Evaluation of a New Sunn Hemp (*Crotalaria juncea* L.) Cultivar in Alabama

by

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Abstract

The southeastern region of the U.S. is often characterized by soils with low innate fertility exacerbated by a history of tillage. Nitrogen (N) is an important and limiting soil nutrient applied to fields to maximize crop yields. As the cost of N supplying fertilizers continues to increase, alternative sources of N are sought. Prior to the advent of artificially derived fertilizers in the last century, leguminous cover crops were a commonly used N source. Southeastern rotations may have a period of time in fields where the land is unutilized after summer harvest and before winter plantings. Sunn hemp (*Crotalaria juncea* L.) is a tropical legume able to produce large quantities of biomass within a short window of time. However, due to limited areas of seed production within the U.S., sunn hemp is difficult to acquire at an affordable price. Recent breeding efforts at Auburn University have produced ‘Selection PBU’, a sunn hemp cultivar able to produce viable seed in the temperate southeastern U.S. Prior to introducing a new plant to the area, a prudent move is to assess the weediness of the non-native. Therefore, an objective of this thesis was to perform a weed risk assessment of ‘Selection PBU’ before southeastern introduction. Secondarily, it was desirable to study cultural practices that maximize the N producing abilities of ‘Selection PBU’. Further objectives of the thesis were to determine optimum planting dates and seeding rates and determine the effect of N from ‘Selection PBU’ on rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.), winter crops commonly grown in the southeastern U.S. To address the first objective, a comprehensive literature review was performed and the Pheloung (1995) weed risk assessment system determined ‘Selection PBU’ to be acceptable as an introduction for southeastern fields. Two separate field studies were conducted to fulfill the next two objectives. In the first study, two fields in Shorter, AL had two planting dates after cash crop harvest and four seeding rates sown. Results showed planting ‘Selection PBU’ early maximized biomass production and N contribution to rye. During times of adequate precipitation, moderate ‘Selection PBU’ seeding rates produced as well as higher seeding rates. A second field study was conducted at Headland, AL and Bella Mina, AL. In this study, ‘Selection PBU’ increased wheat grain yield in two of the five growing seasons. Furthermore, N fertilizer application provided augmentation in wheat grain yields. Results from this thesis study indicate the possibility of ‘Selection PBU’ utilization to provide soil improvement in southeastern crop rotations.

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I. Introduction

Conservation Tillage

The Natural Resources Conservation Service (NRCS) agency of the U.S. Department of Agriculture (USDA) defines conservation tillage as any tillage system leaving at least 30% plant residue on the soil surface after planting in an attempt to reduce soil and water loss (Pierce, 1985). Soil quality improvement occurs over several growing seasons after conservation practices begin as crop residues build and decompose into the soil. Benefits of conservation tillage include reduced soil erosion, increased moisture holding capacity, increased water infiltration, increased nutrient utilization, decreased labor requirements, and improved soil tilth (Pierce, 1985; Brady and Weil, 2002; Phatak et al., 2002). Conservation tillage benefits are typically enhanced by the utilization of cover crops (Langdale et al., 1990; Reeves, 1994).

Cover Crops

Cover crops, generally defined as crops grown to reduce loss of nutrients, pesticides, or sediment from agricultural fields and provide ground cover to reduce soil erosion, are a traditional choice in crop management systems (Reeves, 1994; Dabney et al., 2001; Phatak et al., 2002). Cover crops may be utilized in farming systems as companion crops to cash crops or grown during fallow periods between cash crops in field rotations. Cover crop incorporation provides numerous benefits such as carbon (C) sequestration, increased residue cover, improved soil productivity, integrated pest management, and recycled nutrients (Marshall et al., 2002;

Taboada-Castro et al., 2006; Balkcom et al., 2007). Cover crop residues also affect the amount of nutrients from soils available to subsequent crops (Dalal, 1989; Mehdi et al., 1999).

The predominant cover crop selection in the Southeast is winter annuals, such as cereals (Schomberg et al., 2007). Southeastern cereal cover crops include rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and oat (*Avena strigosa* Schreb.), which are beneficial in nitrogen (N) scavenging (reducing N leaching) and biomass production. Although higher seeding rates are typically used with cereals, the cost of cereal seed is relatively low. Cover crop choice depends on individual preferences such as timing in field rotation, seed cost, and labor. Planting dates and harvest schedules of crop production systems often create restricted periods to maximize the advantages of traditional cover crop use.

