located on the outermost edges of the plantings which had slightly smaller growth than the plants in the middle of the plot. Perhaps the height of the sunn hemp, which reached almost 9 to 10 feet, and it’s thick and dense foliage, made it difficult for the deer to get into the plantings to feed on the innermost plants.
SECTION 4
SUNN HEMP (CROTALARIA JUNCEA)

Biomass Accumulation

Introduction

A rapidly growing tropical legume native to India, sunn hemp (Crotalaria juncea) can accumulate more than 5.6 Mg ha\(^{-1}\) dry matter and 134 kg N ha\(^{-1}\) in 9 to 12 weeks (Reeves, 1998). At 6 WAP total DW ranged from 1.2 to 3.5 Mg ha\(^{-1}\) (Mansoer et al., 1997). The objective of this study was to determine the most effective planting and harvesting dates for sunn hemp as a reference guide for farmers in the Watkinsville and Tifton, GA areas. The most successful dates are defined as the ones that accumulate the largest amount of biomass and best fit into a typical vegetable production rotation plan. The materials and methods section of this portion of the study is discussed in Section 2.

Dry Weight - Tifton

Maximum fresh weight of sunn hemp recorded in Tifton was 46.5±16.3 Mg ha\(^{-1}\) for the May planting harvested 120 DAP. However, this weight is similar to the fresh weights recorded for biomass harvested 120 DAP in the April, June and July plantings which were 41.2±11.0 Mg ha\(^{-1}\), 42.0±2.9 Mg ha\(^{-1}\) and 35.4±8.3 Mg ha\(^{-1}\) respectively. For plantings harvested 120 DAP, the July planting had significantly more biomass (19.8±3.9 Mg ha\(^{-1}\)) based on DW than the May and June plantings (13.3±4.9 Mg ha\(^{-1}\) and 11.3±0.6 Mg ha\(^{-1}\) respectively). The minimum mean biomass fresh weights were recorded for biomass harvested 30 DAP for the April, May and June plantings, these weights, 2.7±1.0 Mg ha\(^{-1}\), 2.8±0.7 Mg ha\(^{-1}\), and 2.8±0.3 Mg ha\(^{-1}\) respectively.
were not significantly different from one another. However, the July planting harvested 30 DAP accumulated 5.9±1.5 Mg ha⁻¹, significantly than the April, May and June plantings harvested 30 DAP. The April planting accumulated the least amount of biomass when harvested 30 DAP with a DW of 0.4±0.1 Mg ha⁻¹ and the May and June plantings accumulated 0.5±0.1 Mg ha⁻¹ and 0.4±0.07 Mg ha⁻¹ respectively. The July (0.7±0.3 Mg ha⁻¹) and April (0.4±0.1 Mg ha⁻¹) plantings were the only plantings to show a significant difference in biomass accumulated 30 DAP.

Sunn hemp harvested 60 DAP accumulated the most biomass when planted in May (5.6±1.0 Mg ha⁻¹), which is not significantly more than the plots planted in June and July with DWs of 4.1±0.4 Mg ha⁻¹ and 4.4±1.2 Mg ha⁻¹ respectively. However, the April planting, with a mean DW of 3.6±0.9 Mg ha⁻¹, accumulated significantly less biomass than the May planting.

For sunn hemp grown in Tifton and harvested 90 DAP, the May planting accumulated the most biomass of 10.1±1.3 Mg ha⁻¹ (mean DW). The April planting accumulated an amount not significantly less (9.4±0.7 Mg ha⁻¹). The June planting accumulated an amount (7.6±1.5 Mg ha⁻¹) significantly less than that accumulated by the plots planted in May and July accumulated the least amount (6.9±1.9 Mg ha⁻¹), not significantly less than that accumulated in June, but significantly less than the amount accumulated in each other month (Figure 4.1).
Figure 4.1 DW (± SE) of sunn hemp (*Crotalaria juncea*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Dry Weight - Watkinsville**

Maximum fresh weight of sunn hemp grown in Watkinsville was for the June planting harvested 90 DAP at 60.7±7.5 Mg ha\(^{-1}\) (Fresh weight) and 13.5±1.6 Mg ha\(^{-1}\) (DW), however, the June planting did not accumulate the most DW. Maximum DW was 15.3±2.3 Mg ha\(^{-1}\) accumulated by the May planting harvested 120 DAP. There was no significant difference, however, between the June planting (13.5±1.6 Mg ha\(^{-1}\)) and the May planting (12.3±0.4 Mg ha\(^{-1}\)) harvested 90 DAP.
The least sunn hemp biomass accumulated in Watkinsville was 1.1±0.14 Mg ha$^{-1}$ (Fresh weight) and 0.17±0.03 Mg ha$^{-1}$ (DW) for the April planting. No significant difference occurred between the April and May plantings harvested 30 DAP (0.56±0.08 Mg ha$^{-1}$) and the April planting harvested 30 DAP was not significantly different from the June and July plantings with DWs of 2.5±0.70 Mg ha$^{-1}$ and 2.5±0.12 Mg ha$^{-1}$, respectively.

