INVESTIGATION OF SUNN HEMP AS A COVER CROP AND A SEED CROP IN FLORIDA

By

ALYSSA HEH-SOON CHO

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2010

To my family

ACKNOWLEDGMENTS

I first and foremost thank my supportive parents and brother for their encouragement throughout my whole life, and especially during this degree. I acknowledge my advisor, Dr. Carlene Chase, for providing me with this opportunity and her constant support. I thank my committee members for their involvement in this degree and their guidance; Dr. Danielle Treadwell, Dr. Rose Koenig and Dr. Alan Hodges. I also thank Dr. Gregory MacDonald for his advice and support.

I extend a million thanks to Michael Alligood for all of his help, especially with those pesky rabbits! I am forever grateful to those who helped with my fieldwork at Rosie's, especially during the harvests of my monstrous plants. I thank Buck Nelson and the entire Citra crew for their assistance with my research. I also acknowledge my statistics consultants Jeremy Gaskins and Lei Bai for their help with data analysis.

I thank all of my friends, both old and new, for their companionship, advice, and all the shared laughter. I thank everyone in the Horticultural Sciences Department for making this a wonderful experience!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RCBD	Randomized complete block design
MAS	Months after seeding
PAR	Photosynthetically active radiation
LAI	Leaf area index

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

INVESTIGATION OF SUNN HEMP AS A COVER CROP AND A SEED CROP IN FLORIDA

By

Alyssa Heh-soon Cho

August 2010

Chair: Carlene A. Chase
Major: Horticultural Science

Sunn hemp (*Crotalaria juncea* L.) provides farm system benefits when incorporated into a cropping system as a cover crop. Sunn hemp rapidly attains canopy closure when planted at appropriate densities, providing weed suppression, biologically fixed nitrogen (N), and soil stability. The limited adoption of sunn hemp as a cover crop in the United States has been attributed to the lack of consistent and affordable domestic seed. Three studies were conducted in 2008 and 2009 to evaluate the potential for sunn hemp as both a cover crop and as a seed crop in Florida. A field study was conducted to evaluate the phenotypes of sixteen accessions of sunn hemp. The sixteen accessions could be separated into two distinct groups based on several vegetative and reproductive parameters. Accessions in Group 1 were tall with few branches, and produced few to no flowers and pods. These accessions included 2 (PI234771), 3 (PI248491), 7 (PI295851), 14 (PI468956), 15 (PI561720), and 16 (PI652939). Accessions in Group 2 flowered early (49-66 days after seeding) and seemed to be daylength insensitive. These accessions were shorter in stature, and lower in biomass than those in Group 1, but had more branches, flowers, and seed produced. These included accessions 1 (PI207657), 4 (PI250485), 5 (PI250486), 6

(PI250487), 8 (PI314239), 9 (PI322377), 11 (PI346297), 12 (PI391567), and 13 (PI426626).

A second field study was conducted in 2008 and 2009 to investigate the effects of seeding rates and removal of apical dominance on weed suppression and seed production. Three seeding rates were used, a representative seed production rate of 11 kg/ha, an intermediate seeding rate of 28 kg/ha, and a cover crop seeding rate of 45 kg/ha. Apical dominance was broken by cutting the main stem at 3, 4, and 5 weeks after planting and comparing its growth habit with an uncut treatment. A weedy fallow was added in 2009, and in comparison to the weedy fallow, all three seeding rates had lower total weed biomass, but were not significantly different from one another. A grower might utilize a lower seeding rate and still obtain weed suppression comparable to the recommended cover crop seeding rate. Cutting to break apical dominance had no significant effect on weed suppression and on flowering, but did induce branch formation.

A third study was conducted to evaluate the economics of utilizing sunn hemp as a cover crop. Partial budgets were prepared for five summer fallow treatments; sunn hemp (*Crotalaria juncea* L.), velvet bean [*Mucuna deeringiana* (Bort) Merr.], cowpea [*Vigna unguiculata* (L.) Walp. cv. Iron Clay], sorghum sudangrass [*S. bicolor x S. bicolor var. sudanese* (Piper) Stapf.], and tillage. These treatments are compared for weed suppression, nitrogen contribution, and the potential impacts on a following cash crop of squash. Sunn hemp was the least expensive summer fallow treatment, followed by velvet bean, cowpea, sorghum sudangrass, and tillage.

CHAPTER 1
INTRODUCTION

Sustainable Cropping Systems

Organic and sustainable crop production systems rely on an integrated approach to crop management. Sustainable crop production attempts to minimize off-farm inputs and environmental impacts while maintaining an economically viable enterprise. Two major challenges that organic and sustainable growers face are weed and nutrient management. Florida's sandy soils require nitrogen (N) mitigation and without synthetic fertilizers organic growers must look for alternative nutrient sources. According to the National Organic Program (NOP), organic growers must use preventative measures, crop rotation, soil and crop nutrient management, cultural practices and mechanical or physical methods for controlling weed and pest populations (USDA-AMS 2000). Weeds can be managed using fully biodegradable mulches, mowing, hand weeding, livestock grazing, with the use of flame or heat, and plastic or synthetic mulches (USDA-AMS 2000). While these measures provide organic growers with several options for weed control, they are all heavily reliant on human labor.

Summer in Florida is hot and inhospitable to crop production due to the high pest and disease pressures. Many growers in Florida opt to leave their fields in a weedy fallow during summer months, which can lead to the augmentation of the weed seed bank in following cash crops (Collins et al. 2007). Weed management in conventional production systems during these summer months is often through use of synthetic herbicides. However, non-synthetic herbicides are expensive and have limited efficacy and therefore, organic growers must focus on cultural and physical control methods to manage their weeds during fallow periods. An alternative to a weedy fallow during the summer in Florida is cover crop utilization. The primary reason for using a cover crop for weed control is to replace an unmanageable weed population with a manageable cover crop (Teasdale 1996). Cover crops can build organic matter, reduce soil erosion by providing soil stability and suppress weeds through competition, modification of the soil environment, and in some cases, allelopathy.

Sunn Hemp (*Crotalaria juncea* L.)

Cover crops used for weed management provide long-term ecological benefits to cropping systems. Sunn hemp (*Crotalaria juncea* L.) is a commonly used leguminous cover crop and important worldwide as a fiber crop (Purseglove 1974; Cook and White 1996). During a short (60 to 90 days), frost-free growing period, sunn hemp rapidly establishes itself providing biomass and biologically fixed N for use as a green manure. Wang et al. (2005) found that sunn hemp retains the most N and phosphorus (P) due to the high production of biomass and high N content in comparison with other cover crops, such as cowpea, velvetbean, and sorghum sudangrass, and a weedy fallow. Based on this study, Wang et al. determined that sunn hemp serves as an ideal cover crop, retaining 94% of total N and 83% of inorganic P.

Biomass production of sunn hemp has been reported in the range of 5.9-7.6 MG ha^{-1} (Mansoer et al. 1997; Balkcom and Reeves 2005). According to Schomberg et al. (2007), growers in most of the South could expect to produce 4.5-9 MG ha^{-1} of biomass from sunn hemp in 90 days. The considerable biomass production provides excellent canopy closure, leading to weed suppression and also serves as green manure for the following cash crop. Balkcom and Reeves (2005) reported an above ground N content of sunn hemp of 144 kg ha^{-1} at first frost (14 weeks after planting). This is comparable to Mansoer et al. (1997) who reported 120 kg ha^{-1} of N at 9-12 weeks after planting. Factors that determine biomass and N content of sunn hemp are planting date and length of growing season (Schomberg et al. 2007).

Root-knot nematodes are major pests in many agricultural crops grown in the Southeastern United States. Options for the suppression of root-knot nematodes in organic systems are limited and cultural methods to manage these pests are vital for organic cropping systems (Wang et al. 2003). The use of suppressive cover crops can also reduce the need for soil fumigants in conventional cropping systems. The 'Tropic Sun' cultivar, has been shown to be resistant and capable of suppressing root-knot nematode populations, and can be used as an alternative to nematicides in organic systems (Rotar and Joy 1983). The resistance to root-knot nematodes makes sunn hemp an excellent cover crop to rotate between crops that are susceptible to damage by root-knot nematodes, such as potatoes and tobacco (White and Haun 1965).

The inflorescence of sunn hemp is a terminal open raceme that grows to 25 cm in length with deep yellow (sometimes reddish) flowers, with indeterminate flowering (Purseglove 1974). Cross-pollination occurs extensively and self-pollination occurs after the stigmatic surface has been stimulated naturally or mechanically. Large insect species, such as *Xylocopa* or *Megachile* genera are needed for effective pollination and the lack of locally available pollinators could lead to ineffective pollination.

A commercially available cultivar of sunn hemp, 'Tropic Sun', is photoperiod sensitive, and flowers in response to short days (White and Haun 1965). Nanda (1962) also recognized the importance of photoperiod sensitivity in flowering of sunn hemp. Plants sown at different times of the year with photoperiods longer than the inductive photoperiod had branches that grew until the photoperiod decreased to below 13 hours in August and then became inductive to flower bud initiation (Nanda 1962). Due to the photoperiod sensitivity of commercially available cultivars of sunn hemp and the consequential lateness in flowering, seed production in the continental US is minimal (Cook and White 1996). Production is limited to areas with short-days and extended frost-free periods that allow for reliable and good quality seed (Cook and White 1996). Commercial production areas of sunn hemp seed, such as Hawaii and South Africa, are overseas, making the domestic price of seed high. The added inability of growers to produce their own seed after the initial purchase has further deterred adoption of this cover crop.

If sunn hemp is grown for seed production, cultural practices that encourage additional flowering are desirable. Abdul-Baki et al. (2001) used the assumption of optimal flower fertilization and growth conditions in concluding that cutting the main stem of sunn hemp at 90 cm above the soil surface leads to increases in the numbers of primary and secondary branches and, therefore, an increase in the total number of flowers per plant in comparison to a control and other cutting treatments. Although Abdul-Baki et al. (2001) were unable to carry out the experiment through seed set due to hurricane damage; the authors infer that from their data that the treatment (cutting at 90 cm) that produced the most flowers would most likely have the highest seed harvest as well.

Although sunn hemp is an excellent cover crop, growers are hesitant to incorporate it into their cropping system due to the high cost of seed and unreliable seed sources. The high cost of seed is amplified by the high recommended seeding rates for cover crop use.

Objectives

The overall goal of this research is to encourage the use of sunn hemp in Florida by demonstrating its benefits as a cover crop and seed crop. The three specific objectives were to: 1) evaluate the phenotypes of 16 accessions of sunn hemp from the USDA-ARS (Griffin, GA) germplasm collection in order to select accessions of sunn hemp that have potential for seed production in Florida and can possibly be used in future breeding projects; 2) investigate the effects of cultural practices of planting densities and breaking apical dominance of sunn hemp on weed suppression and seed yield to determine recommended practices for growers depending on the ultimate goal of the grower for the crop and, 3) conduct an analysis of the farm system benefits and economic impacts of sunn hemp use as a cover crop in Florida.

This work is part of a larger project funded by the Southern Region Sustainable Agriculture Research and Education grant LS08-205 and similar studies were conducted in Griffin, Georgia and Lajas, Puerto Rico.

Hypotheses

It is hypothesized that at least one accession will show potential for seed production in Florida while maintaining the beneficial qualities of a cover crop. It is also hypothesized that seeding density and breaking apical dominance of sunn hemp will impact plant growth and subsequent seed production, as well as the weed suppression of the standing crop. Additionally, it is hypothesized that implementation of sunn hemp as a cover crop during the summer fallow in Florida will be economically feasible for growers.

CHAPTER 2
PHENOTYPIC CHARACTERIZATION OF SIXTEEN ACCESSIONS OF SUNN HEMP FOR VEGETATIVE AND REPRODUCTIVE TRAITS

Introduction

Organic production requires an integrated approach to management to maximize yields and remain competitive in a primarily conventional marketplace. One fundamental crop management for tenet organic producers is utilizing a systems approach. The regulations for the National Organic Program cite crop rotation as one the primary methods for prevention of weed and pest infestations (USDA-AMS 2000). Additionally, if preventative measures of crop rotation and cultural practices are insufficient, an organic producer may use other practices for weed and pest control, including the use of fully biodegradable mulches and plastic mulch for weed control (USDA-AMS 2000). Inclusion of a leguminous cover crop in a cropping system provides an on-site source for biologically fixed nitrogen, suppresses weed and pest populations, and provides soil stability and soil erosion prevention (Lu et al. 2000). Cover crop species are most effective in smothering and suppressing weed populations when they emerge and establish rapidly (Lu et al. 2000). In addition to rapid establishment, high biomass production of the cover crop creates effective competition with weed species for resources (Lu et al. 2000).

Sunn hemp (*Crotalaria juncea* L.) is a leguminous cover crop, with multiple farming system and economic uses. In India, it is one of the most important green manure crops and second to kenaf (*Hibiscus cannabinus* L.) in importance as a bast fiber crop, in addition to being one of the most widely grown green manures in the tropics (White and Haun 1965; Purseglove 1974). Sunn hemp can produce 5.9-7.6 Mg ha^{-1} of biomass in 12-14 weeks (Balkcom and Reeves 2005; Mansoer et al. 1997).

Additionally, sunn hemp can produce 120-144 kg/ha of N in 9-14 weeks (Balkcom and Reeves 2005; Mansoer et al. 1997). In addition to weed suppression and accumulation of biomass and nitrogen, a commercially available cultivar of sunn hemp, 'Tropic Sun', has been shown to be resistant to and capable of suppressing root-knot nematode populations, and can be used as an alternative to nematicides (Rotar and Joy 1983).

Disadvantages of cover crops include costs and management involved in adding another crop to the farming system (Teasdale 1996). These costs can include seeding as well as the cost of terminating and incorporating the cover crop. Recent interest in sunn hemp as a cover crop created an imbalance between supply and demand of sunn hemp seed. This imbalance also contributed to the high cost of sunn hemp seed due to the limited seed sources (Abdul-Baki et al. 2001). The limitation in seed availability has been reported since 1946 as being the major factor in prevention of widespread use of sunn hemp as a soil-improving crop (McKee et al. 1946).

Currently, sunn hemp seed production areas limit the amount of available seed and control the market price of seed (Abdul-Baki et al. 2001). The cultivar developed by the University of Hawaii and the USDA-NRCS, 'Tropic Sun', has been the focus for commercial seed production (USDA 1983; Abdul-Baki et al. 2001). Although 'Tropic Sun' grows well in the Southeastern US, the environmental conditions for seed production cannot be met in sub-tropical regions where the first fall frost prevents effective seed set (White and Haun 1965). Commercial seed production of sunn hemp occurs primarily in tropical locations where photoperiods that are inductive to flowering are abundant and frost is not an issue. Expansion of sunn hemp seed production to a domestic location, such as South Florida, could create a local seed source to meet market demands while simultaneously lowering the cost of seed (Abdul-Baki et al. 2001). Identifying cultivars of sunn hemp with that are better adapted for seed production than ‘Tropic Sun’ in the continental U.S. could also encourage greater utilization of sunn hemp as a cover crop.

The USDA-ARS Plant Genetic Resources Conservation Unit (PGRCU) (Griffin, GA) has twenty-two accessions of sunn hemp from Angola, Brazil, Guadeloupe, India, Mozambique, Myanmar, Nigeria, Pakistan, South Africa, the former Soviet Union, Sri Lanka, Taiwan and the USA (Morris and Kays 2005). Seeds of sixteen accessions (Figure 2-1) from this collection were available in sufficient quantity for evaluation in Florida. The objective of this research was to evaluate the sixteen accessions of sunn hemp for vegetative and reproductive characteristics for cover crop and commercial seed production potential in Florida. It is hypothesized that at least one accession will show potential for seed production in Florida while maintaining the beneficial qualities of a cover crop.