In recent years the cost of chemical fertilizer has fluctuated widely, causing farmers to seek alternative nutrient sources to meet their production goals. Aside from financial concerns, environmental concerns arise regarding producers' dependence on chemicals, such as fertilizer leaching and off-site movement. These concerns heighten the attractiveness of biological sources of N (Aulakh et al., 1991). Leguminous cover crops provide additional advantages as cover crops including an ability to fix atmospheric N and extended periods of accruement during the spring compared to other cover crop types (Vaughn and Evanylo, 1998; Cherr et al., 2006a). Legumes have a lower C:N biomass ratio, reducing decomposition time (Vaughn and Evanylo, 1998).

Numerous field studies have shown that N accumulation, biomass production, and C:N ratio are highly variable when factors such as environmental conditions, legume selection, growth stage, and crop management are considered (Aulakh et al., 1991; Reeves, 1994; Ranells and Wagger, 1996; Mansoer et al., 1997; Cline and Silvernail, 2001; Balkcom and Reeves, 2005). Nitrogen behavior from residue is of particular importance due to the N cycle normally consisting of early immobilization and prolonged mineralization of the nutrient (Aulakh et al., 1991; Maskina et al., 1993; McKenney et al., 1995; Mansoer et al., 1997; Medhdi et al., 1999). Thus, cash crop planting dates following cover crops should be planned to best use the nutrients released from the cover crop residue.

Mansoer et al. (1997) stated that “the practical use of winter legume cover crops is often limited by asynchronization of cover crop planting windows and biomass accumulation with planting windows for summer cash crops.” Legumes are further refined by temperature tolerance and divided into “warm weather” and “cool weather” categories, commonly referred to as tropical and temperate (respectively). Yadvinder et al. (1992) found biomass production occurs in tropical legumes at a more accelerated rate than that of temperate legumes. Although unable to withstand hard freezes, tropical legumes continue growth at temperatures >35° C up to 40° C, whereas temperate legumes decline from 25° C to 30° C (Cherr et al., 2006a). Tropical legumes have been found to increase N inputs and soil organic matter levels during the period before winter freezes (Creamer and Baldwin, 2000; Marshall et al., 2002).

Sunn Hemp

Among tropical leguminous cover crops, sunn hemp (*Crotalaria juncea* L.) has a distinguished history beginning with its use as a fiber crop and soil amendment in India (Montgomery, 1954; Bhardwaj et al., 2005). Most varieties of sunn hemp are specific to regions (Kundu, 1964). Early breeders have focused on improving fiber yield, insect resistance, and hastening maturity (Ribeiro et al., 1977; Miranda, 1991). Their results found a plant height and basal stem girth correlation, indicating cultivars capable of producing large biomass quantities may be breed.

The cultivar ‘Tropic Sun’ was introduced by the NRCS in 1983 and has been incorporated into rotations as an intercrop for the southeastern region since 1996 (Mansoer et al., 1997). ‘Tropic Sun’ was notable for producing 5.9 Mg ha^{-1} biomass within a 9 to 12 wk span after August and mid-September planting in Alabama (Mansoer et al., 1997; NRCS, 1999). Due to limited areas suitable for seed production and high seed cost, cultivars other than ‘Tropic Sun’ have not been as widely researched for cover crop utilization (Cook and White, 1996). ‘Tropic Sun’, the standard sunn hemp cultivar that others are compared to, does not set seed well north of 28° N—another reason for limited seed availability (NRCS, 1999). ‘Selection PBU’, recently developed at Auburn University, was derived from ‘PI 322377’, a tropical Brazilian cultivar notable for southern root-knot (*Meloidyne incognita*) and reniform (*Rotylenchulus reniformis*) nematode suppression (Marla et al., 2008). Unlike tropical cultivars, ‘Selection PBU’ successfully produces viable sunn hemp seed in temperate regions north of 28° N (Mosjidis, 2006; Mosjidis, 2007). Increases in seed production area could lead to wider seed availability and lower seed cost.