Maximum DW for sunn hemp in Watkinsville harvested 60 DAP in Watkinsville was 9.7±0.9 Mg ha$^{-1}$ the June planting. The July planting accumulated significantly less (8.1±0.7 Mg ha$^{-1}$). The May planting accumulated significantly less than both the June and July plantings at 60 DAP with a DW of 5.4±0.72 Mg ha$^{-1}$, while the April planting accumulated 8.1±0.74 Mg ha$^{-1}$, significantly less than all other plantings at 60 DAP (Figure 4.2).
Figure 4.2 DW (± SE) of sunn hemp (*Crotalaria juncea*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Days After Planting, Cumulative Heat Units, Cumulative Heat Units Plus Cumulative Rainfall Units, and Biomass Accumulation**

**Days After Planting and Biomass Accumulation – Sunn Hemp**

The combined model for the two locations, \( \hat{Y} = 0.106 \times \text{DAP} \), where \( \hat{Y} \) is equal to the amount of biomass accumulated in Mg ha\(^{-1}\), and \( r^2 = 0.90 \) can be used to estimate biomass accumulation of sunn hemp as a function of time in DAP. A direct correlation exists between an increase in biomass and an increase in DAP. As seen with the velvetbean model, variability among data points increases with an increase in DAP (Figure 4.3).
Figure 4.3 Biomass accumulation of sunn hemp in dry weight (DW) as a function of days after planting (DAP). Data points are mean of four observations.

Cumulative Heat Units and Biomass Accumulation – Sunn hemp

The model for cumulative heat units and biomass accumulation works well for sunn hemp with relatively little variability among data points. The combined locations fit the model $\hat{Y} = 0.007*\text{CHU}$, where $\hat{Y}$ is equal to the amount of accumulated biomass in Mg ha$^{-1}$, and $r^2=0.90$, shows a proportionate relationship between an increase in CHUs and an increase in accumulated biomass. This model may work as a tool for estimating the biomass accumulation potential of sunn hemp over time based on CHUs (Figure 4.4).
**Cumulative Heat Units and Biomass Accumulation – Sunn hemp**

For sunn hemp, CHU plus CRU and biomass accumulation for sunn hemp were fit to the equation $\hat{Y} = 0.007 \times (CHU + CRU)$, where $\hat{Y}$ equals the amount of DW biomass accumulated in Mg ha$^{-1}$, and $r^2=0.90$. There is a directly proportionate relationship between cumulative heat units plus cumulative rainfall and biomass accumulated displaying a linear pattern. The steady increase in biomass seeming regardless of intermittent rainfall (or CRU) may be a display of drought tolerance in sunn hemp; which is noted in the literature (Figure 4.5).

**Figure 4.4** Biomass accumulation of sunn hemp in dry weight (DW) as a function of cumulative heat units (CHU). Data points are mean of four observations.
Cumulative Heat Units Plus Cumulative Rainfall Units and Biomass Accumulation - Sunn Hemp

![Graph showing the relationship between cumulative heat units plus cumulative rainfall units and dry weight in Mg ha⁻¹. The equation Ŷ = 0.007*(CHU+CRU) and r² = 0.940 is displayed.]

**Figure 4.5** Biomass accumulation of sunn hemp in dry weight (DW) as a function of cumulative heat units (CHU) plus cumulative rainfall units (CRU). Data points are mean of four observations.

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**Nutrient Content**

**Introduction**

Sunn hemp is a versatile cover crop that can be used as a mulch, green manure, or organic fertilizer (Marshall et al., 2002). Knowledge of the nutrients contained in a cover crop is important when implementing a fertilization program for any crop. In Zambia, Steinmaier and Ngoliya (2001) found sunn hemp to have great green manure potential with no fertilizer application. Sunn hemp NIRS (*Crotalaria juncea* cv. NIRS 3) grown in this study contained 232
kg N ha⁻¹, 66 kg P ha⁻¹, and 162 kg K ha⁻¹. Sunn hemp Marejea (*Crotalaria juncea* cv. Marejea) contained 329 kg N ha⁻¹, 79 kg P ha⁻¹, and 280 kg K ha⁻¹. Rupper (2001) reported sunn hemp accumulated 162 kg N ha⁻¹ following broadcast seeding at a rate of 45 to 67 Mg acre⁻¹ and 60 DAP. Marshall et al. (2001) report similar results, showing sunn hemp could accumulate 110 to 140 kg N ha⁻¹, while Fahrney et al. (1987) note *Crotalaria juncea* (cv. Tropic Sun) can contribute 61 to 67 kg N ha⁻¹ to the soil in 60 DAP. In 2002 Marshall et al. in Alabama showed sunn hemp planted in August and harvested in November contained 137 kg N ha⁻¹, 20 kg P ha⁻¹, 74 kg K ha⁻¹, 65 kg Ca ha⁻¹, 18 kg Mg ha⁻¹, 0.003 kg Cu ha⁻¹, 0.07 kg Fe ha⁻¹, 1.01 kg Mn ha⁻¹, 0.03 kg Zn ha⁻¹.