Materials and Methods

This experiment was conducted between May and December in 2008 and 2009 in different locations year to year at Rosie’s Organic Farm, Gainesville, Florida. The experimental design was a split-plot with main plots arranged in a randomized complete block with four replications. The main plot treatments consisted of three planting dates; May, June, and July to determine the effect of planting date on vegetative and reproductive parameters. The main plots’ size was 5.64 m by 18.29 m. The sub-plot treatments consisted of 16 accessions of sunn hemp from the USDA germplasm collection (Griffin, GA) (Table 2-1) and each sub-plot had a target population of 20 plants. Since seed was limited, only 100 seeds per accession per planting date, scarification and transplanting were utilized to maximize germination and survival. Seeds were hot water scarified by dipping in boiling water, and inoculated with cowpea-type *Rhizobium* (Nitragin, Milwaukee, WI) before seeding. Seeds were then planted into 5.72 cm by 5.72 cm size Jiffy peat pots with Fafard (Apopka, FL) organic potting mix in a greenhouse. Seeding occurred on May 5, June 5 and July 7 in 2008 and May 1, June 1 and July 1 in 2009. Seedlings were watered daily, by hand. Seedlings were transplanted by hand in two rows spaced 45.72 cm apart on 1 m bed centers approximately 3 weeks later (May 26, June 25 and July 23 in 2008 and May 26, June 25 and July 23 in 2009). No fertilizer or irrigation was used in the field. Lodging was addressed by performing a tomato weave through the plants using twine and 6 foot bamboo stakes, placed between every other plant.

Vegetative Phenotypic Characteristics

Two months after seeding (MAS), 6 plants from each plot (24 plants total per accession per planting date) were randomly selected for data collection. Plant height, was measured from the soil surface to the top leaf on the tallest branch. Plant width was measured on the broadest point of the plant. The number of nodes and internodes were counted on the main stem up to the terminal bud. The numbers of primary and secondary branches were determined. One leaf from the main stem of each sample plant was harvested and a leaf scan was taken using an Area Meter (LI-3100, Li-Cor Inc., Lincoln, NE) to determine leaf area.

The apical dominance of the accessions (no apical dominance, or apically dominant) was determined visually at 4 MAS. Apically dominant accessions had a main stem that was clearly dominant, with few to no branches. If branches were present, they were shorter than 3 m in length and often clustered slightly below the apical meristem. Accessions that displayed broken apical dominance had main stems that were difficult to determine, with many primary branches growing from the center of the plant where the main stem would typically be found. At 4 MAS, primary lateral branches greater than 1 meter in length were counted. Photosynthetically active radiation (PAR) and leaf area index (LAI) were measured using an AccuPar Ceptometer (Decagon Devices, Pullman, WA) at 4 MAS. Readings were taken at midday with no cloud cover. An unobstructed reading was taken from above the sunn hemp canopy if possible, and if not, an unobstructed reading was taken at 1 m above ground. Below canopy readings were taken by inserting the probe parallel to the sample plants. Five months after seeding the sample plants were harvested at the soil surface from each plot. The samples were dried at 120°C for at least 72 h, or until dry, and dry weights were taken. Final harvests were on August 28, October 29, November 24 in 2008 for the first, second, and third planting dates, respectively. In 2008 earlier harvests were due to Tropical Storm Fay and an early frost on October 29, 2008. In 2009 final harvests were on September 29, November 3, and December 2 for the first, second, and third planting dates, respectively.

Reproductive Phenotypic Characterization

Days from seeding to date of first open flower were recorded. At 2 MAS the number of open flowers per plant was determined. Four months after seeding (MAS) a visual evaluation was conducted to determine the earliness of flowering of the accessions (early, intermediate or late). Early flowering was defined as accessions with the majority of branches having mature pods, but also some open flowers. Intermediate flowering meant that the majority of branches had open flowers, and immature pods may have been present. Late flowering accessions had the majority of branches with no flowers or buds with non-open flowers or a few open flowers but no seedpods. At 4 MAS, numbers of flowers and/or seedpods on the branches were also determined.

Seedpods were harvested from the same 6 sample plants used to assess vegetative parameters. All seed data were collected per 6 plants, rather than by individual plant. Seedpods were harvested at maturity (rattle-stage) and weekly thereafter. Mature pods were counted and seed weights were determined. All seedpods, both mature and immature (green pods), were harvested at final harvest (5 months after seeding). Green pods were counted and were dried at 120°C for at least 72 h and dry weights were recorded.

Data Analysis

All statistical analyses were performed using SAS® statistical software, versions 9.0 and 9.2 (Cary, NC). Analysis of variance was performed using the MIXED procedure and least square means were compared using the DIFF option. Prior to analysis, square root transformations were performed on quantitative data, including the number of days to flowering, the number of open flowers, the number of mature seed pods, the number of immature seed pods, the mature seed weight (g), the immature pod weight (g), the number of primary branches at two months, the number of primary branches at four months, and the number of leaves to approximate normality. Photosynthetically active radiation (PAR) penetrating the canopy was expressed as a fraction of unobstructed PAR measured at 1 m aboveground. A logit transformation was applied to PAR readings to better approximate normality. When considering the proportions of lateral branches that flowered or produced pods, and those that both flowered and had pods, PROC GLIMMIX was employed to allow for a logistic model.

For each of the variables, the model under consideration included fixed effects terms for the accession, year, and planting date. An accession by planting date interaction term was also used. A random effects term for the planting block, nested within planting date, was integrated into the model. Pairwise means comparisons were conducted by using the step-down Student-Newman-Keuls method to control the false discovery rate (FDR) at the 0.05 level of significance. The FDR accounts for the number of false rejections that a test produces, so that the number of false rejections will be on average 5%. The MIXED and GLIMMIX procedures do not automatically perform this test so it was necessary to calculate the mean groupings by sequentially comparing the T-test statistics with the studentized range critical values.

In addition to univariate mean comparisons, the Hotelling's T^2 test of multivariate mean equality was also implemented. The goal was to find similar groups of the accessions based on multiple variables. This goal was accomplished by focusing on the two types of phenotypic parameters: vegetative and reproductive. For the vegetative parameters, the variables considered were: plant height, plant weight, leaf area, number of leaves, and number of primary branches. The reproductive phenotypic parameters were represented by the variables: seed weight, number of pods, number of immature pods, and immature pod weight. Code to perform the Hotelling's test was written in PROC IML, using output from other SAS procedures including GLM and CORR. Since the Hotelling's test is performed 120 times to compare each accession to all others, it was necessary to utilize a method to control the overall error. As before, a method was chosen to control the false discovery rate by comparing the ordered p-values of the individual tests to 0.05 divided by the ordered test number. To interpret the results, graphics were constructed by connecting the accessions that were not significantly different (see Figures 2-1 & 2-4). Lines were arbitrarily drawn and do not signify the level of separation between accessions.

One challenge was that for five of the sixteen accessions (accessions 2, 3, 7, 14, and 15) all or almost all of the plants failed to flower during the five-month experimental period. Such accessions had zero values for variables that included flowering and seed production data and were excluded from some statistical analyses.

Results and Discussion

Vegetative Parameters

Vegetative parameters were analyzed using both multivariate and univariate analyses to understand the phenotypic differences between accessions. A Hotelling's T test was conducted using the parameters of plant height at 2 months after seeding (MAS), total number of leaves per plant at 2 MAS, leaf size at 2 MAS, total branches (primary) at 4 MAS, and plant weight at final harvest (5 MAS). Based on these parameters, Figure 2-1 was created by using lines to connect accessions that were not significantly different from one another. The length of the line does not reflect the level of separation of the accessions. These vegetative parameters separated the accessions into two groups, which is consistent with field observations. Accessions in Group 1 (accessions 2, 3, 7, 10, 14, 15, and 16) demonstrated erect growth, larger leaves, higher plant biomass, and fewer branches than accessions in Group 2 (1, 4, 5, 6, 8, 9, 11, 12, and 13). Figure 2-2(a) is an example of accessions from Group 1, and 2-2(b) is an example of Group 2 accessions.

The results of the univariate analysis of each vegetative parameter can be found in Table 2-2. Similar patterns appeared in the univariate analyses that were also observed in the multivariate analysis. The number of primary branches per plant, plant weight, and leaf size are all significantly different between the two groups of accessions. The number of primary branches per plant was lower in accessions from Group 1 (2, 3, 7, and 15), but the plant weight (2, 3, 7, 10, 14, 15) and leaf size (2, 3, 7, 10, 15, 16) were higher in accessions from Group 1 than Group 2. These three parameters are important for consideration of these accessions for use as cover crops. High biomass accumulation (plant weight) and canopy closure (branching and leaf size) are important characteristics for use of sunn hemp as a cover crop. Accessions in Group 1 displayed these desirable characteristics, and could be used as cover crops. Group 1 included a commercially available cultivar (‘Tropic Sun’), which was accession 14 (PI 468956). These results support those of White and Haun (1965) who predicted that early yielding varieties of sunn hemp, such as those in Group 2, would not produce as much biomass as late maturing varieties (Group 1 accessions). Although at 2 MAS there were few significant differences in plant height among accessions, Group 2 accessions were in the process of terminating vegetative growth and beginning to flower. However, Group 1 accessions remained in vegetative and continued to grow and reach great heights (Figure 2-2a). Plant heights were not measured subsequently but the differences due to more prolonged vegetative growth by the Group 1 accessions are reflected in the above ground biomass (Table 2-2).

In addition to differences among the plant weights due to accession, planting date also produced significant differences in plant weight (Table 2-2). Planting dates 1 (May), 2 (June), and 3 (July) produced the highest, intermediate, and lowest plant biomass: 603 g, 377 g, and 231 g, respectively. By the last planting date, the daylengths had dropped to below 13 hours (Figure 2-3), which are inductive to flowering (Nanda 1962). These photoperiods would have reduced the time that sunn hemp plants seeded in June remained in vegetative growth, thereby reducing the total plant biomass. Planting date 1 (May) resulted in the highest plant biomass at final harvest, since those plants were exposed to the greatest numbers of days exceeding 13 hours, extending the period of vegetative growth, especially for those accessions that are photoperiod sensitive, and do not flower until short days induce flower bud initiation.

Although accessions in Group 1 had larger leaf size at 2 MAS (Table 2-2), it is difficult to determine the superiority of this group in comparison to Group 2 for canopy closure. PAR readings were taken at 4 MAS, but there were not many significant differences among accessions (Table 2-2) most likely due to the wide plant spacing used in this study. Since accessions in Group 2 had more primary branches per plant than accessions in Group 1, these accessions may have potential for weed suppression through canopy closure, although this is not reflected in the leaf size or PAR results. Since planting density of sunn hemp affects the height and formation of primary and secondary branches (Rotar and Joy 1983), and wide spacing (46 cm) was used in this study, these accessions should be evaluated at higher planting densities. In order to determine the effect of increased branching on weed suppression, accessions from Group 2 should be planted at seed production and cover crop seeding densities to determine their phenotypic expressions under these seeding rates.

The between plant spacing in this experiment was 46 cm, to allow each plant to fully express its phenotype. The resulting planting density may explain the lodging, as sunn hemp is prone to lodging when planted in low densities (White and Haun 1965).

Although bamboo stakes and string were used in this study to minimize lodging, under normal growing conditions, this additional management is unlikely. When planted at seed production or cover crop seeding rate ranging from 11-45 kg/ha these accessions may not branch as much under the higher planting densities as they did in this study. Additionally, lodging may not be such a problem under higher planting densities.

Reproductive Parameters

Accessions that fell into Group 2 based on the vegetative parameters were the accessions that also produced flowers and seeds. Table 2-3 lists the average days from seeding in the greenhouse to the first open flower observed. Accessions in Group 2 (1, 4, 5, 6, 8, 9, 11, 12, and 13) flowered from 49-65 days after seeding, whereas accessions from Group 1 (2, 3, 7, 10, 14, 15, 16) flowered 65 days after seeding and later, while some (7 and 15) did not flower at all during the experimental period. Previous observations of sunn hemp recognize the photoperiod sensitivity of the plant for flower initiation (White and Haun 1965; Nanda 1962). The accessions in Group 1 seem to be photoperiod sensitive, since with all three planting dates they were late to produce flowers. The mean number of days to first flower (Table 2-3) was longest at the second planting date (June), and shortest at the first (May) and third (July) planting dates. Figure 2-3 charts the daylength hours for Orlando, Florida for 2008 (similar results for 2009), and the longest days are in June, which may have influenced the flowering of accessions planted at this time. Nanda (1962) observed that sunn hemp did not become inductive to flower bud initiation until photoperiods decreased below 13 hours. A study conducted by Keatinge et al. (1997) indicated that the earliest days to flowering in sunn hemp occurred at 38 days after planting under daylengths of 11.5 hours. In the present study, accessions from Group 1 followed this pattern, and did not flower until August, at the earliest, when daylength dropped below 13 hours. Accessions from Group 2, however, flowered as early as June, and did not demonstrate photoperiod sensitivity.

Although transplants were used in the main study, in practical application sunn hemp is not transplanted, but direct seeded using a planter or through broadcast application. To determine if extensive flowering observed in accessions from Group 2 was a result of transplant stress, a small side study was conducted in 2009. Seeds of accessions 1, 4, 5, 6, 8, 9, 10, 12, and 13 were direct seeded into the field at the same spacing as the transplanted sunn hemp on June 1, 2009 (PD 2) and July 1, 2009 (PD 3). This study was not repeated and was not analyzed, but the observations provide applicable information about flowering under direct seeding. Table 2-4 lists the days from direct seeding to the first open flower in each accession from this side study. In comparison to the mean days to the first open flower (Table 2-2), direct seeding sunn hemp actually reduced the days to first open flower in these accessions by 8 to 10 days. Therefore, we can assume that the flowering observed in sunn hemp accessions was not a result of transplant stress, but rather a phenotypic expression. Additionally, this side study may indicate that transplanting delays flowering, and direct seeding would result in earlier yields in the accessions tested.

In a study conducted in Alabama, Mansoer et al. (1997) observed flowering in sunn hemp at 35-49 days after planting. Seed was sown in mid-April, but no seedpods were produced before the first frost killed the cover crop. The results from this study support the time to flowering observed by Mansoer et al. (1997), but in their study seed was not produced during the extended experimental timeframe, whereas there was seed produced in Gainesville by some of the accessions.

Table 2-5 lists some of the flowering and fruiting parameters. The average number of flowers per plant at 2 MAS was highest in accessions 1, 4, 8, and 9. These accessions, along with other accessions from Group 2 had higher proportions of branches that had flowers, pods, and both flowers and pods at 4 MAS. The higher numbers of flowers coincide with the earliness of flowering of some accessions (Table 2-3) as well as the seed production that follows. Since flowers of sunn hemp appear on the terminal racemes of secondary branches, flower number is greatly related to branching (Purseglove 1974; Nanda 1962). At 2 MAS, accessions from Group 1 had fewer primary branches per plant, while accessions from Group 2 have more primary branches per plant, while accessions from Group 2 had more primary branches per plant (Table 2-2). The increase in branching may be an influential factor for the higher number of flowers in accessions from Group 2. These results are consistent with those of Abdul-Baki et al. (2001) who hypothesized that there is a positive correlation between branching and flower number.

Accessions 1, 4, 8, 9, 12, and 13 all produced the most mature pods per plant and also had the most seed production overall. The results from the Hotelling's test utilizing the parameters of total mature seedpods, total mature seed weight, total immature seedpods, and total immature seedpod weight are illustrated in Figure 2-4. Accessions 8 and 9 are significantly different from all the other accessions based on these seed production parameters. This could be attributed to the high seed production of accessions 8 and 9 in comparison with the other seed producing accessions. Both accessions 8 and 9 had higher mature and immature seedpods and seed than the other accessions (Table 2-6). Although these two accessions seem to stand out as seed producers, there is an important factor to consider about the data. The Hotelling's test included immature seedpod data, which were collected at the time of final harvest. Unless a grower is able to leave the crop in the field for more than 5 months, these immature seed would never have time to reach maturity and, therefore, only have relevance in production systems that have environmental conditions and crop rotations that would allow for an extended sunn hemp production period for seed production.