Current areas of major seed production, such as Hawaii, Brazil, and India, are characterized by high relative humidity, average rainfall between 150 to 200 mm, and daily temperatures between 23° C and 29.4° C during sunn hemp growth period (Dempsey, 1975). Southern Texas has been an area of small-scale seed production in the continental United States; however, yields have been inconsistent due to early freezes (Cook and White, 1996). Although *C. juncea* is considered by the NRCS to have limited weed potential (NRCS, 1999), the genus Crotalaria has been registered as a noxious weed in Arkansas (NRCS, 2007). Due to sunn hemp being a non-native species, the prolificacy and perpetuation of a new sunn hemp cultivar outside of normal growing conditions should be observed. A complete weed risk assessment would contribute to developing management practices for sunn hemp varieties currently used in the Southeast; furthermore, assessing the invasive potential of new sunn hemp cultivar 'Selection PBU' would be beneficial prior to wide-spread usage as it lives beyond tropical conditions (unlike other cultivars) (Mosjidis, 2006; Mosjidis, 2007).

Sunn hemp has been noted to tolerate a wide range of soil types, preferring well-drained conditions making sandy Coastal Plain fields good production area candidates. The relatively innate low fertility of sandy soils in this region may be augmented by the soil organic matter provided by decomposing sunn hemp biomass. The soil amendments would be particularly beneficial for degraded Ultisols that are prevalent across the Southeast (Schomberg et al., 2006; Shaw et al., 2002). Soil organic matter for the southeastern region would need to be sustained by high biomass yields providing consistent recalcitrant residue additions (Collins et al., 1990; Cobo et al., 2002; Cherr et al., 2006a).

Sunn hemp dry matter production and N content during early growth stages were recorded by Cherr et al. (2006b). Four wk after planting (WAP), sunn hemp leaves accounted for 50 to 60% of total dry matter production (Cherr et al., 2006b). Their study found this entire amount was transferred to the stem after another 4 wk interval. Leaves and blooms, which appeared 8 to 10 WAP, held well over 50% of the N concentration at termination 14 WAP (Cherr et al., 2006b). Sunn hemp produces large biomass yields at least 9 WAP in sandy loam soils ranging from 4.8-7.3 Mg ha^{-1} (Mansoer et al., 1997) to 6.1-9.6 Mg ha^{-1} biomass (Ramos et al., 2001). With fertilization, sunn hemp yields 7.6 Mg ha^{-1} (Balkcom and Reeves, 2005) to 12.1 Mg ha^{-1} biomass (Steinmaier and Ngoliya, 2001) 14 WAP. As observed form these biomass yields, length of growth time has influence on vegetative production.

Planting dates of various sunn hemp cultivars differ among areas due to warm-weather conditions and soil moisture (White and Haun, 1965; Cook and White, 1996; Cook et al., 1998; Bhardwaj et al., 2005; Schomberg et al., 2007). A 1962 Kansas field study by White and Haun (1965) found a 2 wk planting delay resulted in 40% less biomass and notable decreases in plant height and stem diameter compared to the same delay in 1963.

Photoperiod length has the greatest impact on sunn hemp biomass production. Pandey and Sinha (1979) found sunn hemp dry weight and leaf area growth reached optimum production with 14 h day-length. Sunn hemp has been found to begin its reproductive growth stage in response to decreasing photoperiods, making it a short-day crop (White and Haun, 1965; Qi et al., 1999).

Marshall et al. (2002) found whole 'Tropic Sun' yielded 138-47-90 kg ha^{-1} of N-P_2O_5-K_2O which roughly translates into a 3:1:2 fertilizer ratio. During this same study, plant termination at mid-bloom was determined to be most beneficial to vegetable systems due to raised macronutrient availability and low C:N ratio (Marshall et al., 2002). Expanded research on 'Tropic Sun' C:N ratio found stem ratios were >20:1, while leaf ratios were <20:1 (Mansoer et al, 1997). Cherr et al. (2006b) confirmed these results by finding sunn hemp retained large amounts of N and slowed decomposition due to the structural portioning of dry matter and minerals to the stem.

Humid weather hastens the breakdown of sunn hemp residue (Cherr et al., 2006a), especially in the leaves and flowers which contain 80.6% of the total sunn hemp N and 66.5% of sunn hemp total phosphorous (P) concentrations (Marshall et al., 2002). Mansoer et al. (1997) suggested that winter temperatures in the southeastern states of Alabama and Georgia "are not cold enough to retard microbial transformations of N to any great extent". Furthermore, overwinter N release from ‘Tropic Sun’ was 75 kg N ha^{-1} in Alabama (Mansoer et al., 1997). At this point, N is subject to denitrification and leaching losses when nutrient scavenging methods are not applied.