The objective of this portion of the study was to determine approximate target dates for planting sunn hemp and cutting, rolling, or planting into the cover crop according to the nutrient content found in the tissue analysis conducted on the whole plant. The most successful treatments (planting and harvest dates) will be those plantings that accumulate the most nutrients.

**Nitrogen - Tifton**

At 30 DAP no significant difference occurred in N accumulated between each month of planting. Sunn hemp harvested 30 DAP accumulated the most N (14.3±7.6 kg ha⁻¹) when planted in May. This was the maximum N accumulated when velvetbean was harvested 30 DAP. The April, June and July plantings accumulated 11.4±6.5 kg N ha⁻¹, 10.2±5.1 kg N ha⁻¹, and 12.1±1.5 kg N ha⁻¹, respectively.

At 60 DAP there was no significant difference in N production among plantings. However, the May planting accumulated the most N with 159.6±119.8 kg N ha⁻¹ and the July planting accumulated the least with 106.4±39.6 kg N ha⁻¹. The April and June plantings at 60 DAP accumulated 109.7±62.6 N kg ha⁻¹ and 106.8±50.2 kg N ha⁻¹, respectively. For the sunn
hemp harvested 90 DAP there was no significant difference between N accumulated, however, the April planting accumulated the most with $276.8 \pm 103.6$ kg N ha$^{-1}$ and the July planting accumulated the least with $164.1 \pm 54.6$ kg N ha$^{-1}$. The May and June plantings accumulated $253.8 \pm 116.8$ kg N ha$^{-1}$ and $180.5 \pm 64.6$ kg N ha$^{-1}$ respectively. There was no significant difference among plantings harvested 120 DAP with N production ranging from $447.7 \pm 323.6$ kg N ha$^{-1}$ for the April planting to $297.4 \pm 102.0$ kg N ha$^{-1}$ for the June planting (Figure 4.6).

**Figure 4.6** Nitrogen content (± SE) of sunn hemp (*Crotalaria juncea*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.
Phosphorus - Tifton

There was no significant difference among sunn hemp plantings at 120 DAP with P content ranging from 44.9±25.5 kg ha\(^{-1}\) for the April planting to 26.2±11.60 kg ha\(^{-1}\) for the June planting. At 30 DAP there was no significant difference between plantings, with values ranging from 1.5±0.7 to 1.2±0.4 kg P ha\(^{-1}\) for the May and June plantings, respectively. At 60 DAP no significant difference occurred between the plantings with values ranging from 18.9±13.9 kg P ha\(^{-1}\) for the May planting to 6.5±5.8 kg P ha\(^{-1}\) for the July planting. At 90 DAP again no significant difference occurred between plantings with the maximum of 30.8±13.1 kg P ha\(^{-1}\) accumulated by the May planting and a minimum of 15.1±7.6 kg P ha\(^{-1}\) for the June planting (Figure 4.7).
Figure 4.7 Phosphorus content (± SE) of sunn hemp (*Crotalaria juncea*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Potassium - Tifton**

For sunn hemp at 120 DAP, maximum K was accumulated in the April planting (358.7±174.1 kg ha\(^{-1}\)), however, this was similar to the other plantings harvested 120 DAP. At 120 DAP the June planting accumulated the least K at 201.2±45.2 kg ha\(^{-1}\). No significant difference occurred between plantings at 30 DAP, with K content ranging from the maximum of 11.0 kg ha\(^{-1}\) for the July planting to the minimum of 7.7±174.1 kg ha\(^{-1}\) for the June planting. The May planting accumulated the most K at 60 DAP (111.3±49.5 kg K ha\(^{-1}\)) while the July planting accumulated the least (70.6± 26.5 kg K ha\(^{-1}\)), no significance in difference was found for the plantings at 60 DAP. At 90 DAP May accumulated significantly more K at 237.1±83.4 kg ha\(^{-1}\).
than the June and July plantings with July producing the least K at 112.4±64.3 kg ha⁻¹. A significant difference occurred between the May, June and July plantings, however, the April (211.5±57.7 kg K ha⁻¹) and May plantings (237.1±83.4 kg K ha⁻¹) were similar (Figure 4.8).

**Figure 4.8** Potassium content (± SE) of sunn hemp (*Crotalaria juncea*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Other Nutrients - Tifton**

Generally the April planting accumulated more nutrients, however not significantly more than the other plantings except for Mn, Zn, and Ca, all for which June was the only planting that accumulated significantly less than the April planting (Table 3.1). As seen with velvetbean,
copper, zinc, iron, and manganese content in sunn hemp was minimal, while fair amounts of magnesium and calcium were present (Table 4.1).