For this North Florida location, the first and third planting dates of May and July seemed to allow for the most mature seedpod production (Table 2-6). This could be due to the environmental conditions that were available during this growing period, as well as the presence of appropriate pollinators. The first planting date could be appropriate for seed production of sunn hemp in North-Central Florida. The second planting date (June) did not produce as many mature and immature seedpods, and could be recommended for growers who want to avoid seed set and only want to utilize sunn hemp as a cover crop.

Although there was profuse flowering in several accessions (1, 4, 8, 9), optimal seed production was not achieved. For example, accession 8 had an average of 194 open flowers at 2 MAS (Table 2-3), but only 36 mature seedpods at first mature seedpod harvest (Table 2-6). A significant factor to consider in discussion of these data is effective pollination of sunn hemp. In order to have good consistent seed set, a large insect, such as a bee, is needed to depress the keel of the flower and stimulate the stigmatic surface (Morris and Kays 2005). Large bees from the *Xylocopa* or *Megachile* genera are capable of stimulating the stigmatic surface (Purseglove 1974). Keatinge et al. (1997) investigated the effects of photoperiod and temperature on flowering and reproduction. They observed a lack of seed production in all photoperiod treatments, despite flowering in sunn hemp, even after 173 days. They attributed the lack of fruit set in sunn hemp to reproductive problems within a new environment where there was an absence of appropriate pollinating insects. Apparently in this study a large, non-native species of bee (*Megachile sculpturalis*) was present at the Gainesville location, and seemed to be an effective pollinator for sunn hemp (Pers. Com. H. Glenn Hall). Researchers at other locations in Florida investigating the seed production of sunn hemp have encountered issues with pollination, noting the presence of honeybees, but also their inability to pollinate sunn hemp effectively (USDA-NRCS 2000). Honeybees were also present at this study, and were also observed to be ineffective pollinators (Pers. Com. H. Glenn Hall). Despite the presence of this large bee (*M. sculpturalis*) at this location it seems that pollination was limited in the study, and the full seed production potential of accessions producing flowers was not reached.

Future research could utilize some accessions for breeding programs to develop a cultivar of sunn hemp to be used for domestic commercial seed production. Although the Group 2 accessions have characteristics for seed production, they produce less biomass than accessions in Group 1. Biomass production influences many of the farming system benefits that a cover crop like sunn hemp provides; such as the amount nitrogen produced, weed suppression from canopy closure, and biomass available for use as a green manure. Within the seed producing accessions, there were limitations to seed production, such as natural effective pollinators at flowering. It is imperative that further research investigate the pollination issue, as well as the ability for seed producing accessions to suppress weed populations and provide other farming system services, such as nitrogen accumulation, under cover crop planting densities. As this project developed, it became clear that the invasive potential of sunn hemp needs to be addressed before it can be introduced as a seed crop in Florida. Planting date should also be further investigated as a potential tool for avoiding the problem of sunn hemp as an invasive species.

Table 2-1. List of the sixteen accessions from the USDA-ARS[z] (Griffin, GA) evaluated for their vegetative and reproductive phenotypes in Gainesville, Florida in 2008 and 2009

Accession	USDA Designation	Plant ID	Country of Origin
1	PI 207657	----	Sri Lanka
2	PI 234771	----	Nigeria
3	PI 248491	Guizo de Cascavel	Brazil
4	PI 250485	K679	India
5	PI 250486	K680	India
6	PI 250487	K681	India
7	PI 295851	----	Brazil, Sao Paulo
8	PI 314239	Col No 524	Former Soviet Union
9	PI 322377	IRI 2473	Brazil, Sao Paulo
10	PI 337080	----	Brazil
11	PI 346297	----	India, Delhi
12	PI 391567	T'ai-yang-ma	South Africa
13	PI 426626	Sanni	Pakistan
14	PI 468956	Tropic Sun	United States
15	PI 561720	IAC-1	Brazil, Sao Paulo
16	PI 652939	Texas 374	United States, Texas

[z]United States Department of Agriculture-Agricultural Research Service

Table 2-2. Vegetative characteristics of sixteen accessions of sunn hemp at three planting dates in 2008 and 2009[z]

Treatment	Height at 2 MAS (cm)		Number of Primary Branches at 2 MAS[y]		Total Leaves at 2 MAS[y]		Number of Lateral Branches at 4 MAS[y]		Aboveground Plant Weight at 5 MAS (g)[y]		Leaf Size at 2 MAS		PAR at 4 MAS[x]	
Accession														
1	136.2	ab	9.8	bc	138.1	a	4.1	abc	259.4	c	28.7	a	0.2	ab
2	113.9	b	3.6	a	121.9	a	5.5	c	500.9	a	40.2	c	0.1	a
3	117.8	ab	4.3	a	144.0	a	4.4	abc	584.8	a	36.0	c	0.2	ab
4	131.6	ab	7.8	b	144.5	a	2.3	a	274.0	bc	22.2	a	0.3	b
5	132.2	ab	9.8	cb	152.3	a	3.2	ab	269.9	bc	25.3	a	0.3	ab
6	129.7	ab	12.6	c	175.2	a	4.6	abc	284.1	bc	29.7	a	0.3	ab
7	117.9	ab	2.5	a	109.8	a	4.8	bc	494.0	a	43.9	c	0.2	ab
8	131.3	ab	9.3	bc	149.1	a	2.4	ab	212.8	c	23.8	a	0.3	b
9	127.9	ab	12.9	c	192.9	a	4.1	abc	261.4	c	26.9	a	0.2	ab
10	123.2	ab	9.4	bc	170.4	a	7.0	c	478.4	a	39.2	c	0.1	ab
11	127.2	ab	12.9	c	187.8	a	4.4	abc	315.2	bc	28.4	a	0.3	ab
12	141.8	a	9.2	bc	145.9	a	5.4	c	305.0	bc	33.7	b	0.2	ab
13	136.5	ab	11.6	c	192.7	a	4.2	abc	330.1	bc	30.9	a	0.2	ab
14	119.5	ab	6.0	b	141.8	a	5.3	ab	500.3	a	31.4	a	0.2	ab
15	126.5	ab	2.8	a	109.1	a	4.0	abc	464.4	a	41.9	c	0.2	ab
16	124.2	ab	6.5	b	126.9	a	5.4	bc	429.1	ab	37.0	c	0.2	ab
Planting Date														
1	91.2	c	4.3	c	105.5	c	4.4	a	603.3	a	28.0	b	0.1	b
2	131.9	a	9.2	a	159.3	a	4.0	a	377.3	b	32.4	a	0.4	a
3	127.1	b	7.7	b	120.5	b	2.4	b	230.7	c	29.0	b	0.4	a

[z]Data averaged over planting dates (PD): PD 1 (May 5, 2008 and May 1, 2009), PD 2 (June 5, 2008 and June 1, 2009), and PD 3 (July 7, 2008 and July 1, 2009). Pairwise means comparisons were conducted using Student-Newman-Keuls method. Accessions with the same letter within a column were not significantly different at α=0.05.
MAS indicates months after seeding.
[y]Data square root transformed for analysis.
[x]Data logit transformed for analysis.

Table 2-3. Effect of accessions and planting date on the number of days from seeding to first open flower in of sunn hemp at three planting dates for 2008 and 2009

Treatment	Days to First Flower[z]	
Accession		
1	55	de
2	73	ab
3	72	ab
4	54	de
5	58	cde
6	54	de
7	--	
8	49	e
9	52	de
10	61	cd
11	65	bc
12	65	bc
13	59	cd
14	78	a
15	--	
16	67	bc
Planting Date[y]		
1	56	b
2	61	a
3	56	b

[z]Accessions and planting dates with the same letters were not significantly difference at α=0.05 level of significance. Pairwise means comparisons were conducted using Student-Newman-Keuls method. Accessions without means did not flower during the 4 month data collection period.

[y]Planting dates (PD) were: PD1= May 5, 2008 and May 1, 2009; PD2= June 5, 2008 and June 1, 2009; and PD3= July 7, 2008 and July 1, 2009.

Table 2-4. Number of days from direct seeding in the field to first open flower of nine accessions of sunn hemp in 2009[z]

Accession	PD2	PD3
1	48	41
4	43	43
5	48	41
6	45	41
8	43	41
9	48	43
10	48	45
12	55	48
13	50	48

[z]A side study was conducted in 2009 with excess seeds. These were direct seeded into the field at 45.72 cm between plant spacing on the same day that seeding occurred in the greenhouse of transplants for the field trial (PD2= June 1, 2009; PD3= July 1, 2009) to determine any effect of transplanting on earliness of flowering. This was not repeated, and therefore not analyzed.

Table 2-5. Effect of accession and planting date on flower and pod number per plant in sunn hemp. 2008 and 2009[z]

Treatment	Number of open flowers at 2 MAS[y]		Branches with open flowers at 4 MAS[x]		Branches with pods at 4 MAS[x]		Branches with open flowers and pods at 4 MAS [x]	
Accession								
1	41.2	cd	0.98	g	0.37	c	0.34	c
2	4.0	ab	0.30	b	0.00	--	0.00	--
3	0.7	a	0.28	b	0.00	--	0.00	--
4	77.3	d	0.98	g	0.51	e	0.46	de
5	20.4	bc	0.98	g	0.45	de	0.40	cd
6	8.8	ab	0.96	f	0.17	b	0.15	b
7	0.9	a	0.13	a	0.00	--	0.00	--
8	194.4	e	0.96	f	0.56	e	0.49	e
9	62.4	cd	0.95	e	0.54	e	0.42	cd
10	0.0	a	0.74	d	0.08	a	0.08	a
11	0.2	a	0.97	f	0.22	b	0.18	b
12	0.9	a	0.98	g	0.41	cd	0.37	cd
13	2.6	a	0.97	g	0.49	e	0.43	de
14	0.6	a	0.54	c	0.00	--	0.00	--
15	0.8	a	0.14	a	0.00	--	0.00	--
16	1.6	a	0.94	e	0.23	b	0.23	b
Planting Date[w]								
1	0.9	a	1.10	c	0.27	a	0.17	a
2	0.2	b	3.48	a	0.18	b	0.16	a
3	0.8	a	8.96	b	0.21	b	0.17	a

[z] Pairwise means comparisons were conducted using Student-Newman-Keuls method. Accessions and planting dates with the same letter within a column were not significantly different at α=0.05. Accessions with no letters were left out of the analysis due to the lack of flowering or pod production at the data collection. MAS indicates months after seeding.

[y] Square-root transformed for analysis

[x] logit transformed for analysis

[w] Planting dates (PD) were: PD 1= May 5, 2008 and May 1, 2009, PD 2= June 5, 2008 and June 1, 2009, and PD 3= July 7, 2008 and July 1, 2009

Table 2-6. Comparison of sunn hemp accession and planting date effects on mature seedpod and seed production and immature seedpod production in 2008 and 2009[z]

Treatment	Number of Mature Seedpods[y]		Mature Seed Weight (g)		Number of Immature Seedpods[y]		Immature Pod Weight (g)	
Accession								
1	5	bcd	6.8	abc	31	cdef	21.6	bcd
2	1	de	4.2	abc	1	fg	6.0	cd
3	0	e	0	c	0	g	1.3	d
4	35	ab	9.8	abc	69	abcd	25.3	abcd
5	12	bcd	5	abc	53	bcde	24.6	bcd
6	5	cde	4	abc	29	cdef	15.0	bcd
7	0	e	0	c	0	g	1.2	d
8	36	ab	8.4	abc	37	bcde	11.9	bcd
9	59	a	16.3	ab	160	a	51.5	a
10	36	ab	1.9	bc	17	defg	12.2	bcd
11	2	cde	0.9	c	11	efg	6.8	cd
12	20	cd	7.9	abc	84	abc	31.4	abc
13	32	a	18.2	a	111	ab	36.0	ab
14	0	e	0.1	c	0	g	0.9	d
15	0	e	0	c	0	g	1.6	d
16	0	de	0.3	c	21	cdefg	7.0	cd
Planting Date[x]								
1	15.1	a	8.1	a	46	a	28.1	a
2	5.3	b	3.3	a	33	a	16.9	b
3	11.3	ab	8.2	a	28	a	14.2	b

[z]Six plants per accession were sampled. Pairwise means comparisons were conducted using Student-Newman-Keuls method. Accessions and planting dates with the same letter within a column were not significantly different at α=0.05.
[y]Data square root transformed for analysis.
[x]Planting dates (PD) were: PD 1= May 5, 2008 and May 1, 2009, PD 2= June 5, 2008 and June 1, 2009, and PD 3= July 7, 2008 and July 1, 2009.

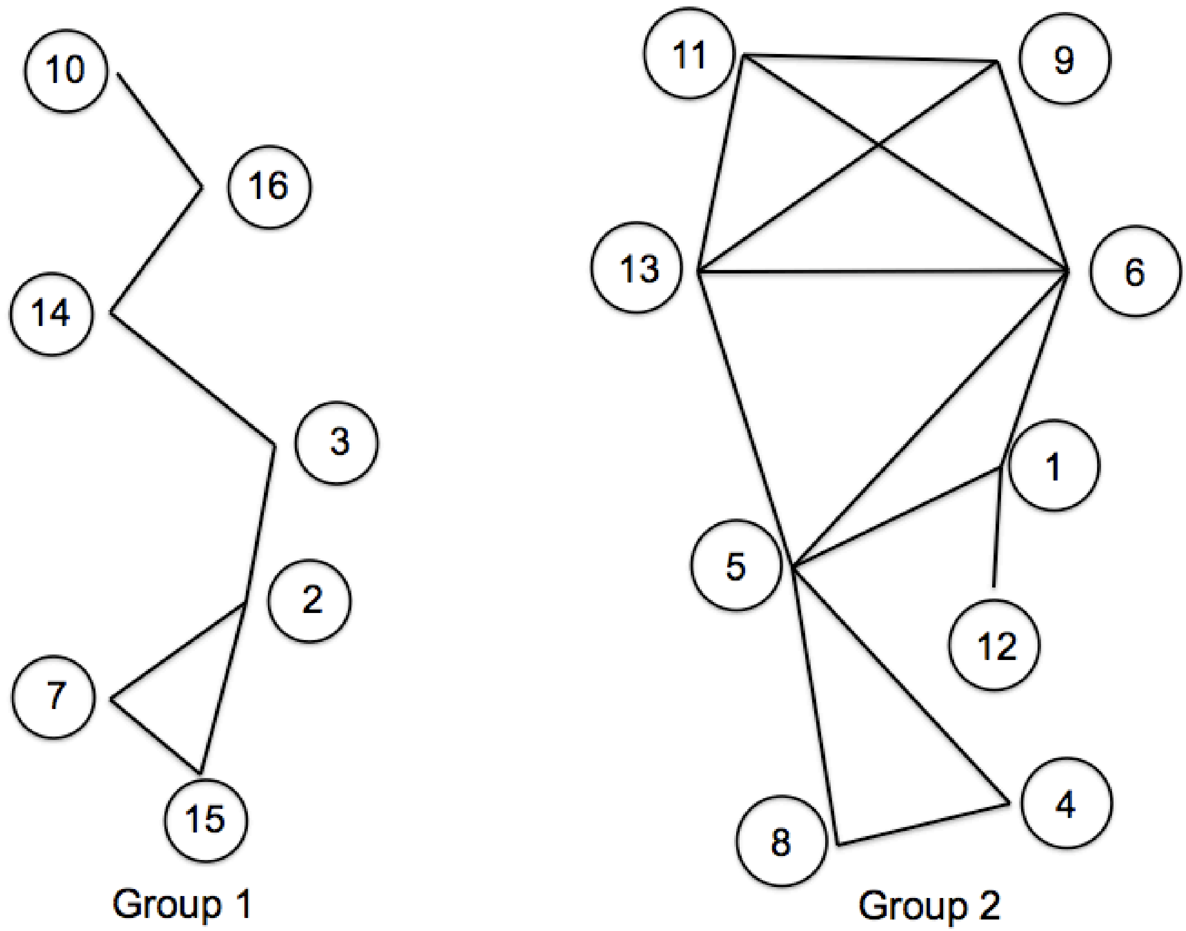
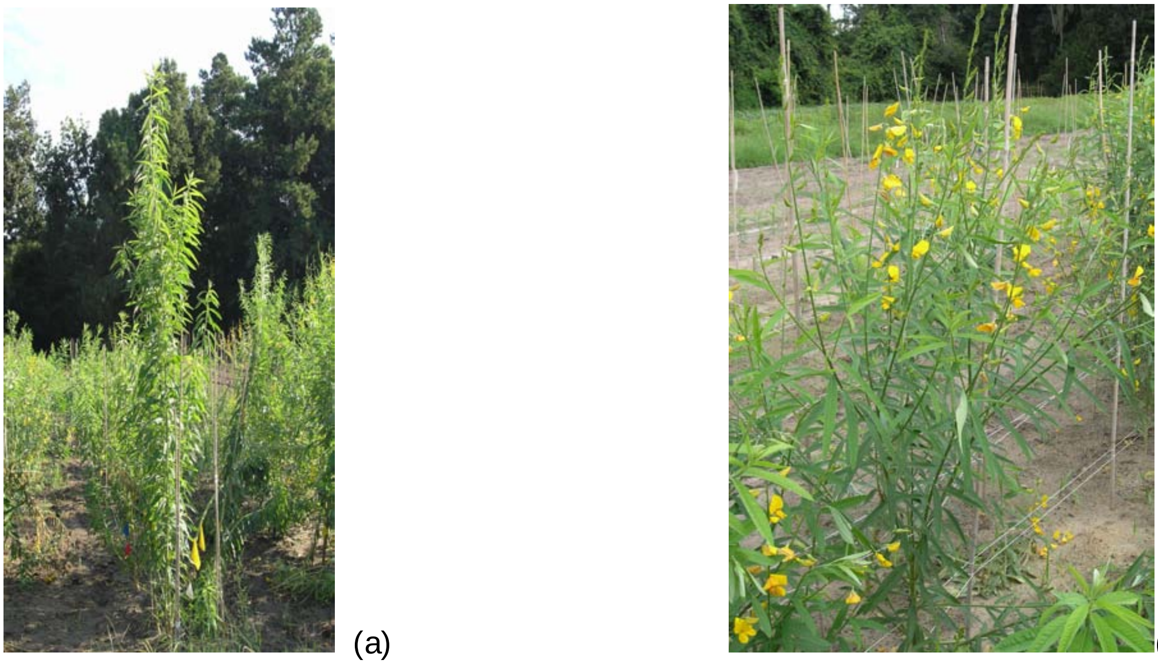