Sunn Hemp in Field Rotations

Sunn hemp has been extensively grown as a soil amendment; however, the N contribution of sunn hemp has only been assessed in limited studies. Schomberg et al. (2007) appraised the performance of sunn hemp in regard to maximizing biomass and N content to provide southeastern producers production estimates. Study results were favorable and recommended further studies on scavenging residual N following the crop.

Winter cereal cover crop planted following sunn hemp termination may be beneficial to optimize ‘Tropic Sun’ N mineralization and reduce N losses before cash crop planting (Marshall et al., 2002; Balkcom and Reeves, 2005; Cherr et al., 2006b). Rye may be planted as a winter cover crop to reduce erosion by providing ground cover; however, it is more notable for its ability to scavenge nutrients from the soil via its extensive root system. Studies have found rye effectively scavenged residual N made available by overwintering residue, improving the efficiency of increased mineralizable N (Dabney et al., 2001; Schomberg et al., 2007). However, few studies have been conducted on the scavenging ability of rye following sunn hemp in rotation with a cash crop such as corn (*Zea mays* L.) or wheat.

Sunn hemp cannot totally fulfill “all or two-thirds of the recommended rate of synthetic N without significant loss of sweet corn ear yield” (Cherr et al., 2006b). Balkcom and Reeves (2005) found planting ‘Tropic Sun’ as a cover prior to corn resulted in reduced N fertilizer needs and increased grain yields for corn. However, precipitation after ‘Tropic Sun’ termination appeared to have a stronger effect on corn yield and grain content (Balkcom and Reeves, 2005).

This response was attributed to increased precipitation surpassing evapotranspiration, increasing N loss through leaching and denitrification, effectively lowering N available to the next crop (Balkcom and Reeves, 2005).

Another alternative would be to utilize the residual N from sunn hemp on a subsequent wheat cash crop. Few studies have been conducted in this area, but a wide array of literature suggests that winter cereal crops would successfully utilize N mineralized from sunn hemp during the winter if planted immediately after sunn hemp termination (Mansoer et al., 1997; Balkcom and Reeves, 2005; Cherr et al., 2006b).

As we look to the future, more ecologically responsible methods of supplying nutrients are sought for application to current crop management systems. These methods need to utilize our current resources in a beneficial manner to producers. Sunn hemp seed availability should increase with the introduction of 'Selection PBU', a temperate sunn hemp cultivar. The capabilities of sunn hemp appear to be quite favorable; however, the usage of this promising cover crop need to be further refined. An aforementioned weed risk assessment would be a prudent method to evaluate the riskiness of sunn hemp cultivars introduction and continuation in the Southeast. Future research on these topics would greatly contribute to southeastern crop management.

Experimental Objectives

To address the aforementioned points, three objectives were created for this research thesis:

1. To utilize the Pheloung (1995) system for conducting a weed risk assessment of sunn hemp on the basis of deciding its introduction to southeastern U.S.
2. To assess the performance of 'Selection PBU' for two planting dates following corn and wheat harvest across different seeding rates. Secondarily, to determine how a

cereal rye cover crop responds to subsequent sunn hemp biomass levels and N contents.

3. To determine if the N accumulation of sunn hemp cover crop would provide an alternative to winter wheat N fertilizer application in Alabama.

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II. A Weed Risk Assessment of Sunn Hemp in Southeastern United States

Abstract

Sunn hemp (*Crotalaria juncea* L.) is non-native to the U.S. and understanding its potential impact following introduction to this region would contribute in management decisions. Information on the biology and management of sunn hemp was collected and analyzed for a risk assessment across southeastern U.S. Literature regarding biographical/historical and biological/ecological research was gathered to address the potential invasiveness of sunn hemp and 'Selection PBU', a newly developed sunn hemp cultivar. The Pheloung (1995) weed risk assessment found despite climate match, alkaloid toxicity, and persistence attributes, sunn hemp and 'Selection PBU' should not be considered introduction risks. Sunn hemp and 'Selection PBU' growth in the Southeast may proceed with more assurance.

Introduction

To augment inherently low fertility soils of the southeastern region, producers may use legumes to provide nitrogen (N) to crops and improve soil characteristics. Sunn hemp (*Crotalaria juncea* L.) is a tropical legume indigenous to India notable for producing 5.9 Mg ha^{-1} biomass within a 9 to 12 wk span after August and mid-September plantings in Alabama (Mansoer et al., 1997; NRCS, 1999). Previous publication on the suitability of sunn hemp cultivation in the U.S. predates the 20th century (Smith, 1896). In the U.S., cover crop research involving sunn hemp began in the early 20th century (Waksman, 1917) and continued research during the 1930s found sunn hemp adept at improving soil conditions (Cook and White, 1996).