**Table 4.1** Other Nutrients in Sunn Hemp in Tifton (±SE) in kg ha⁻¹

<table>
<thead>
<tr>
<th>Planted</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvested</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 30</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>3.7±2.2</td>
<td>1.6±0.9</td>
</tr>
<tr>
<td>April 60</td>
<td>0.0±0.0</td>
<td>0.4±0.2</td>
<td>0.4±0.3</td>
<td>0.2±0.1</td>
<td>30.6±9.5</td>
<td>17.0±5.4</td>
</tr>
<tr>
<td>April 90</td>
<td>0.0±0.0</td>
<td>2.4±2.9</td>
<td>0.7±0.4</td>
<td>0.6±0.1</td>
<td>95.3±38.7</td>
<td>43.4±17.2</td>
</tr>
<tr>
<td>April 120</td>
<td>0.0±0.0</td>
<td>2.0±1.5</td>
<td>1.2±1.0</td>
<td>0.9±0.2</td>
<td>183.6±99.4</td>
<td>71.1±30.8</td>
</tr>
<tr>
<td>May 30</td>
<td>0.0±0.0</td>
<td>0.1±0.1</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>4.4±1.3</td>
<td>2.3±1.2</td>
</tr>
<tr>
<td>May 60</td>
<td>0.0±0.0</td>
<td>0.6±0.3</td>
<td>0.3±0.1</td>
<td>0.3±0.1</td>
<td>49.8±24.9</td>
<td>21.2±10.9</td>
</tr>
<tr>
<td>May 90</td>
<td>0.0±0.0</td>
<td>1.1±0.4</td>
<td>0.5±0.2</td>
<td>0.6±0.1</td>
<td>104.4±42.9</td>
<td>45.2±16.6</td>
</tr>
<tr>
<td>May 120</td>
<td>0.1±0.0</td>
<td>1.4±1.0</td>
<td>0.7±0.4</td>
<td>0.8±0.3</td>
<td>98.2±38.9</td>
<td>51.3±35.7</td>
</tr>
<tr>
<td>June 30</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>3.4±1.5</td>
<td>1.6±0.5</td>
</tr>
<tr>
<td>June 60</td>
<td>0.0±0.0</td>
<td>0.7±0.6</td>
<td>0.2±0.0</td>
<td>0.2±0.0</td>
<td>29.8±12.5</td>
<td>15.0±3.8</td>
</tr>
<tr>
<td>June 90</td>
<td>0.1±0.1</td>
<td>0.8±0.3</td>
<td>0.2±0.1</td>
<td>0.4±0.0</td>
<td>58.8±19.6</td>
<td>29.2±9.6</td>
</tr>
<tr>
<td>June 120</td>
<td>0.1±0.1</td>
<td>1.4±0.5</td>
<td>0.4±0.1</td>
<td>0.6±0.1</td>
<td>88.2±38.2</td>
<td>42.4±10.8</td>
</tr>
<tr>
<td>July 30</td>
<td>0.0±0.0</td>
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<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>4.1±1.5</td>
<td>1.9±0.4</td>
</tr>
<tr>
<td>July 60</td>
<td>0.0±0.0</td>
<td>0.5±0.2</td>
<td>0.2±0.1</td>
<td>0.2±0.1</td>
<td>32.4±23.6</td>
<td>13.6±4.6</td>
</tr>
<tr>
<td>July 90</td>
<td>0.0±0.0</td>
<td>0.8±0.4</td>
<td>0.3±0.2</td>
<td>0.3±0.1</td>
<td>47.8±27.4</td>
<td>20.7±10.5</td>
</tr>
<tr>
<td>July 120</td>
<td>0.1±0.1</td>
<td>2.6±1.2</td>
<td>0.9±0.5</td>
<td>1.0±0.2</td>
<td>148.1±64.8</td>
<td>63.3±21.7</td>
</tr>
</tbody>
</table>
Nitrogen - Watkinsville

Means (of 16 repetitions) for time grown show that regardless of the month it was planted, sunn hemp grown 120 days contained the most N (340.6±78.3 kg ha⁻¹) while in general the sunn hemp grown 90 days accumulated 225.2±62.6 kg N ha⁻¹ and the sunn hemp grown 60 and 30 days accumulated 126.8±44.2 kg N ha⁻¹ and 36.7±32.5 kg N ha⁻¹, respectively.

Sunn hemp accumulated significantly more N (83.9 ±20.7 kg ha⁻¹) when harvested 30 DAP from the June planting as compared to the other planting months. However, the June planting also accumulated significantly more N (40.1±4.4 kg ha⁻¹) than the April and May plantings (4.7±1.4 kg N ha⁻¹ and 18.0±1.7 kg N ha⁻¹ respectively).

Sunn hemp harvested 60 DAP from the July planting accumulated the most N (169.0±20.3 kg ha⁻¹) as compared to the other plantings harvested 60 DAP. However there was no significant difference between the July planting and the June planting (151.9±15.6 kg N ha⁻¹). The May planting accumulated 119.7±16.1 kg N ha⁻¹, significantly less than both the June and July plantings, the April planting accumulated 66.8±25.6 kg N ha⁻¹, an amount significantly less than that accumulated in the other plantings.