Figure 2-1. Results for Hotelling's test for vegetative data 2008-2009. Variables included: height (2 months after seeding (MAS)), total leaves (2 MAS), leaf area (4 MAS), total number of lateral branches (4 MAS), plant weight (5 MAS). Accessions connected by a line are not significantly different from one another at α=0.05. The length of the line does not represent the level of separation of the accessions. Data were averaged over planting dates: PD 1 (May 5, 2008 and May 1, 2009), PD 2 (June 5, 2008 and June 1, 2009), and PD 3 (July 7, 2008 and July 1, 2009), and years (2008, 2009).



(a) (b)

Figure 2-2. Group 1 accessions (a) display erect growth, few lateral branches, and late flowering. Group 2 accessions (b) branch and flower earlier, but produce less biomass than accessions in Group 1.

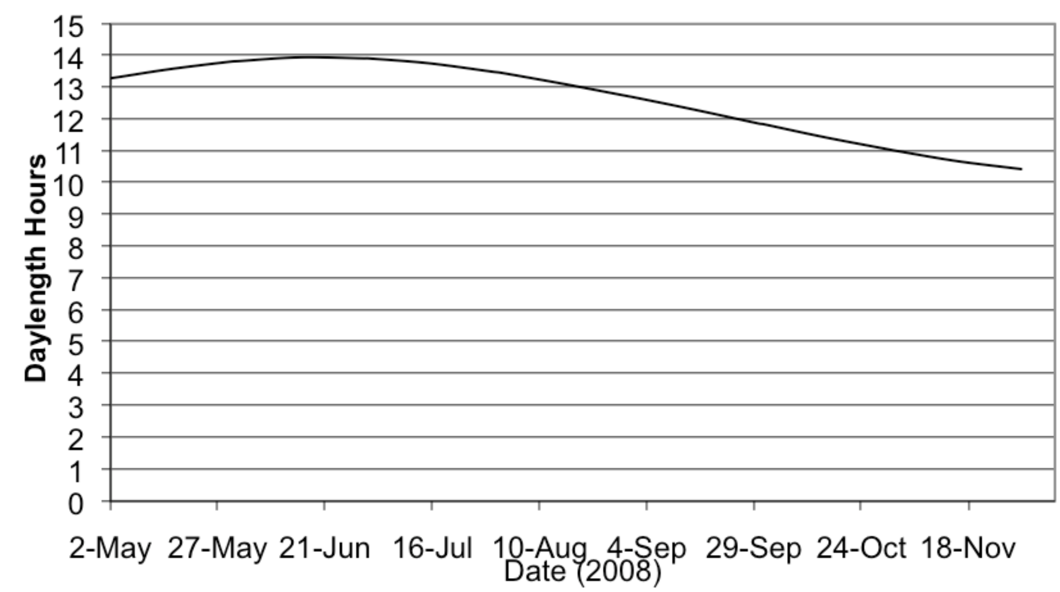


Figure 2-3. Daylength hours for 2008. Data collected for Orlando, Florida. Data from 2009 was + 1 minute for some dates, therefore 2008 represents both years. http://www.timeanddate.com/worldclock/astronomy.html?n=867&month=5&year=2010&obj=sun&afl=-11&day=1

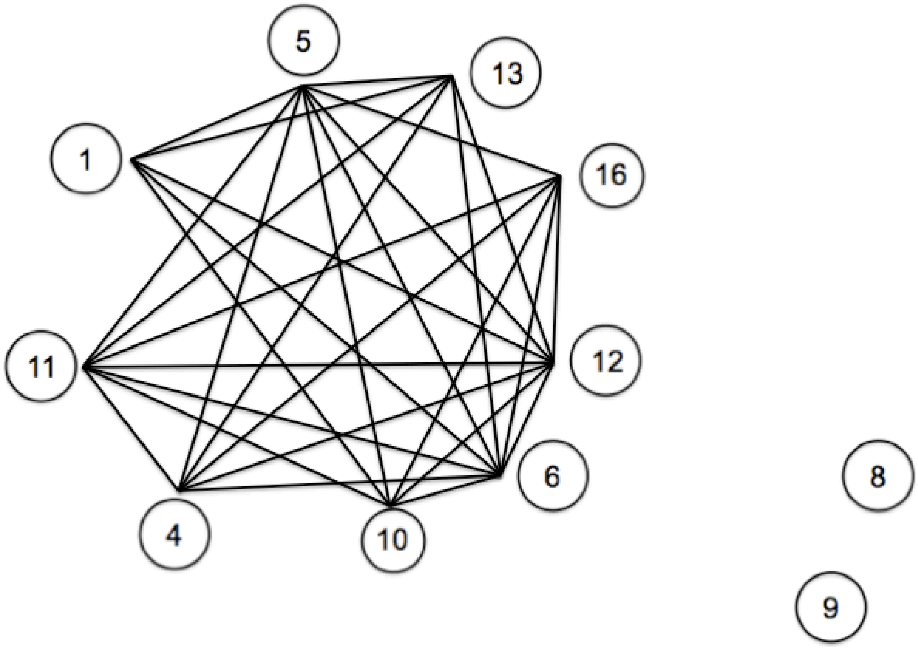


Figure 2-4. Results for Hotelling's test for seed data 2008-2009. Variables included: mature pod number, mature seed weight, immature pod number, immature pod weight (excludes accessions 2, 3, 7, 14, 15 that did not produce seed). Accessions connected by a line were not significantly different from one another at α=0.05. The length of the line does not represent the level of separation of the accessions. Data were averaged over planting dates: PD 1 (May 5, 2008 and May 1, 2009), PD 2 (June 5, 2008 and June 1, 2009), and PD 3 (July 7, 2008 and July 1, 2009), and years (2008, 2009).

CHAPTER 3
APICAL DOMINANCE AND PLANTING DENSITY EFFECTS ON WEED SUPPRESSION AND SEED YIELD BY SUNN HEMP

Introduction

Weed management is a major cost and constraint in both organic and conventional cropping systems (Walz 1999). Weeds must be managed during the growing season, but should be managed during fallow periods to avoid weed infestations in following cash crops. In Florida, vegetable crops are grown during the fall, winter, and spring, while during the hot, rainy summer months the land is often left fallow (Wang et al. 2005). The integration of a cover crop fallow into a cropping system as an alternative to a weedy fallow can incur additional production costs, but can also provide beneficial farm services. The use of a cover crop in place of a weedy fallow can suppress weed populations and limit or prevent additions to the weed seed bank. Additionally, a cover crop can provide soil stability, reduce leaching and runoff, provide nutrients such as nitrogen and thus serve as a green manure.

Cover crop species are most effective in smothering and suppressing weed populations when they emerge and establish rapidly and produce a large amount of shoot biomass (Teasdale 1998). Cover crops reduce weed pressure through physical interference with weed seed germination and seedling growth through alteration of light quantity, light quality, temperature, soil moisture content, and nutrient availability (Teasdale and Mohler 1993). Some cover crops also interfere with weed seed germination and growth through chemical interference (allelopathy). Various types and amounts of allelochemicals are produced and can be released from the plant via leaching, volatilization, root exudation, and death and decay of plant parts, aided by various biotic and abiotic factors (Rice 1984). Scientists agree that allelopathy is an aspect of plant interference: however, there is a lack on consensus in the importance of allelopathy in weed suppression and information on the modes of action (Putnam and Tang 1986).

Sunn hemp (*Crotalaria juncea* L.) has rapid stand establishment and shoot biomass accumulation and thus is a suitable cover crop for weed suppression. A leguminous cover crop, sunn hemp obtains nitrogen (N) via biological N fixation, and the commercial cultivar 'Tropic Sun' has been shown to suppress root-knot nematodes (Rotar and Joy 1983). As a tool for weed suppression, sunn hemp is low maintenance and requires no attention after planting until time of harvest (White and Haun 1965). Sangakkara et al. (2006) investigated crops, including sunn hemp, which could be used in place of weedy fallows in tropical farming systems. Sunn hemp was found to have the largest above ground biomass, and therefore, the greatest weed suppression in comparison with other crops (*Tithonia diversifolia*, *Phaseolus* beans, and a natural fallow), suppressing 82% of weeds. They also showed that a cash crop of mungbean planted after the sunn hemp fallow had the lowest weed populations, indicating that a grower might see a continued benefit of reduced weed populations in their cash crops following a sunn hemp cover crop.

Collins et al. (2007) suggested that branching in an erect cover crop, such as sunn hemp, could increase leaf area of the cover crop and thereby increase the competitive nature of the cover crop with weed species. Additionally, Collins et al. (2007) suggested that the selection of cultivars of cover crops with growth habits that reduce light penetration to the soil surface and reduce weed seed germination will be beneficial for determining an effective summer cover crop for weed suppression.

Branching in sunn hemp depends on the planting density and apical dominance of the plant. Planting density can influence the height and formation of primary and secondary branches (Rotar and Joy 1983). Low planting densities led to an increase in branching (Abdul-Baki et al. 2001). The flowers of sunn hemp appear in racemes on the terminal 15 to 20 cm of secondary branches, and an increase in branches could also mean an increase in flowering (Abdul-Baki et al. 2001). Nanda (1962) noted the importance of apical dominance on flower bud formation. Only after the terminal flower buds break would the lateral buds begin to flower (Nanda 1962). Abdul-Baki et al. (2001) reported that cutting the main stem to break apical dominance at 90 cm significantly reduced plant height at maturity, but increased stem diameter, and increased the number of branches and flowers per plant. The results in this study indicate that the most responsive morphological changes from cutting the main stem were the significant increases in weight and numbers of primary and secondary branches.

There is limited adoption of sunn hemp as a cover crop in the United States due to the high cost of seed and unreliable sources (McKee 1946; Abdul-Baki et al. 2001). Identification of cultural practices, such as planting densities and removal of apical dominance, to increase efficiency of sunn hemp as a cover crop and potentially as a seed crop could provide growers with knowledge of how to manage sunn hemp in a profitable manner. The aim was to determine the effect of planting densities and removal of apical dominance on weed suppression, branch formation and seed production to determine the applicability of these practices for use of sunn hemp as a cover and seed crop. The hypothesis was that seeding rate and cutting to remove apical dominance would impact plant morphology, weed suppression, and seed production of sunn hemp.

Materials and Methods

The experiment was conducted in the organic unit at the University of Florida Plant Science Research and Education Unit (PSREU) in Citra, Florida. The experimental design was a randomized complete block with four replications and a factorial arrangement of treatments that included seeding rates and cutting dates. Plots were 3.66 m by 7.62 m with 1.83 m between rows and 6.1 m between replications. The first factor was seeding rate with three rates used. The lowest seeding rate of 11 kg/ha represented a commercial seed production rate. The highest seeding rate of 45 kg/ha represented a cover crop seeding rate, and the intermediate rate of 28 kg/ha was appointed for comparisons. The second factor was removal of apical dominance. The apical meristem was removed by cutting the top 2-3 cm of the main stem at 3, 4, or 5 weeks after planting or plants were left uncut. In 2009, an untreated weedy check was added.

Sunn hemp seed imported from South Africa was purchased from Kauffman Seed (Haven, KS) and inoculated with cowpea-type *Rhizobium* (Nitragin, Milwaukee, WI) prior to seeding. Seeds were drilled in 45 cm rows with a Monosem air planter (NG Plus, Edwardsville, KS).

Photosynthetically active radiation (PAR) and Leaf Area Index (LAI) were measured using an AccuPar Ceptometer (Decagon Devices, Pullman, WA). Readings were taken at 3, 6, 9, and 12 weeks after planting (WAP) at midday with no cloud cover. An unobstructed reading was taken from above the sunn hemp canopy if possible, and if not an unobstructed reading was taken at 1 m above ground. Below canopy readings were taken by inserting the probe perpendicular through the rows (Figure 3-1).

At 4 months after planting (MAP), the number of primary branches greater than 1 m in length was counted. Three plants were randomly selected from the center row of each plot and branches were counted. At 5 MAP, the same plant selection process occurred and the number of open flowers per plant was recorded.

Weed data were collected at 8 and 12 WAP in 2008 and at 4, 8 and 12 WAP in 2009. A quadrat (91 cm by 46 cm) was randomly placed in the center row of each plot and weeds were counted by species (Figure 3-2). Weeds were harvested at the soil surface and separated into monocotyledon and dicotyledon species. Weed biomass was dried at 120°C for 1 week and dry weights were recorded.

Data were analyzed using SAS (V 9.1, Cary, NC). Analysis of variance was performed using the GLM procedure and means separation was done using the PDIFF option of LSMEANS statement at α=0.05.

Results and Discussion

Weed Species

Weed species varied by year, most likely due to the use of different fields in the organic unit of the Plant Science Research and Education Unit in Citra, FL (Figures 3-3 and 3-4). There was a significant interaction between years, so data are presented by year. In 2008, the primary weed species were hairy indigo (*Indigofera hirsuta* Harvey), bahiagrass (*Paspalum notatum* Fluegge), and purple nutsedge (*Cyperus rotundus* L.). In 2009, the primary weed species were Florida pusley (*Richardia scabra* L.), bahiagrass (*P. notatum*), and carpetweed (*Mollugo verticillata* L.).