During 1983, ‘Tropic Sun’—currently a widely used sunn hemp cultivar—was jointly released by the USDA-NRCS and the University of Hawaii after seed was acquired from a Hawaiian farmer in 1958 (Rotar and Joy, 1983). Experimental sunn hemp has provided biomass residue and supplemental N in southeastern rotations (Balkcom and Reeves, 2005; Schomberg et al., 2007; Bauer et al., 2009). However, sunn hemp is a tropical plant unable to produce viable seed beyond tropical environments (NRCS, 1999). In the U.S., production is limited to the Hawaiian islands, the territory of Puerto Rico, and southern parts of Florida and Texas below 28° N latitude. Recent breeding efforts at Auburn University, AL have resulted in ‘Selection PBU’, a sunn hemp cultivar able to produce viable seed within temperate climates (Mosjidis, 2006; Mosjidis, 2007). ‘Selection PBU’ was developed using tropical ‘PI 322377’, a Brazilian cultivar notable for southern root-knot (*Meloidogyne incognita*) and reniform (*Rotylenchulus reniformis*) nematode suppression, at the Plant Breeding Unit (PBU) of the E.V. Smith Research Center near Tallassee, AL (Mosjidis, 2006; Mosjidis, 2007; Marla et al., 2008). Establishing ‘Selection PBU’ could improve sunn hemp usage as this temperate cultivar could have larger production area, improved availability, and lower seed cost.

Prior to introducing sunn hemp (which is non-native to the U.S.) and ‘Selection PBU’, it would be prudent to assess potential threat statuses to existing systems. Kudzu (*Pueraria Montana* Lour.) is a well-known example of a non-native invasive plant species introduced before its weed potential was evaluated (Forseth and Innis, 2004). Knowledge on the threat of exotic plant introduction to native species has greatly improved over the last few decades and has become an independent branch of research. Weed risk assessments serve to identify and prevent the entry and initial expansion of species likely to be invasive. These assessments often focus on the immediate impact of introduced species. The economic impacts of potential introductions have a higher priority than prospective problems, i.e., associated plant disease, related pest insect (Parker and Reichard, 1998; Westbrooks, 1998; White and Schwarz, 1998; Pimentel et al., 2000; Lodge and Shrader-Frechette, 2003). Various risk assessment systems are utilized globally which review extrinsic and intrinsic plant qualities for potential non-native introductions (Hiebert and Stubbendieck, 1993; Pheloung, 1995; Daehler et al., 2004; Gordon et al., 2008; Randall et al., 2008). The assessment criteria of most WRAs is related to plant species biology, climate suitability, incursion background, and undesirable characteristics (Parker et al., 2007; Gordon et al, 2008). Some systems find success in weed risk classification by relying on the invasiveness of the non-native species elsewhere (Reichard, 1994; Daehler et al., 2004).

Weed risk systems are constantly evolving and the recent trend in weed assessments is toward numeric scoring (Groves et al., 2001; Werren, 2001). In the U.S., weed restrictions are governed by state (Hiebert and Stubbendieck, 1993) and generally apply to existing weed problems (Randall et al., 2008). Additionally, the USDA Animal and Plant Health Inspection Service (APHIS) publishes a Federal Noxious Weed List to prevent interstate movement of weeds and their importation (APHIS, 2010). Risk assessment procedures are largely founded on the experience of Australia, New Zealand, and Hawaii (areas of endemic plant ecology). These areas include formal weed assessments among operational protocols for weed introduction prevention and prohibited species reduction (Pheloung, 1995). Werren (2001) reviewed risk assessment on 4 systems for “preventative quarantine purposes” and 8 systems for “prioritizing existing weed incursions”. Upon this review, the clear quantitative bases and flexible tiered system of Pheloung (1995) was deemed an improved method of appraising non-native plant introduction over other simpler and more rigid weediness assessment systems (Hazard, 1988;

Panetta, 1993). Werren (2001) found less complex systems rejected non-problem plants and created superfluous “evaluate” recommendations.