At 90 DAP the May planting accumulated the maximum N (287.0±80.3 kg ha⁻¹), not significantly more than that accumulated by the June planting (246.5±24.5 kg N ha⁻¹). The April and July plantings accumulated 191.1±23.7 kg N ha⁻¹ and 176.1±39.4 kg N ha⁻¹, not significantly less than the N accumulated by the June planting. The July planting harvested 120 DAP accumulated the most N (450.4±46.5 kg N ha⁻¹) when compared to sunn hemp planted in other months and harvested 120 DAP. There was a significant difference between the May, April and June plantings which accumulated 342.2±28.7 kg N ha⁻¹, 301.3±27.7 kg N ha⁻¹, and 268.5±42.5 kg N ha⁻¹.
kg N ha\(^{-1}\) respectively, and the July planting which accumulated 450.4±46.5 kg N ha\(^{-1}\) (Figure 4.9).

![Nitrogen Content of Sunn Hemp - Watkinsville](image)

Figure 4.9 Nitrogen content of sunn hemp (Crotalaria juncea) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Phosphorus - Watkinsville**

Phosphorus accumulated in 120 DAP was significantly more in the July planting (38.5±2.8 kg ha\(^{-1}\)) than in the other plantings. At 30 DAP the June planting accumulated significantly more P (6.9±1.5 kg ha\(^{-1}\)) than the other plantings. At 60 DAP the June planting (11.9±1.4 kg ha\(^{-1}\) P) accumulated insignificantly more P than the July and May plantings which accumulated 11.2±0.7 kg P ha\(^{-1}\) and 10.2±1.7 kg P ha\(^{-1}\). However, the April planting accumulated significantly less than the other plantings at 5.4±2.3 kg P ha\(^{-1}\). At 90 DAP, greatest
P content was significantly more in the May planting (23.6±3.7 kg ha\(^{-1}\)) than in the other plantings, while the April, June, and July plantings were similar in their accumulation of P, with values ranging from 13.5±2.2 kg P ha\(^{-1}\) to 16.5±5.8 kg P ha\(^{-1}\) (Figure 4.10).

![Phosphorus Content of Sunn Hemp - Watkinsville](image)

**Figure 4.10** Phosphorus content of sunn hemp (*Crotalaria juncea*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Potassium - Watkinsville**

In sunn hemp in Watkinsville, the most K was accumulated in the July planting harvested 120 DAP with 317.6±47.2 kg K ha\(^{-1}\), although this was similar to the K accumulated in the May planting (285.3±43.3 kg K ha\(^{-1}\)), it was significantly more than the K accumulated by the other plantings, April and June with 244.9±9.9 kg K ha\(^{-1}\) and 243.6±13.3 kg K ha\(^{-1}\) respectively. At 90
DAP the July planting accumulated not significantly (209.9±22.6 kg K ha\(^{-1}\)) more than the May and June plantings with 209.3±27.8 and 198.5±9.3 kg K ha\(^{-1}\) respectively. At 60 DAP maximum K was accumulated in the June planting (147.7±20.5 kg K ha\(^{-1}\)), but this was not significantly more than the K accumulated in the July planting (119.5±23.5 kg K ha\(^{-1}\)). The June planting accumulated significantly more K (147.7±20.5 kg K ha\(^{-1}\)) than the April and May plantings (40.4±15.6 kg K ha\(^{-1}\) and 97.2±15.6 kg K ha\(^{-1}\) respectively), however, the K in the July planting was similar to the K accumulated in the May planting (Figure 4.11).

**Other Nutrients - Watkinsville**

At 90 DAP, the Ca accumulation in sunn hemp was significantly greater in the May planting than in the other plantings. The April and June plantings were similar in their accumulation of Ca at 90 DAP, while the July planting only accumulated significantly less Ca than the June planting. Ca accumulation at 120 DAP was similar for the April, May and July plantings, while June was significantly less. For Mg accumulation at 90 DAP, the May planting accumulated significantly more than the June and July plantings, but was similar to the April planting. For Mg at 120 DAP, the May and July plantings accumulated the most and were similar, while the April and June plantings accumulated significantly less. The June planting accumulated significantly less Mg than all the other plantings (Table 4.2).
Figure 4.11 Potassium content of Sunn hemp (*Crotalaria juncea*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP.

**Days After Planting, Cumulative Heat Units, Cumulative Heat Units Plus Cumulative Rainfall Units, and Nitrogen Accumulation**

For sunn hemp, the relationship between DAP and nitrogen accumulation was examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in sunn hemp as a result of DAP. The model developed is $\hat{Y} = 2.64 \times \text{DAP}$, where $\hat{Y}$ is equal to the amount of N in kg ha$^{-1}$ and $r^2 = 0.929$. The scatter plot shows more variability in N accumulated with an increase in time or DAP, particularly after 90 DAP (Figure 4.12).
The relationship between CHU and nitrogen accumulation was also examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in sunn hemp as a result of CHU. The model developed is $\hat{Y}=0.174*CHU$, where $\hat{Y}$ is equal to the amount of N in kg ha$^{-1}$ and $r^2 = 0.821$. The scatter plot shows more variability in N accumulated with an increase in time or CHU and nitrogen accumulation appears to be more positively effected by CHU in Tifton than in Watkinsville (Figure 4.13).