Apical Dominance and Weed Biomass

In 2008, there was no effect of cutting date on monocotyledon, dicotyledon, or total weed biomass (Table 3-1). In 2009, there was no effect of cutting date on monocotyledon weed biomass except for higher weed biomass at 12 WAP when cutting had been done at 3 WAP, but cutting did affect dicotyledon and total weed biomass (Table 3-1). The lack of observed effects of cutting on monocotyledon weed biomass in both years could be a function of the weed population composition. In both 2008 and 2009, dicotyledon weed species comprised the majority of weed species, with hairy indigo composing 48% of all weed species in 2008, and Florida Pusley composing 66% of all weed species in 2009. At the first and second data collection dates (4 WAP and 8 WAP) in 2009, treatments where apical dominance was removed at 4 WAP led to lower dicotyledon weed biomass compared to the uncut control. Treatments that were cut at 4 and 5 WAP in 2009 had lower total weed biomass than the uncut control. By the third data collection date of 12 WAP, all cutting dates had lower dicotyledon and total weed biomass than the uncut control. Although there was no effect of cutting on weed biomass in 2008, results from 2009 support that cutting to remove apical dominance leads to a reduction of weed biomass.

Results from the PAR readings in response to cutting date can be found in Figures 3-5 and 3-6. In 2008 by 12 WAP there were no differences among the cutting dates for PAR penetrating the canopy. These results indicate similar canopy closure among the cutting treatments by 12 WAP, which is supported by the total weed biomass from 2008, where no differences were observed at 12 WAP. In 2009, no differences were observed in PAR penetrating the canopy at 12 WAP, but are not supported by the weed biomass results, since the uncut control had higher total weed biomass than the cut treatments.

Sunn Hemp Density and Weed Biomass

Seeding rates affected dicotyledon and total weed biomass in 2008 and 2009. Monocotyledon weed biomass was not affected by seeding rate in either year, but as discussed in previous sections, this could be a result of the species composition in the study areas. In 2008 at the first collection date of 8 WAP, dicotyledon weed biomass was lower in the highest seeding rate (45 kg/ha) than the intermediate seeding rate (28 kg/ha) (Table 3-2). At 12 WAP in 2008, the highest seeding rate (45 kg/ha) had lower dicotyledon weed biomass than the lowest seeding rate (11 kg/ha). In 2008, total weed biomass was lower at 8 WAP in the highest seeding rate of 45 kg/ha than the lowest seeding rate of 11 kg/ha, but by 12 WAP there were no differences among seeding rates for total weed biomass.

In 2009, a weedy untreated check was added. In comparison to the weedy control in 2009, all 3 seeding rates had lower dicotyledon and total weed biomass at all data collection dates (4, 8, and 12 WAP) (Table 3-2). At 4 and 8 WAP, all three seeding rates suppressed dicotyledon and total weed biomass to similar levels. At 12 WAP, while all seeding rates had lower dicotyledon and total weed biomass than the weedy control, there were differences among the seeding rates. For both dicotyledon and total weed biomass at 12 WAP the highest seeding rate (45 kg/ha) had lower weed biomass than the lowest seeding rate (11 kg/ha). Although the highest seeding rate had lower dicotyledon and total weed biomass than the lowest seeding rate, weed biomass with the intermediate seeding rate (28 kg/ha) was not significantly different from that with the highest (45 kg/ha) and lowest (11 kg/ha) seeding rates. These results could support a reduction of the recommended seeding rate for sunn hemp as a cover crop for weed suppression, thereby reducing the seed cost for growers. Additionally, these results may allow the conclusion that a grower producing sunn hemp for seed could achieve weed suppression even at a low seeding rate of 11 kg/ha.

In 2008 at 3 WAP the intermediate and high seeding rates resulted in lower PAR penetrating the canopy than the low seeding rate (Figure 3-7). At 12 WAP in 2008, no differences were observed among the seeding rates, indicating similar canopy closure in all treatments. These results are consistent with those for total weed biomass at 12 WAP, where no differences were observed among the three seeding rates. In 2009 the low and intermediate seeding rates had similar PAR penetrating the canopy at 3 WAP (Figure 3-8). At 6 WAP the intermediate and high seeding rates had lower PAR penetrating the canopy than the low seeding rate. In 2009, at 12 WAP the low and intermediate seeding rates had similar PAR penetrating the canopy. Additionally, total weed biomass was similar between the low and intermediate seeding rate at 12 WAP.

Flowering and Branch Formation

Since sunn hemp flowers occur on the terminal racemes of branches, an increase in branching could also increase flowering and seed production (Purseglove 1974; Abdul-Baki et al. 2001). Since Abdul-Baki et al. (2001) observed an increase in primary and secondary branches and an increase in flowering when the main stem of sunn hemp was cut at 90 cm, the effects of removing apical dominance on branch and flower formation were considered in this study. Removing apical dominance at all three cutting dates (3, 4, 5 WAP) induced branching (Table 3-3). These branches were oriented vertically, more like secondary main stems (Figure 3-9). Although cutting induced branching (Table 3-3), cutting did not affect flowering when assessed at 5 MAP, which differs from the results of Abdul-Baki et al. (2001).

Seeding rates affected both branch and flower formation in both years. In 2008 the intermediate rate (28 kg/ha) had more branches than the highest seeding rate (45 kg/ha), and in 2009, the lowest seeding rate (11 kg/ha) had more branches than both the intermediate (28 kg/ha) and the highest seeding rate (45 kg/ha). Rotar and Joy (1983) noted that lower planting densities led to more primary and secondary branches, which is supported by the results from 2009. In 2008, the lowest seeding rate (11 kg/ha) produced more flowers than the other two seeding rates, but in 2008, the lowest seeding rate (11 kg/ha) only produced more flowers than the highest seeding rate (45 kg/ha). The lowest seeding rate (11 kg/ha) is representative of a recommended seeding rate for seed production. Rotar and Joy (1983), for example, recommend 3-5 kg/ha. Our results support the use of a low planting density when utilizing sunn hemp as a seed crop.

Despite purchasing seed from the same company, Kauffman Seed (Haven, KS), it seems we may have received different cultivars of sunn hemp each year. It was observed that in 2009 the sunn hemp plants had more branching and flowering in comparison to the 2008 stands. The branching data do not support this statement since branches were only counted if they were at least 1 m in length (Table 3-3). The branches in 2009 were shorter and, therefore, not counted in the branching data reported in this study. The more prolific flowering in 2009 can be observed in the results from the flower counts, where in 2008 the average number of flowers per plant at 5 MAP ranged from 1-3, whereas in 2009 they ranged from 4-10. Although there is no data to support the contention that the seeds planted in each year affected the results, and we are unable to confirm these suspicions about the cultivars of seed, this could be a reason why there were significant interactions between years and the main effects.

Regardless of flowering in both 2008 and 2009, seedpods were not produced in either year; therefore seed yield data cannot be reported. In 2008, after flowering occurred but no seedpods were set, commercial bumblebees (*Bombus impatiens*) were bought from Koppert Biological Systems (Romulus, WI). Seedpods were still not produced, but this was attributed to the lateness in placement of bumblebee hives. In 2009, two quads of commercial bumblebees were purchased again from Koppert Biological Systems (Romulus, WI), and placed in the study area. Despite profuse flowering, seedpod production was not achieved in 2009. Sunn hemp needs large insects, such as bees in the *Xylocopa* or the *Megachile* genera, for effective pollination (Purseglove 1974). Bumblebees may not have been large enough to accomplish the depression of the keel of the sunn hemp flower to release the pollen (pers. com. H. Glenn Hall). Future studies need to address the issue of pollination in sunn hemp prior to introduction as a seed crop.

Although the objective to determine the effects of the treatments on seed production could not be achieved, the results from the study are applicable for extension of recommended practices for use of sunn hemp as a cover crop. Since the costs involved in additional management and added expenses to a farming system limit the adoption of any cover crop, a reduction in seed cost could encourage the use of sunn hemp (Teasdale 1996). Cutting to remove apical dominance as early as 3 to 5 weeks after planting did not produce significant beneficial results that would merit recommendation to growers. The weed suppression achieved by the sunn hemp cover crop in this study demonstrates the efficiency of physical interference of rapid establishment and canopy closure on weed seed germination and growth. Sunn hemp leaf litter also provided additional physical impedance of weed development, and while sunn hemp suppresses weeds through resource competition, and modification of the soil microclimate, the suppression could also be due in part to allelopathy (Adler and Chase 2007).

Sunn hemp can provide several farm system benefits, such as weed suppression, soil stabilization, nitrogen accumulation, and root-knot nematode suppression (Mansoer et al. 1997; Balkcom and Reeves 2005; Sangakkara et al. 2006). Additionally it can be used to sequester carbon and can serve as a pollen and nectar resource for native bees and honey bees. Future research needs to take the potential obstacles for adoption of sunn hemp into closer consideration. Due to the lack of a domestic seed source, it is important to continue to investigate cultivars of sunn hemp that could produce viable and consistent seed in the southeastern United States. This would need to include studies on pollination issues of sunn hemp, since these may be a major limiting factor for development of seed production in the U.S. Additionally, the potential for sunn hemp to become an invasive species needs to be evaluated carefully before adoption as a seed crop in Florida, and the continental U.S. Another important issue that needs to be addressed is to demonstrate to proper authorities and to growers that unlike other species of *Crotalaria*, sunn hemp is not toxic to livestock. Demonstration of the toxicity level could encourage growers to utilize sunn hemp as a nutritious livestock feed, which in summertime in Florida can be difficult to locate. Further studies could also investigate the use of sunn hemp in the United States as a fiber, paper pulp, fuel, seed crop, and as commercial mulch. Identification of multiple applications of this crop could further its use in the United States.

 a  b

Figure 3-1. Photosynthetically active radiation (PAR) was measured using an AccuPar ceptometer (Decagon Devices, Inc.; Pullman, WA). Above canopy or an unobstructed reading at 1 m above ground (a) and below the plant canopy perpendicular to row orientation (b) were taken at 3, 6, 9, and 12 weeks after planting (WAP).

Figure 3-2. Quadrat (91 cm by 46 cm) was used to count weed species and to harvest weeds above ground for dry weights. Quadrat was placed randomly around the middle row of each plot for sampling, or in the middle of the plot for the weed untreated check (as shown here).

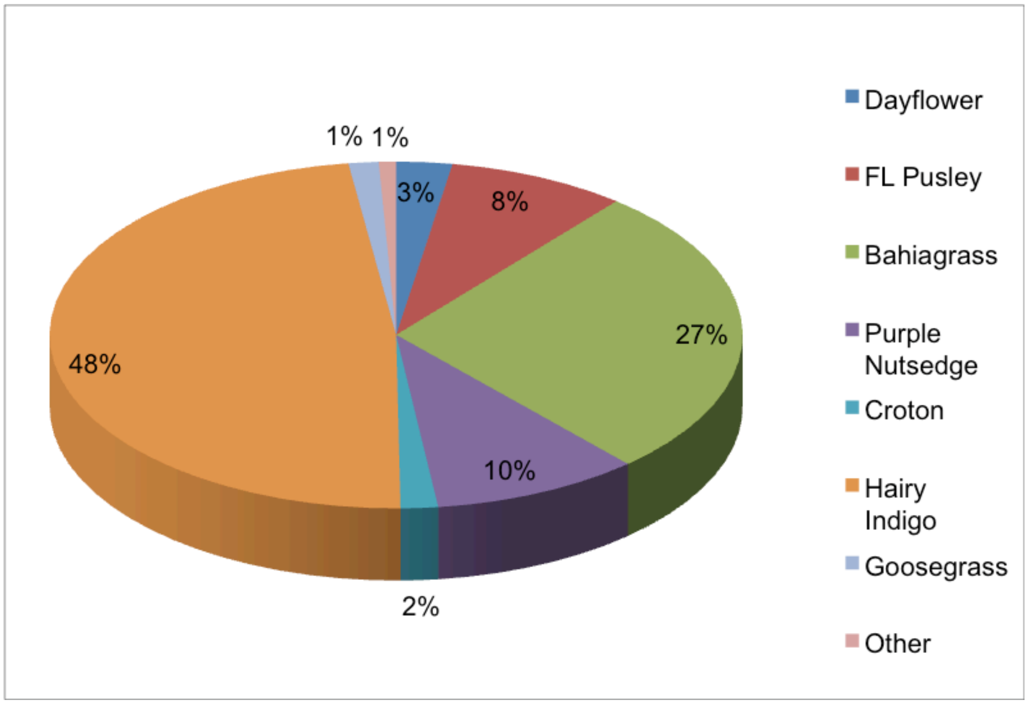


Figure 3-3. In 2008 weeds were counted by species within a 91 cm by 46 cm quadrat at 8 and 12 weeks after planting. Weed species composition averaged over collection date.

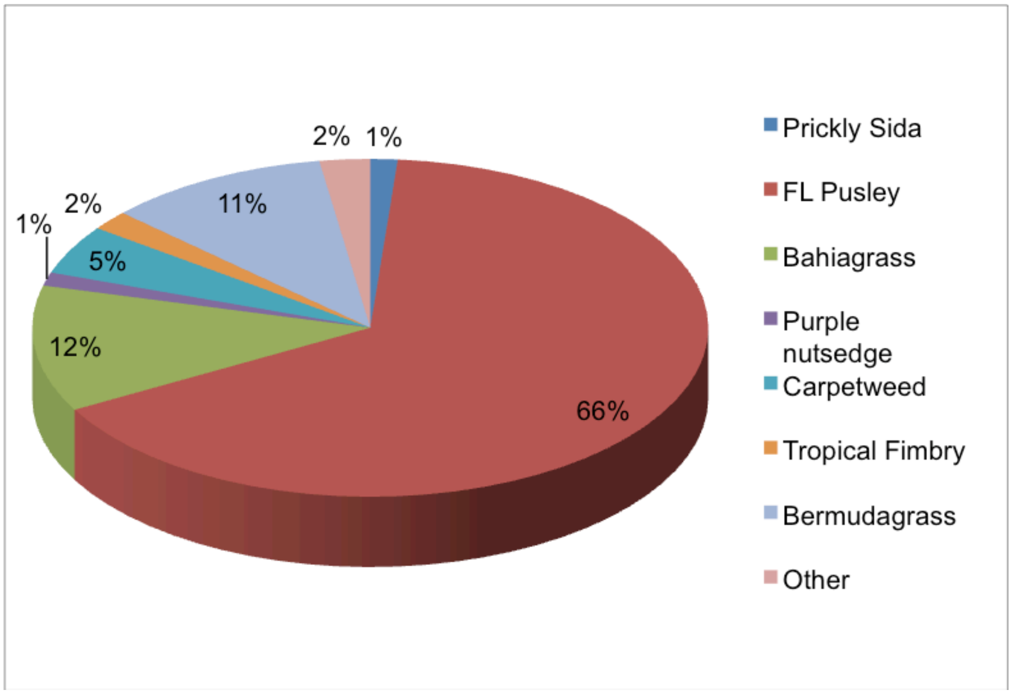


Figure 3-4. In 2009 weeds were counted by species within a 91 cm by 46 cm quadrat at 4, 8, and 12 weeks after planting. Weed species composition averaged over collection date.