The relationship between CHU + CRU and nitrogen accumulation was also examined to attempt to develop a model that could be used to estimate the amount of nitrogen accumulated in sunn hemp as a result of CHU + CRU. The model developed is $\hat{Y}=0.178*(CHU+CRU)$, where $\hat{Y}$ is equal to the amount of N in kg ha$^{-1}$ and $r^2 = 0.890$. The scatter plot shows increased variability in N accumulated with an increase in time or CHU + CRU and nitrogen accumulation appears to be more positively effected by CHU + CRU in Tifton than in Watkinsville. Overall, when regression analyses were used to determine the above relationships, more variability is seen in N accumulation in sunn hemp than in biomass accumulation (Figure 4.14).
Figure 4.12 Nitrogen accumulation in sunn hemp as a function of days after planting (DAP).

Data points are mean of four observations.
Figure 4.13 Nitrogen accumulation in sunn hemp as a function of cumulative heat units (CHU).

Data points are mean of four observations.
**Figure 4.14** Nitrogen accumulation in sunn hemp as a function of cumulative heat units (CHU) and cumulative rainfall (CRF). Data points are mean of four observations.

**Conclusions**

In Watkinsville, at 120 DAP DW biomass produced was similar for the sunn hemp planted in May and June. DW biomass was also similar for the April and July plantings. In Tifton at 120 DAP, the biomass accumulated in the April planting was similar to the biomass accumulated in the May and June plantings. The April and May plantings accumulated the most DW at 90 DAP than the other plantings.
Table 4.2 Other Nutrients in Sunn Hemp in Watkinsville (±SE) in kg ha\(^{-1}\)

<table>
<thead>
<tr>
<th>Planted Harvested</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 30</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>1.4±0.5</td>
<td>0.7±0.2</td>
</tr>
<tr>
<td>April 60</td>
<td>0.0±0.0</td>
<td>0.5±0.3</td>
<td>0.4±0.3</td>
<td>0.1±0.0</td>
<td>26.1±9.6</td>
<td>8.9±3.3</td>
</tr>
<tr>
<td>April 90</td>
<td>0.0±0.0</td>
<td>0.4±0.2</td>
<td>0.9±0.1</td>
<td>0.6±0.1</td>
<td>84.1±9.7</td>
<td>30.9±3.3</td>
</tr>
<tr>
<td>April 120</td>
<td>0.0±0.0</td>
<td>2.0±1.5</td>
<td>1.3±0.1</td>
<td>0.8±0.1</td>
<td>108.4±14.3</td>
<td>39.0±3.6</td>
</tr>
<tr>
<td>May 30</td>
<td>0.0±0.0</td>
<td>0.7±0.4</td>
<td>0.1±0.0</td>
<td>0.0±0.0</td>
<td>5.9±1.8</td>
<td>2.4±0.4</td>
</tr>
<tr>
<td>May 60</td>
<td>0.0±0.0</td>
<td>0.1±0.0</td>
<td>0.7±0.3</td>
<td>0.6±0.1</td>
<td>55.6±6.8</td>
<td>18.9±3.4</td>
</tr>
<tr>
<td>May 90</td>
<td>0.0±0.0</td>
<td>0.5±0.2</td>
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<td>1.1±0.2</td>
<td>131.7±2.9</td>
<td>40.4±1.5</td>
</tr>
<tr>
<td>May 120</td>
<td>0.1±0.0</td>
<td>0.7±0.2</td>
<td>1.3±0.3</td>
<td>1.3±0.2</td>
<td>119.4±12.8</td>
<td>45.6±4.6</td>
</tr>
<tr>
<td>June 30</td>
<td>0.0±0.0</td>
<td>0.3±0.2</td>
<td>0.4±0.1</td>
<td>0.2±0.0</td>
<td>33.1±9.4</td>
<td>11.6±3.1</td>
</tr>
<tr>
<td>June 60</td>
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<td>0.6±0.1</td>
<td>0.7±0.1</td>
<td>75.6±7.0</td>
<td>27.2±2.4</td>
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<tr>
<td>June 90</td>
<td>0.2±0.1</td>
<td>1.3±0.6</td>
<td>1.2±0.3</td>
<td>0.8±0.2</td>
<td>74.9±46.7</td>
<td>28.9±11.1</td>
</tr>
<tr>
<td>June 120</td>
<td>0.1±0.1</td>
<td>1.4±0.3</td>
<td>1.0±0.1</td>
<td>0.7±0.1</td>
<td>69.3±8.3</td>
<td>28.7±11.1</td>
</tr>
<tr>
<td>July 30</td>
<td>0.0±0.0</td>
<td>0.3±0.0</td>
<td>0.2±0.0</td>
<td>0.2±0.0</td>
<td>11.7±2.9</td>
<td>5.0±0.8</td>
</tr>
<tr>
<td>July 60</td>
<td>0.1±0.0</td>
<td>1.0±0.1</td>
<td>0.7±0.1</td>
<td>0.5±0.1</td>
<td>41.4±2.8</td>
<td>16.9±0.7</td>
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<tr>
<td>July 90</td>
<td>0.1±0.1</td>
<td>1.3±0.3</td>
<td>1.2±1.0</td>
<td>0.5±0.2</td>
<td>42.8±3.8</td>
<td>20.6±5.1</td>
</tr>
<tr>
<td>July 120</td>
<td>0.1±0.0</td>
<td>3.8±2.2</td>
<td>3.3±2.2</td>
<td>0.7±0.1</td>
<td>108.6±42.9</td>
<td>45.6±5.0</td>
</tr>
</tbody>
</table>

Mean DW production of sunn hemp in Watkinsville was 12.85 Mg ha\(^{-1}\) for 120 DAP and 11.02 Mg ha\(^{-1}\) for 90 DAP, so although it would be recommended to grow the sunn hemp for a full 120 days, this would allow some flexibility for a farmer to fit sunn hemp into a late summer, early fall or early winter vegetable crop rotation. In Tifton, a grower may derive good soil-building benefits from sunn hemp planted in April, May, June, or July and cut 60 to 120 DAP, giving the grower flexibility as to how they can fit sunn hemp into a rotation with their main cash crop.
The April and May plantings harvested 90 DAP also provided substantial biomass (12.1 Mg ha$^{-1}$ and 11.3 Mg ha$^{-1}$, respectively).

The May and June planting of sunn hemp grown in Watkinsville were similar for DW biomass when harvested 120 DAP. However, biomass harvested 90 DAP from the May and June plantings was also similar. Little difference occurred in the DW production of the April, May, June, and July plantings harvested 120 DAP, or the May, June, and July plantings harvested 90 DAP. This small amount of difference in yields of DWs may provide opportunity for sunn hemp to be used in a vegetable production rotation plan.

At 60 DAP there was not a significant difference among plantings for N content in Tifton. The N accumulated at 120 DAP was similar for the April, May and July plantings. The June planting did not perform well, however this may be due to a problem in the processing of the sample to be analyzed by the lab because the other weights for the month of June, regarding N content show a fairly consistent pattern with the other months. Harvesting at 90 DAP also provides substantial N content of above ground sunn hemp litter.

Mansoer et al., (1997) report N concentration reached a maximum at 3 weeks after planting (WAP), ranging from 33.5 to 57.6 g kg$^{-1}$ in leaves and 18.1 to 34.3 g kg$^{-1}$ in stems. Concentrations of N ranged from 39.6 to 46.8 g kg$^{-1}$ in leaves and from 11.3 to 15.7 g kg$^{-1}$ in stems at 9 WAP (Mansoer et al., 1997). In our study, at 60 DAP in Tifton sunn hemp had an N concentration of 28.1 g kg$^{-1}$ for the entire above-ground biomass. Concentrations of N in Tifton reached a maximum at 120 DAP (16 WAP), with 32.7 g kg$^{-1}$ for total above-ground matter. In Watkinsville at 60 DAP sunn hemp had an N concentration of 27.9 g kg$^{-1}$ with a maximum N concentration of 46.7 for the July planting harvested 120 DAP. Total accumulation of N at 12 WAP was 136 kg ha$^{-1}$ in one Alabama location and 120 kg ha$^{-1}$ at 9 WAP in another Alabama
location (Mansoer et al., 1997). In our study, N accumulation in sunn hemp at 90 DAP (approximately 12 WAP) in Tifton was 225.4 kg N ha\(^{-1}\) and 225.2 kg N ha\(^{-1}\) in Watkinsville.

The Phosphorus accumulated in sunn hemp in Tifton was similar for all plantings except the June planting at 120 DAP. The May planting, however, performed better than the other plantings for all other treatments (DAP). At 120 DAP there was no significant difference in K content between the April planting and the other plantings. The June planting again performed the worst of all the plantings with the least K content.

In Watkinsville at 120 DAP the most nitrogen in sunn hemp was significantly more in the July planting than in the other plantings. The April planting accumulated a substantial amount of N as well. The biggest advantage from N for sunn hemp in Watkinsville is obtained after 120 days, however, substantial amounts of N were also accumulated at 90 DAP for the May and June plantings. At 60 DAP in Watkinsville for sunn hemp, phosphorus content was similar among all plantings except the April planting which accumulated significantly less than the other plantings. At 90 DAP, phosphorus content was significantly greater in the May planting than the other plantings. At 120 DAP, phosphorus content was significantly greater for the July planting than the other plantings. Potassium accumulation at 60 DAP was greatest in the June planting, however the June and July plantings were similar, while the May and April plantings produced significantly less K than the June planting. At 90 DAP K accumulation was similar among the May, June, and July plantings while the April planting accumulated significantly less. Potassium accumulation at 120 DAP was similar among plantings. At 60 DAP the June planting accumulated the most Ca and Mg. For Ca content at 90 DAP the plantings were similar, while for Mg at 90 DAP the May planting accumulated significantly more Mg than the April planting. At 120 DAP the May planting accumulated the most Ca, and Mg. These findings suggest sunn
hemp may fit well into rotation with vegetable crops and other cover crops due to the significant amount of biomass and nutrients accumulated in a fairly short time (60 DAP), though cutting and/or incorporating the sunn hemp 90 to 120 DAP is optimal.
Table 4.3 Test of Heterogeneity for Dry Weight Equals Cumulative Heat