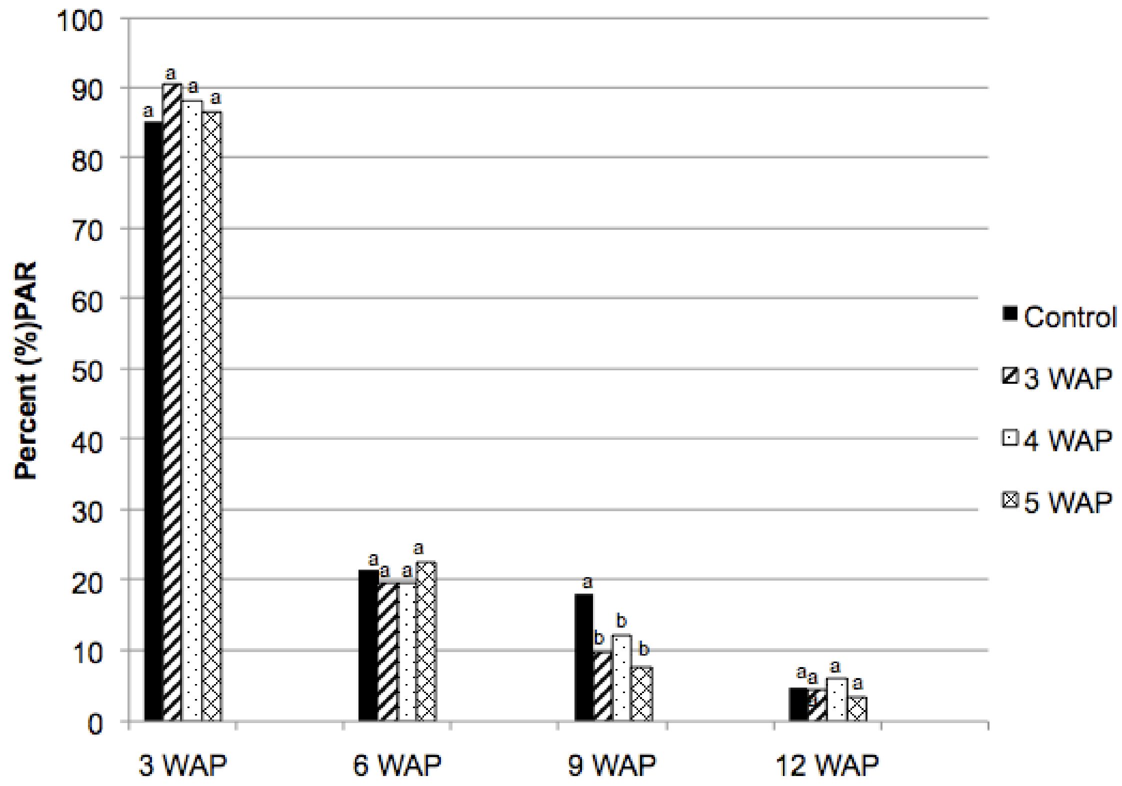


Figure 3-5. Percent photosynthetically active radiation (PAR) penetrating the canopy by cutting date in 2008. PAR was measured at 3, 6, 9, and 12 weeks after planting using an AccuPar Ceptometer (Decagon Devices Inc.; Pullman, WA). Readings were taken above the plant canopy, or an unobstructed reading at 1 m above ground, and under the plant canopy perpendicular to the rows. Unobstructed reading and below canopy reading of PAR were used to calculate the percent PAR. Bars with the same letter were not significantly different at α=0.05.

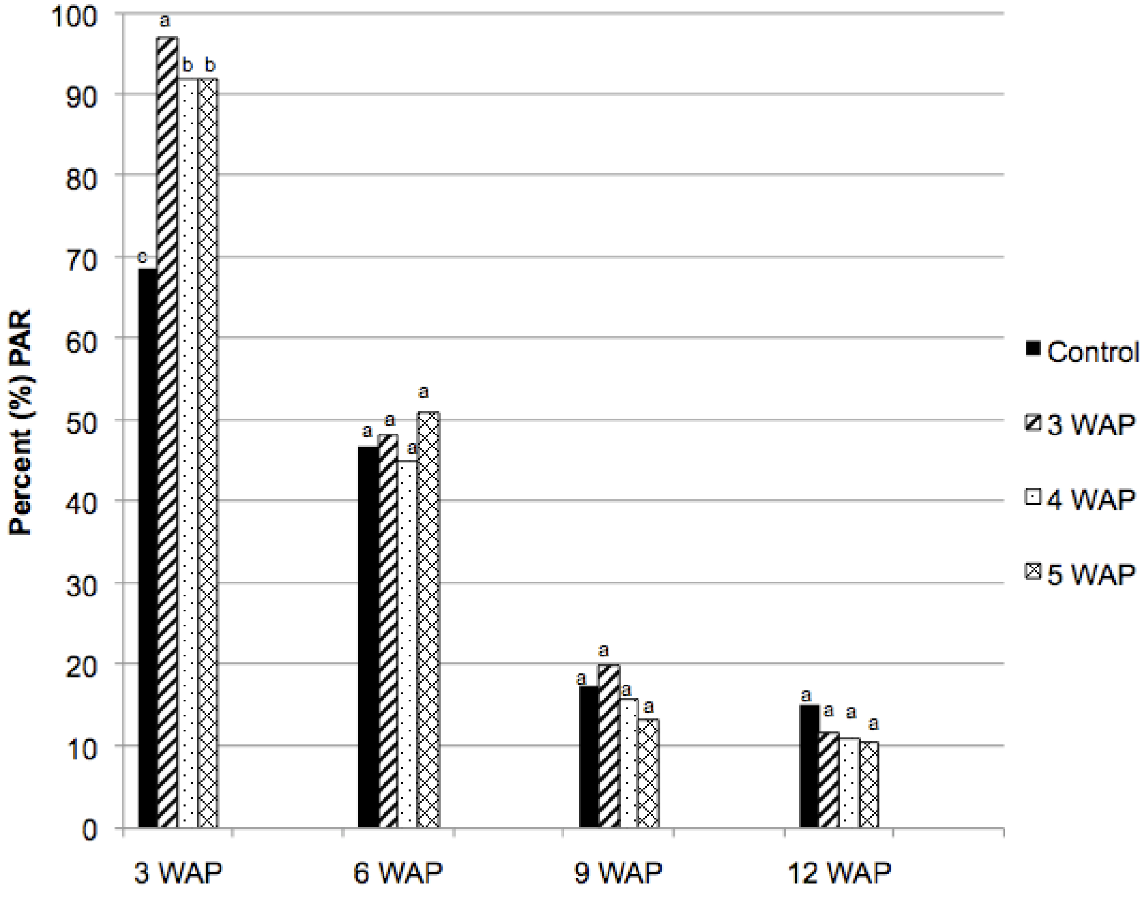


Figure 3-6. Percent photosynthetically active radiation (PAR) penetrating the canopy by cutting date in 2009. PAR was measured at 3, 6, 9, and 12 weeks after planting using an AccuPar Ceptometer (Decagon Devices Inc.; Pullman, WA). Readings were taken above the plant canopy, or an unobstructed reading at 1 m above ground, and under the plant canopy perpendicular to the rows. Unobstructed reading and below canopy reading of PAR were used to calculate the percent PAR. Bars with the same letter were not significantly different at α=0.05.

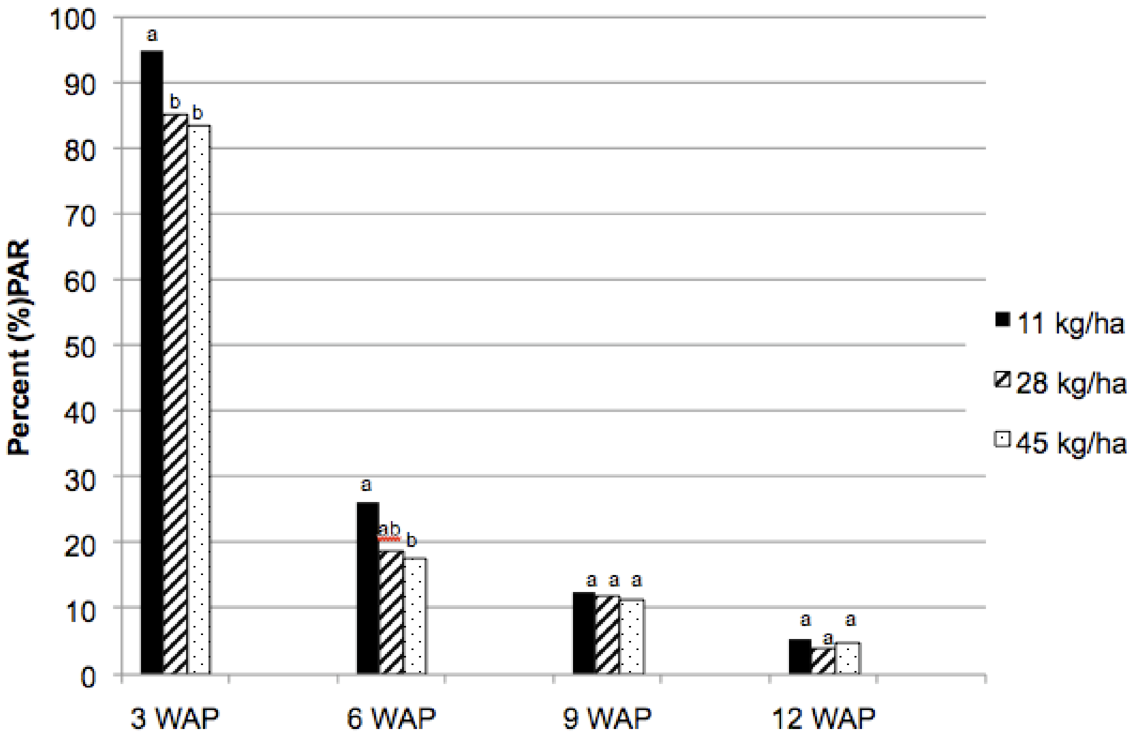


Figure 3-7. Percent photosynthetically active radiation (PAR) penetrating the canopy from seeding rates in 2008. PAR was measured at 3, 6, 9, and 12 weeks after planting using an AccuPar Ceptometer (Decagon Devices Inc.; Pullman, WA). Readings were taken above the plant canopy, or an unobstructed reading at 1 m above ground, and under the plant canopy perpendicular to the rows. Unobstructed reading and below canopy reading of PAR were used to calculate the percent PAR. Bars with the same letter were not significantly different at α=0.05.

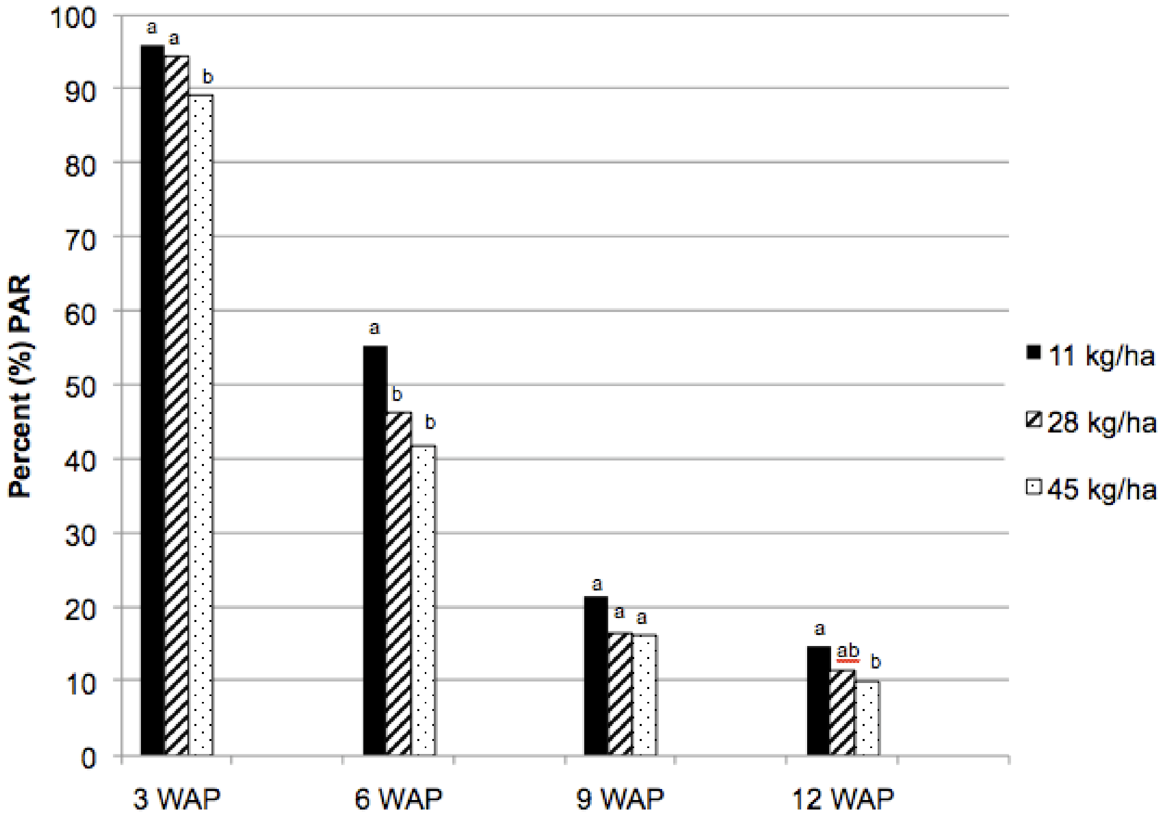


Figure 3-8. Percent photosynthetically active radiation (PAR) penetrating the canopy by seeding rate in 2009. PAR was measured at 3, 6, 9, and 12 weeks after planting using an AccuPar Ceptometer (Decagon Devices Inc.; Pullman, WA). Readings were taken above the plant canopy, or an unobstructed reading at 1 m above ground, and under the plant canopy perpendicular to the rows. Unobstructed reading and below canopy reading of PAR were used to calculate the percent PAR. Bars with the same letter were not significantly different at α=0.05.

 a

 b

Figure 3-9. Effect of removing apical dominance by cutting the main stem 3, 4, or 5 weeks after planting (WAP) on branch formation. Cut (b) versus uncut (a).

Table 3-1. Effect of cutting date on monocotyledon, dicotyledon and total weed dry weights in 2008 and 2009[z]

Cutting Date	Monocotyledon						Dicotyledon						Total					
	4 WAP		8 WAP		12 WAP		4 WAP		8 WAP		12 WAP		4 WAP		8 WAP		12 WAP	
2008[y]									g/m^2									
None	----		14.1	ab	7.8	ab	----		2.5	a	5.7	a	----		16.6	a	13.5	a
3 WAP	----		9.6	b	2.4	b	----		3.2	a	4.4	a	----		12.8	a	6.8	a
4 WAP	----		15.5	a	9.2	a	----		2.4	a	4.2	a	----		18.0	a	13.4	a
5 WAP	----		9.8	ab	7.2	ab	----		2.9	a	3.5	a	----		12.7	a	10.6	a
2009[y]																		
None	2.8	a	13.8	a	16.6	b	10.6	a	132.0	a	165.9	a	13.4	a	145.9	a	182.6	a
3 WAP	3.0	a	16.8	a	33.9	a	7.7	ab	86.5	ab	80.0	b	10.7	ab	103.3	ab	113.8	b
4 WAP	2.5	a	18.2	a	25.0	ab	5.8	b	77.1	b	66.2	b	8.3	b	95.4	b	91.3	b
5 WAP	1.1	a	9.8	a	12.0	b	7.7	ab	81.3	ab	88.0	b	8.8	b	91.1	b	100.0	b

[z] Means in columns followed by the same letter are not significantly different at α=0.05

[y] Results presented by year due to interaction. In 2008, weed counts and dry weights were taken from a 91 by 46 cm quadrat at 8 and 12 weeks after planting (WAP). In 2009, weed counts and dry weights were taken from a 91 by 46 cm quadrat at 4, 8 and 12 WAP.

Table 3-2. Effect of seeding rate of sunn hemp on monocotyledon, dicotyledon and total weed dry weights in 2008 and 2009[z]

Seed Rate	Monocotyledon			Dicotyledon			Total		
(kg/ha)	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
2008[y]					g/m^2				
0	----	----	----	----	----	----	----	----	----
11	----	14.3 a	4.9 a	----	3.6 ab	7.8 a	----	17.9 a	12.7 a
28	----	12.8 a	6.7 a	----	3.8 a	3.6 ab	----	16.6 ab	10.3 a
45	----	9.6 a	8.2 a	----	1.0 b	2.0 b	----	10.5 b	10.2 a
2009[y]									
0	4.4 a	7.3 a	24.8 a	16.8 a	267.8 a	416.9 a	21.3 a	275.1 a	441.8 a
11	1.9 a	15.3 a	16.7 a	7.2 b	94.8 b	110.3 b	9.1 b	110.1 b	127.1 b
28	2.8 a	15.2 a	30.6 a	9.0 b	85.2 b	75.1 bc	11.8 b	100.4 b	105.7 bc
45	1.9 a	15.2 a	16.3 a	6.1 b	68.8 b	51.9 c	8.0 b	84.0 b	68.2 c

[z] Means in columns followed by the same letter are not significantly different at α=0.05

[y] Results presented by year due to interaction. Weed counts and dry weights were taken using a 91 by 46 cm quadrat at 8 and 12 weeks after planting (WAP) in 2008 and at 4, 8 and 12 WAP in 2009.

Table 3-3. Effect of cutting date and seeding rate on number of primary branches per plant at 4 months after planting (MAP) and on the number of flowers per plant at 5 MAP[z]

	Branches		Flowers	
Treatment	2008[y]	2009[y]	2008[y]	2009[y]
Cutting Date	No. per Plant			
None	0.0 b	0.0 c	1.5 a	7.2 a
3 WAP	2.1 a	0.7 b	1.0 a	4.5 a
4 WAP	2.1 a	1.2 ab	1.3 a	7.2 a
5 WAP	2.3 a	1.5 a	1.8 a	8.2 a
Seed Rate				
11 kg/ha	1.3 ab	1.3 a	3.2 a	10.0 a
28 kg/ha	1.3 a	0.6 b	0.8 b	6.3 ab
45 kg/ha	1.1 b	0.4 b	0.7 b	4.1 b

[z] Only primary branches greater than 1 m in length were counted. Means in columns followed by the same letter are not significantly different at α=0.05

[y] Results presented by year due to interaction

CHAPTER 4
ECONOMIC ANALYSIS OF SUMMER COVER CROP FALLOWS FOR ORGANIC NUTRIENT AND WEED MANAGEMENT

Introduction

Florida ranks fifth in the nation for vegetable production with a market value of $2.65 million in 2008 (USDA-NASS 2009). The state overall has 9,231,570 acres of farmland with total crop sales of $6.37 billion in 2007 (USDA-NASS 2009). According to the 2008 Organic Production Survey from the USDA census of agriculture, certified and exempt organic farms had $3.16 billion in total sales, including crops and livestock (USDA-NASS 2010). In 2008 the same survey reported 14,540 organic farmers and ranchers, making up 4.1 million acres of land (USDA-NASS 2010)

Nutrient Management

Organic producers must use non-synthetic, natural resources for nutrient management of cash crops. A survey conducted in 1995 by Swisher and Monaghan found that the three most common sources of nutrients used by organic producers in Florida were 1) animal (especially chicken) manure, 2) bagged organic fertilizers and 3) fish emulsion. It was also noted that the bagged fertilizers were mostly based on poultry manure as well. Hildebrand et al. (1997) surveyed north Florida organic growers and also found that chicken manure ranked first as a fertilizer source and fish emulsion as second. Although organic producers utilize natural sources for nutrient management, these fertilizers are often bulky and need to be applied at heavy rates to meet the needs of the cash crop. The average nitrogen (N) content of chicken manure is 26-72 lbs/ton of manure and application rates are commonly 5-25 tons/acre/year (Ferguson and Ziegler 2004). Utilization of an on-site source of N greatly reduces an organic grower’s need for off-site nutrients. A solution for Florida organic growers to reduce their fertilizer costs is to add a cover crop into their cropping system that increases the nutrient availability in their soils.

Weed Management

A major consideration for organic producers is weed management (Walz 1999). Hildebrand et al. (1997) found that in north-central Florida weeds are the major constraints to switching from conventional to organic production. Additionally, weeds significantly limit large-scale organic production. Despite the use of organic mulches, plastic sheeting and mowing, weeds are persistently a problem for organic producers (Hildebrand et al. 1997).

Swisher and Monaghan (1995) found that 90% of Florida's organic vegetable growers use some combination of hand hoeing and mechanical cultivation for weed control. Due to the limited use of permitted herbicides and other weed management techniques, organic producers rely heavily on human labor and mechanical equipment to manage weed populations. The majority of organic producers in Florida manually cultivate as often as 5-6 times during a growing season (Swisher and Monaghan 1995). With the cost of fuel and labor rising, and possible adverse effects of frequent cultivation, organic weed management could benefit from a more ecological approach.

In Florida, organic producers generally do not grow crops during the hot, humid, summer months. This break in their crop production cycle is often a weedy fallow treatment but some growers may utilize tillage to manage weed populations. While tillage suppresses the weed populations to an extent, tillage can build the weed seed bank and spread weed seeds. Additionally, tillage is sometimes overused and utilizes labor, machinery, and fuel that could otherwise be spared. Florida organic producers could use cover crops or green manures as tools for managing weed populations and as an alternative to a weedy fallow. Although there is significant literature and data to support the adoption of cover crops into organic cropping systems for environmental reasons, few economic studies of the benefits and costs of the use of cover crops have been conducted, and a gap exists in the understanding the economics of using cover crop (Lu et al. 2000).

Cash crops following cover crops often experience reductions in weed populations. These reductions can lead to benefits including an increase in cash crop productivity and potential reductions in pest pressure (Li et al. 2006). In organic systems, this reduction in weed populations could mean a decrease in labor costs associated with hand weeding. Sangakkara et al. (2006) looked at crops that could be used in place of weedy fallows in tropical farming systems. Sunn hemp produced the most ground cover and, therefore, the greatest weed suppression in comparison with other cover crops, suppressing 82% of weeds. The study also showed that a cash crop of mungbean following the sunn hemp fallow had the lowest weed populations.

Although many growers recognize the benefits of integrating a cover crop into their cropping systems, often it is difficult to justify the costs to implement these cover crops. This economic analysis evaluates the costs of cover crop implementation. It attempts to appoint economic values to the ecosystem services provided by cover crops, emphasizing the nutrient accumulation and the weed suppressive capabilities and how these benefits interact with the overall cash flow of the cropping system.

Materials and Methods

In this study data from several sources were utilized to create partial budgets for five summer fallow treatments; sunn hemp (*Crotalaria juncea* L.), velvet bean [*Mucuna deeringiana* (Bort) Merr.], cowpea [*Vigna unguiculata* (L.) Walp. cv. Iron Clay], sorghum sudangrass [*S. bicolor x S. bicolor var. sudanese* (Piper) Stapf.], and use of tillage to manage weeds. These treatments were compared for their abilities to suppress weed populations and to contribute N to a following cash crop of squash. The biomass and N accumulation of each cover crop species and their recommended seeding rates are outlined in Table 4-1. Tables 4-2 and 4-3 list the costs of implementing the cover crop and tillage treatments, respectively, not including the cost of seed and inoculant. A breakdown of the variable costs of each fallow treatment can be found in Table 4-4. This outlines the cost of seed, inoculant and the total cost of each fallow treatment.

The importance of weed suppression by cover crops is well documented, but economic data are lacking to support the monetary benefits growers might obtain by using a cover crop in place of a weedy fallow. Weed suppression by a cover crop is correlated with the biomass production of that crop (Klassen et al. 2006). Weed reduction with sunn hemp can range from 50-82% (Sangakkara et al. 2006). Since the level of weed suppression by sunn hemp will be highly dependent on the existing weed populations as well as the planting densities, this study uses 70% reduction as an average for weed suppression by sunn hemp. Using this value, along with existing data on biomass production of the other cover crop species, Table 4-5 was created, summarizing the fertility and weed control benefits of each treatment. Based on surveys of Florida organic growers, hand weeding is the most common method of weed control in organic production systems (Hildebrand et al. 1997; Swisher and Monaghan 1995). Therefore, Table 4-5 also includes the cost of hand weeding during the cash crop following the various fallow treatments using five hand weeding events as the baseline cost for weed management in squash production.

Table 4-6 is based on a production budget created by Hewitt (2006) for squash production in North Florida. Squash production in Florida is recommended to have 150 lbs N/A (Hochmuth and Hanlon 2000). The column for organic production was derived by taking into consideration nutrient and weed management. Removing several inputs that are not permitted in organic production and adding in the cost of organic fertilizer costs and additional labor for hand weeding allowed for the estimation of the values for organic production. Table 4-7 provides the breakdown for fertilizer costs used for this analysis. Fertilizer costs are weighted by percentage of organic growers who use poultry manure and fish emulsions as fertilizer sources (Swisher and Monaghan 1995; Hildebrand 1997). Values were then appointed to the weighted value of each nitrogen source and compiled for a total fertilizer cost for the organic system. The fertilizer value would vary depending on the growers' practices and cash crop following the summer fallow.

Results and Discussion

Despite the initial costs involved with establishing a summer cover crop, utilizing a summer fallow treatment that provides on farm services to the cropping system can be economically beneficial to the growers in the long term. Additionally, the farming system services that the cover crops provide are invaluable in terms of long-term sustainability.

Partial budgets are provided in Table 4-8 for the five summer fallow treatments including the variable costs in each production system and how they are affected by the nitrogen production of each crop as well as the weed suppression provided by the biomass production of each crop. This table assumes that at least half of the N produced by the cover crop will remain available for the following cash crop of squash.

Schomberg et al. (2007) found that sunn hemp accumulated 130 kg/ha^{-1} of N in a 60-day growing period, and they assumed that 50% of the N would be available for a subsequent vegetable crop, which for most vegetables would account for half of the required amount. There are many factors that affect the uptake of biologically fixed nitrogen, which can include the temperature, rainfall and timing of cover crop mowing and cash crop planting. Weed control by biomass production alone will also have variable results depending on location. Existing weed populations and environmental factors will also influence the level of success of weed suppression by the cover crops. Bhan (2010) noted the variability of stand establishment of velvet bean, which can lead to poor weed suppression.

According to this analysis, which emphasizes the N accumulation and the weed suppression by cover crops, sunn hemp is the most inexpensive cover crop. Table 4-9 adds the production costs of squash following each summer fallow treatment with the cost of the summer fallow treatment itself to create the total comparative costs of each treatment. Although the cost of seed is high in some cover crops such as sunn hemp and velvet bean, the ecological benefits that these cover crops provide is superior to the other fallow treatments and this is reflected in the reduction in production costs. For example, although sorghum sudangrass seed is inexpensive, it is not a legume, and cannot biologically fix N like the other cover crops used in this study.

Overall sunn hemp is the least expensive summer fallow treatment, followed by velvet bean, cowpea, sorghum sudangrass, and tillage. The cost of seed of these cover crops is often the deciding factor for adoption, and the cost of each summer fallow treatment is not reflected in the total costs of each production system. In terms of implementing the summer fallow treatments alone, tillage is the least expensive, followed by sorghum sudangrass, cowpea, sunn hemp, and velvet bean. Once the farming system benefits of each fallow treatment are taken into consideration for the following cash crop and the reduced need for off-site nitrogen and physical labor for weed control, the least expensive treatment becomes the most expensive (Table 4-9).

Table 4-1. Summer cover crops evaluated for economic feasibility in Florida

Cover Crop	Best Variety[z]	Vigor[z]	Seeding rate[z]	Nitrogen in Cover Crop[y] (lb/A)	Max. Dry Matter[y] (T/A)
Sunn Hemp	Tropic Sun	Excellent	50	300	5
Velvet Bean	Georgia Bush	Excellent	30	282	6
Cowpea	Iron Clay	Good	100	86	3
Sorghum Sudangrass	-----------	Good	40	33	2

[z]Abdul-Baki and Teasdale 2007
[y]Li et al. 2006

Table 4-2. Cost of cover crop implementation excluding cost of seed and inoculant

Cover Crop Implementation				
Variable Costs	Unit	Qty	Price	$/A
Operator Labor[z,y]	hours	2.14	10.90	23.33
Tractors[z]	dollars	1.07	6.37	6.37
Implements[z]				
Heavy Disc	hours	0.16	7.97	1.28
Moldboard Plow	hours	0.43	7.87	3.38
Rotary Mower	hours	0.34	7.97	2.71
Planters	hours	0.14	9.17	1.28
Diesel Fuel[x,w]	gal	0.21	3.51	0.72
Total Variable Costs				38.35
Fixed Costs				
Implements[z]				
Heavy Disc	hours	0.16	9.50	1.52
Moldboard Plow	hours	0.43	9.40	4.04
Rotary Mower	hours	0.34	8.40	2.86
Planters	hours	0.14	11.60	1.62
Total Fixed				10.04
TOTAL				48.39

[z] Hewitt (2006)
[y] Florida Agency for Workforce Innovation (www.floridajobs.org)
[x] Downs and Hansen (1998)
[w] Energy Information Administration (www.eia.doe.gov)

Table 4-3. Cost of tillage treatment for control of weeds during summer fallow in Florida

Tillage				
Variable Costs	Unit	Qty.	Price	$/A
Operator Labor[x,w]	hours	3.54	10.90	38.59
Tractors[z]	dollars	1.77	6.37	11.27
Implements[z]				
Heavy Disc	hours	0.48	7.97	3.83
Moldboard Plow	hours	1.29	7.87	10.15
Diesel fuel[x,w]	gal	0.34	3.51	1.19
Total Variable Costs				65.03
Fixed Costs				
Implements[z]				
Heavy Disc	hours	0.48	9.50	4.56
Moldboard Plow	hours	1.29	9.40	12.13
Total Fixed Costs				16.69
TOTAL				81.72

[z] Hewitt (2006)
[y] Florida Agency for Workforce Innovation (www.floridajobs.org)
[x] Downs and Hansen (1998)
[w] Energy Information Administration (www.eia.doe.gov)

Table 4-4. Seed, inoculant, and implementation costs of summer fallow treatments evaluated for Florida

Seed[z,y,x]	Unit	Qty	Price	Seed	Inoculant[y]	Total Seed Cost/A	Total Cost
Sunn hemp	lbs	50.00	4.50	225.00	9.50	234.50	282.89
Velvet Bean	lbs	30.00	10.00	300.00	9.50	309.50	357.89
Cowpea	lbs	100.00	1.15	115.00	9.50	124.50	172.89
Sorghum sudangrass	lbs	40.00	1.20	48.00	0.00	48.00	96.39
Tillage						---	81.72

[z] The Velvet Bean Shoppe (2009)
[y] Adams-Briscoe Seed Company (2009)
[x] Abdul Baki and Teasdale (2007)

Table 4-5. Fertility and weed control benefits

Cover crop	Available N (lb/A)[z,y]	Dry Matter (T/A)[z]	Percent Weed Reduction[x]	Cost of Weeding in Following Cash Crop
Sunn hemp	150	5	70	$16.35
Velvet Bean	141	6	84	$8.72
Cowpea	43	3	42	$31.61
Sorghum Sudangrass	16.5	2	28	$39.24
Fallow[w]	---	----	----	$54.50

[z]Li et al. (2006)

[y] Pers. com. Danielle Treadwell (2009)

[x]Sangakkara et al. (2006)

[w] Based on 5 weeding events of 1 hour each in cash crop following the summer fallow treatment at $10.90/hour (Florida Agency for Workforce Innovation)

Table 4-6. Conventional and organic squash production budgets[z]