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<td>0.00663</td>
<td>33.68</td>
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<td>Velvetbean</td>
<td>0.00378</td>
<td>21.86</td>
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Table 4.4 Test of Heterogeneity for Dry Weight Equals Cumulative Heat Units Plus Cumulative Rainfall Units

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<th>$P&gt;t$</th>
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<td><strong>Sunn hemp</strong></td>
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<td>Slope: CHU</td>
<td>0.00520</td>
<td>10.98</td>
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<td>Slope: CRU</td>
<td>0.29761</td>
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<td>0.09031</td>
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<td><strong>Velvetbean</strong></td>
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<td>Slope: CHU</td>
<td>0.00502</td>
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<td>Slope: CRU</td>
<td>-0.2239</td>
<td>-2.17</td>
<td>0.0374</td>
<td>0.10343</td>
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Using separate intercepts for the sunn hemp at the two locations the $P$-value=0.0803 so the two locations were combined to fit one model with no intercept. The test of heterogeneity for both models is among locations.
SECTION 5

CONCLUSIONS

Maximum dry weight for Velvetbean in Tifton was for the April planting at 120 DAP, although there was no significant difference among dry weights for all the plantings harvested at 120 DAP except for the June planting; which accumulated significantly less DW biomass than the other plantings due to a suspected virus. The April and May plantings also accumulated substantial DW biomass at 90 DAP. In Watkinsville, the May planting of velvetbean accumulated substantial biomass at 90 DAP, unfortunately few samples were taken for this location due to detrimental damage from deer browsing and caterpillar feeding.

In Tifton N content of the April, May and July plantings were substantial when harvested 90 and 120 DAP, the June planting did not perform as well due to a suspected virus. N content of velvetbean in Watkinsville was also substantial for the plantings harvested 90 to 120 DAP. In Tifton the April planting performed best in producing more of the other nutrients analyzed in this study. For the other nutrients analyzed in velvetbean grown in Watkinsville the content shows a pattern of increasing to 90 DAP and then decreasing to 120 DAP.

The data collected for the velvetbean grown in Tifton and in Watkinsville, suggest a farmer may benefit as well from growing velvetbean 90 days as from growing velvetbean 120 days. This allows a short time frame for growing velvetbean as a green manure/cover crop and helps it fit easier into a vegetable crop production system. Hence, velvetbean appears to help rejuvenate and replenish depleted soils, and as a cover crop can provide shorter fallow periods (Jordan, 1998, Phatak et al., 2002) by providing large amounts of biomass and nutrients in a
relatively short time. However, when planting velvetbean one must take care in protecting the crop from deer browsing and insect pests using biological methods when possible.

Sunn hemp also performed well in biomass accumulation and nutrient content in both locations. Sunn hemp also generally performed as well after 90 DAP as after 120 DAP, with substantial amounts of accumulated biomass and nutrients contained in aboveground plant tissue. The July planting in Tifton performed best in DW production at 120 DAP, it accumulated significantly more DW biomass than the May and June plantings, but not significantly more than the April planting. The July planting of sunn hemp in Tifton harvested 30 DAP accumulated a significantly larger amount of biomass as compared to the April, May and June plantings at 30 DAP. Sunn hemp overall performed best in accumulated biomass in Tifton most likely due to the warmer temperatures because of Tifton’s more southern location. Sunn hemp performed well in biomass accumulation in Watkinsville at 60 DAP. Sunn hemp accumulated substantial N and other nutrients at 60, 90, and 120 DAP in both locations. This suggests sunn hemp may perform well as a late summer/early winter cover crop sown in mid summer, or as an early summer cover crop with a short fallow; which allows flexibility for fitting sunn hemp into a vegetable production rotation plan.

When considering the relationships discovered between CHUs, CRF, and DAP versus accumulated biomass one can see from the figures that essentially for both cover crops variability increases with time as a function of CHUs, CRF, and DAP. However, with sunn hemp a line fit easier with each model, indicating a fairly good equation for estimating potential biomass accumulation based on the different time variables. The CHU plus CRF versus cumulative biomass figure shows sunn hemp as being less affected by intermittent water, displaying a drought tolerant characteristic unlike velvetbean and as mentioned in the literature.
(Fahrney et al., 1987; Russell et al., 2002), which could make it valuable in filling a space between summer harvest and fall planting. In general sunn hemp and velvetbean may work well as cover crops in the Watkinsville and Tifton, GA areas due to the flexibility for growing the cover crops throughout the growing season. This allows a few opportunities for growing the legumes in rotation with cool or warm season vegetable crops because of the substantial biomass and nutrients accumulated in the cover crops in a relatively short time.
REFERENCES


### APPENDIX A: PLOT PLAN FOR ‘GA BUSH’ VELVETBEAN

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APPENDIX B: PLOT PLAN FOR SUNN HEMP

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