Item	Unit	Quantity	Price	Value	Organic
Variable Costs					
Seed	lb.	2.00	50.00	100.00	100.00
Lime, applied	ton	0.50	33.00	16.50	
Fertilizer	cwt.	10.00	10.13	101.30	415.98
Sidedressing	lb.	100.00	0.43	43.00	43.00
Herbicide	acre	1.00	5.98	5.98	
Insecticide	appl.	1.00	35.47	35.47	
Fungicide	appl.	1.00	26.11	26.11	
Plastic	roll	2.80	120.00	336.00	336.00
Plastic Removal	acre	1.00	75.00	75.00	75.00
Nematicide	acre	1.00	52.76	52.76	
Tractor +Machinery	acre	1.00	60.46	60.46	60.46
Labor[y]	hr.	8.00	10.90	87.20	141.70
Land rent	acre	1.00	70.00	70.00	70.00
Irrigation	acre	1.00	408.00	408.00	408.00
Interest on Oper. Cap.	$	1386.59	0.07	97.06	97.06
Pre-Harvest Variable Costs				1483.65	1747.20
Harvest and Marketing Costs					
Picking and Hauling	bu.	275.00	0.90	247.50	247.50
Grading and Packing	bu.	275.00	0.75	206.25	206.25
Containers	ea.	275.00	0.90	247.50	247.50
Marketing	bu.	275.00	0.40	110.00	110.00
Total Harvest and Marketing				811.25	811.25
Total Variable Costs				2294.90	2558.45
Fixed Costs					
Machinery	acre	1.00	61.34	61.34	61.34
Irrigation	acre	1.00	85.00	85.00	85.00
Overhead and Management	$	1483.65	0.10	148.36	148.36
Total Fixed Costs				294.71	294.71
Total Budgeted Cost Per Acre				2589.60	2853.16

[z]Based on Hewitt (2006)

[y]Added 5 hand weeding events of 1 hour each for the organic system

Table 4-7. Fertilizer costs for organic production in Florida based on the weighted value of the commonly used sources for fertilizer

	Percent of Source Used[z]	Unit	Amt/A	Cost	Cost/A	Weighted cost
Chicken manure[y,x]	38%	Tons	15	$23	$345	$131.10
Bagged Organic fertilizer[v]	33%				$731	$241.23
Fish emulsion with kelp or seaweed[w]	29%	Gallons	5		$150.50	$43.65
Total Fertilizer Cost						$415.98

[z]Swisher and Monaghan (1995)
[y]McMahon (2007)
[x]Ferguson and Ziegler (2004)
[w]Neptune's Harvest (www.neptunesharvest.com)
[v]Hodges (2007)

Table 4-8. Summer squash partial budgets for cover crops in Florida

Production costs	Tillage	Sunn hemp	Velvet Bean	Cowpea	Sorghum Sundangrass
Fertilizer Costs	$415.98	$0	$24.96	$296.73	$370.22
Weed Control	$54.50	$16	$8.72	$31.61	$39.24
Preharvest costs	$1,618.50	$1,164.37	$1,181.70	$1,476.36	$1,557.48
Harvest Costs	$811.25	$811.25	$811.25	$811.25	$811.25
Fixed Costs	$278.80	$278.80	$278.80	$278.80	$278.80
Total Costs	$2,708.55	$2,254.42	$2,271.75	$2,566.41	$2,647.53

[z]Hewitt (2006),Table 4-3, Table 4-5

Table 4-9. Total comparative costs of summer fallow treatments with following cash crop of squash

	Tillage	Sunn hemp	Velvet Bean	Cowpea	Sorghum Sundangrass
Total Production Costs	$2,708.55	$2,254.42	$2,271.75	$2,566.41	$2,647.53
Summer Fallow Treatment	$81.72	$282.89	$357.89	$172.89	$96.39
Total Cost Summer Cover and Cash Crop	$2,790.27	$2,537.31	$2,629.64	$2,739.30	$2,743.92

[z]Table 4-4, Table 4-8

CHAPTER 5
SUMMARY AND CONCLUSIONS

The limited adoption of sunn hemp (*Crotalaria juncea* L.) as a cover crop due to the expensive and unreliable seed sources led to the development of this research. The overall objective was to encourage the use of sunn hemp as a cash cover crop in Florida by demonstrating the benefits of sunn hemp as both a cover crop and as a seed crop. The three specific objectives were: 1) to evaluate the phenotypes of 16 accessions of sunn hemp from the USDA-ARS (Griffin, GA) germplasm collection in order to select accessions of sunn hemp that have potential for seed production in Florida and can possibly be used in future breeding projects; 2) to investigate the effects of planting densities and breaking apical dominance of sunn hemp on weed suppression and seed production to determine recommended practices for growers depending on the ultimate goal of the grower for their cover crop; and 3) to conduct an economic analysis for the farming system and economic impacts of sunn hemp use as a cover crop in Florida.

To accomplish the first objective a field study was conducted to compare the vegetative and reproductive characteristics of the sixteen accessions at three planting dates. Two distinct groups of accessions were identified from these observations. One group of accessions (Group 1) was made up of short day accessions that remained in vegetative growth for the majority of the study and had delayed flowering and seed production (if any at all). The other group (Group 2) of accessions was composed of daylength insensitive accessions that flowered early, producing mature seed during the study period. Additionally, accessions in Group 2, these accessions were shorter in stature, smaller in leaf area and canopy closure, and in total shoot biomass.

Accessions in Group 2 also produced more branches than accessions in Group 1, which may correspond with the increase in flowering and seed production among these accessions. Accessions in Group 1 are similar to the commercially available cultivars of sunn hemp, with erect growth, tall in stature, few branches, and little flower and seed production. Accessions in Group 1 and Group 2 could potentially be used in breeding programs to develop a cultivar that maintains the desired vegetative qualities as a cover crop while also maintaining the reproductive capabilities of the accessions in Group 2.

The second objective was to determine the effects of cutting and seeding rate on weed suppression, plant morphology, and seed production of sunn hemp. Cutting sunn hemp to remove apical dominance did not produce consistent results between years for weed suppression. Although cutting induced branching in both years, the increase in branching did not result in increased weed suppression or flower production. Therefore, this practice would not be recommended to growers for management of sunn hemp as a cover crop or as a seed crop. All seeding rates had similar weed suppressive capabilities, but were not significantly different from one another. All seeding rates had lower total weed biomass than the weedy check by 12 WAP. Although the highest seeding rate of 45 kg/ha is the current recommendation as a cover crop seeding rate, in this study, the intermediate seeding rate of 28 kg/ha provided weed suppression that was statistically the same as the highest seeding rate. The intermediate seeding rate could be recommended for cover crop use, and growers could obtain the weed suppressive benefits of sunn hemp with a decrease in total seed cost. Additionally, the lowest seeding rate of 11 kg/ha, which represented the seed production seeding rate, had the same total weed biomass as the intermediate rate, and could provide some weed suppression benefits to growers utilizing sunn hemp as a seed crop.

The third objective was to investigate the economic feasibility of utilizing sunn hemp in a cropping system. When compared with four other summer fallow treatments, including cowpea, velvet bean, sorghum sudangrass, and tillage, sunn hemp was found to be the most economically feasible summer fallow treatment. This study took into consideration the ability of these cover crops to cycle nutrients as well as suppress weeds that would reduce the need for weed control in the following cash crop. This outcome of this type of analysis can change depending location as well as on the current cost of labor and seed.

The uses of sunn hemp are already well established, especially in India where it is commonly used as a fiber crop. Future research should address the potential for sunn hemp as an economically beneficial crop. Uses could include fodder, fiber, fuel, commercial mulches, and seed. Additional studies need to investigate the vital role of available natural pollinators to effectively pollinate sunn hemp. Pollination may very well be the limiting factor for sunn hemp seed production in Florida, and throughout the Southeast. Another concern that needs to be addressed in future studies is the potential for sunn hemp to become an invasive weed and how this can be prevented.

LIST OF REFERENCES

Abdul-Baki, A.A., H.H. Bryan, G.M. Zinati, W. Klassen, M. Codallo, and N. Heckert. 2001. Biomass yield and flower production in sunn hemp: effect of cutting the main stem. J. Veg. Crop Prod. 7:83-104.

Abdul-Baki, A.A. and J.R. Teasdale. 2007. Sustainable production of fresh-market tomatoes and other vegetables with cover crop mulches. USDA-ARS Farmer's Bulletin No. 2280.

Adams-Briscoe Seed Company. 2009. www.abseed.com. Seed Price List. Accessed May 22,2009.

Adler, M.J. and C.A. Chase. 2007. Comparison of the allelopathic potential of leguminous summer cover crops: cowpea, sunn hemp, and velvetbean HortScience 42(2):289-293.

Balkcom, K.S. and D.W. Reeves. 2005. Sunn-hemp utilized as a legume cover crop for corn production. Agron. J. 97:26-31.

Bhan, M. 2010. Cropping system complexity for suppressing pests in organic vegetable production. Ph.D. Differtation, University of Florida, Gainesville, FL.

Cook, G.C. and G.A. White. 1996. *Crotalaria juncea*: a potential multi-purpose fiber crop. In Progress in New Crops, J. Janick (ed.). ASHS Press, Arlington, VA. P. 389-394.

Downs, H.W. and R.W. Hansen. 1998. Estimating farm fuel requirements. Farm and Ranch series no. 5.006. http://www.ext.colostate.edu/PUBS/farmmgt/05006.pdf

Ferguson, J.J. and M.R. Ziegler. 2004. Guidelines for purchase and application of poultry manure for organic crop production. IFAS publication HS973.

Hewitt, T.D. 2006. Estimated costs of producing one acre of squash on plastic for fresh market, north Florida. Extension economist, Food and Resource Economics Department, University of Florida NFREC, Marianna.

Hildebrand, P., D. Zimet and G. Brinen (eds.). 1997. Organic agricultural production in north and central Florida: a sondeo report. University of Florida staff paper SP97-4.

Hodges, A.W. 2007. Economic analysis of integrated weed control in organic vegetable production final project report to USDA-SARE.

Hochmuth, G.J. and E.A. Hanlon. 2000. IFAS Standardized fertilization recommendations for vegetable crops. IFAS publication CIR1152.

Keatinge, J.D.H, A. Qi, T.R. Wheeler, R. H. Ellis, and R.J. Summerfield. 1998. Effects of temperature and photperiod on phenology as a guide to the selection of annual legume cover and green manure crops for hillside farming systems. Field Crop Research 57:139-152.

Klassen, W., M. Codallo, I.A. Zasada and A.A. Abdul-Baki. 2006. Characterization of velvetbean (*Mucuna pruriens*) lines for cover crop use. Proc. Fla. State Hort. Soc. 119:258-262.

Li, Y., A. Hanlon, W. Klassen, Q.Wang, T. Olczyk, and I.V. Ezenwa. Cover crop benefits for south Florida commercial vegetable producers. EDIS publication SL-242. 2006. http://edis.ifas.ufl.edu (June 30, 2009).

Lu, Y.C., K.B. Watkins, J.R. Teasdale, and A.A. Abdul-Baki. 2000. Cover crops in sustainable food production. Food Rev. Int. 16(2):121-157.

Mansoer, Z., D.W. Reeves, and C.W. Wood. 1997. Suitability of sunn hemp as an alternative late-summer legume cover crop. Soil Sci. Soc. Am. J. 61:246-253.

McKee, R., G.E. Ritchey, J.L. Stephens, and H.W. Johnson. 1946. Crotalaria culture and utilization. USDA Farmers Bull. 1980, 17p.

McMahon, K. Waste not. Farm Industry News March 1, 2007. http://farmindustrynews.com/mag/waste_not_manure/index.html. Accessed 11/28/2009.

Morris, J.B. and S.E. Kays. 2005. Total dietary fiber variability in a cross section of *Crotalaria juncea* genetic resources. Crop Sci. 45:1826-1829.

Nanda, K.K. 1962. The emergence and development of branches in *Crotalaria juncea* and their relationship to flowering. Amer. J. Bot. 49:334-341.

Purseglove, J. W. 1974. Tropical Crops Vol. 1-2. Longman Group LTD, London.

Putnam, A.R. and C. Tang. 1986. Allelopathy: state of the science in A.R. Putnam and C. Tang (eds.) The science of allelopathy. John Wiley and Sons, NY. 1-19 p.

Rice, E.L. 1984. Allelopathy. Second Ed. Orlando, FL: Academic Press Inc.

Rotar, P.P. and R.J. Joy. 1983. 'Tropic Sun' sunn hemp, *Crotalaria juncea* L. Research Extension Series 036. University of Hawaii. 7 pp.

Sangakkara, U.R., P.R.S.D. Bandaranayake, D.N.K. Weerakekera, and P. Stamp. 2006. Interseasonal cropping- its potential for managing weeds in the Asia tropics. J. of Plant Dis. and Prot. 20:921-927.

Schomberg, H.H., N.L. Martini, J.C. Diaz-Perez, S.C. Phatak, K.S. Balkcom, and H.L. Bhardwaj. 2007. Potential for using sunn hemp as a source of biomass and nitrogen for the piedmont and coastal plain regions of the southeastern USA Agron. J. 99:1448-1457.

Swisher, M.E. and P. Monaghan. 1995. Florida's organic farmers: a profile. Journal of Extension 33:3.

Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J. Prod. Agric. 9:475-479.

Teasdale, J.R. 1998. Cover crops, smother plants, and weed management. In J.L. Hatfield, D.D. Buhler, and B.A. Stewart (eds) Integrated weed and soil management. Ann Arbor Press, Chelsea, MI: 247-270.

Teasdale, J.R. and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673-680.

Treadwell, D.D., W. Klassen and M. Alligood. 2008. Annual cover crops in Florida vegetable systems part 2: Production. IFAS Publication HS1141.

[USDA]. United States Department of Agriculture. 1983. 'Tropic Sun' sunn hemp. Soil Conservation Service, Program Aid No. 1335. USDA, Washington, DC.

[USDA-NASS]. United States Department of Agriculture. National Agricultural Statistics Service. 2009. Census of Agriculture; United States summary and state data. Vol. 1, Part 51.

[USDA-NASS]. United States Department of Agriculture . National Agricultural Statistics Service. 2010. Census of Agriculture; Organic Production Survey (2008). Vol. 3, Part 2.

[USDA-AMS]. United States Department of Agriculture. Agricultural Marketing Service. 2000. National Organic Program; Final Rule Federal Register 65(246):80548-80684.

USDA-NRCS. 2000. Year 2000 annual technical report. Brooksville, Florida Plant Materials Center. 34-36.

Walz, E. 1999. Third biennial national organic farmers' survey. Santa Cruz, CA. Organic Farming Research Foundation.

Wang, K.H., R. McSorley, and R.N. Gallaher. 2003. Effect of *Crotalaria juncea* amendment on nematode communities in soils with different agricultural histories. J. Nematol. 35(3):294-301.

Wang, Q., Y. Li and W. Klassen. 2005. Influence of summer cover crops on conservation of soil water and nutrients in a subtropical area. J. Soil Water Conserv. 60:58-64.

White, G.A. and J.R. Haun. 1965. Growing *Crotalaria juncea*, a multi-purpose fiber legume, for paper pulp. Econ. Bot. 19:175-183.

BIOGRAPHICAL SKETCH

Alyssa Heh-soon Cho was born and raised in St. Petersburg, Florida. In 2005 Alyssa successfully completed the International Baccalaureate program at St. Petersburg High. She received her Bachelor of Science degree from the University of Hawaii at Manoa in natural resources and environmental management in May 2008. In the fall of that year she began her Master of Science degree in horticultural science under the guidance of Dr. Carlene Chase. Alyssa presented at several state, regional and national conferences, including Weed Science Society of America, Florida Weed Science Society, Southern Weed Science Society, American Society for Horticultural Sciences (ASHS), and Southern Region ASHS meetings. Alyssa plans to continue at the University of Florida with Dr. Gregory MacDonald for her PhD in agronomy with an emphasis in international agricultural development.