By comparing agricultural, botanical, and conservational expert rating against modeling, Pheloung et al. (1999) found classifications correlated well and significant inputs were made by all weed risk assessment parts. Gordan et al. (2008) reported the Pheloung system adaptable to areas beyond Australia. Daehler and Carino (2000) found the modified Pheloung (1995) system was more successful than the systems of Reichard and Hailton (1997) and Tucker and Richardson (1995) at accurately distinguishing potentially invasive weeds for Hawaii. These results, paired with Werren (2001), offered the Australian weed risk assessment protocols (Pheloung, 1995) as appropriate to measure sunn hemp weediness. Therefore, the objective of the study is to utilize the Pheloung (1995) system for conducting a weed risk assessment of sunn hemp and the newly developed cultivar, ‘Selection PBU’, on the basis of deciding its introduction to southeastern U.S.

Weed Risk Assessment

Literature on biological, ecological, and biogeographical qualities of sunn hemp were assembled for the Pheloung (1995) weed risk assessment (Table 1.01). This modified assessment is presented in 8 sections which have subsections addressing the agricultural, environmental, and nuisance aspects of sunn hemp (Table 1.02). The island areas where the Pheloung (1995) system was developed are considered more vulnerable to introduced species establishment and expansion than larger land areas (Lonsdale, 1999). Utilizing this system would provide a very conservative approach for the southeastern region. Following the WRA of tropical sunn hemp, a separate WRA assessed the unique traits of ‘Selection PBU’ for southeastern U.S. introduction of this temperate cultivar. ‘Selection PBU’ traits are further elaborated on within the discussion section.

Similar to Daehler et al. (2004), the scope of some environmental questions was altered for this assessment based on differences in area of potential introduction. All aspects were addressed, although all questions were not required to be answered (Pheloung, 1995). The format of the assessment is similar to that of Pheloung (1995), 2 literature blocks further separated into 8 sections (3 in biographical/historical literature, 5 in biology/ecology literature). Within each section specific questions are answered and a point value is assigned to the answer (Table 1.01).

Biographical/Historical Literature

Section 1: Domestication/Cultivation

Sunn hemp cultivation has been centered on India where it is grown as a fiber crop (Montgomery, 1954; Cook and White, 1996). Despite long standing historical use in southeastern Asia (White and Haun, 1965), sunn hemp has not drastically diverged from its wild relatives due to a lack of selective cultivation. Usually, this domestication process involves over 20 generations of breeding and produces a cultivar unable to flourish outside of cultivated areas (Daehler et al., 2004). Most cultivars originated from the selection of improved types suited to specific localities (Purseglove, 1968; Dempsey, 1975). Past attempts to develop cultivars from interspecific crosses among *Crotalaria* have not been successful (Kundu, 1964). Although the genus *Crotalaria* contains some well-known pest plants (e.g. *Crotalaria spectabilis* Roth), sunn hemp does not have any known rampant weedy varieties. Some concern regarding sunn hemp introduction to a new area would be due to the congeneric banning of the entire *Crotalaria* genus, such as in the state of Arkansas (Arkansas State Plant Board, 1997).

Section 2: Climate/Distribution

Sunn hemp is well suited to climates with moderate to high humidity and warm temperatures (McKee et al., 1946; Dempsey, 1975; Duke, 1981; Qi et al., 1999), like the southeastern region of the U.S. (Kimmel, 2000). Köppen (1936) classification found summer southeastern U.S. climatic conditions, including precipitation, were comparable to humid tropics (Kimmel, 2000). Tropical sunn hemp is adapted to droughty, low fertility soils and warm temperatures common to Florida (Seneratne and Ratnasinghe, 1995; Cook and White, 1996; Cherr et al., 2006). Although it did not produce seed due to photoperiod requirements, 'Tropic Sun' was grown experimentally in the southeastern U.S. (Balkcom and Reeves, 2005; Schomberg et al., 2007). Studies in the U.S. found tropical sunn hemp would not mature in Maryland (McKee et al., 1946) and did not establish in the southwest, despite irrigation (McLeod, 1982). Although sunn hemp may grow up to 600 m altitude (Valenzuela and Smith, 2002), Yost and Evans (1988) suggest best growth is below 300 m. Dempsey (1975) reported sunn hemp should receive 170-200 mm rainfall during its summer growing season, which the southeastern climate typically provides (Kimmel, 2000). Sunn hemp is vulnerable to frost (Miller et al., 1989) and its growth may be delayed during cool seasons (Yost and Evans, 1988). McKee et al. (1946) reported sunn hemp tolerated low temperatures of -2.2° C without damage.

Section 3: Weed Elsewhere

Tropical sunn hemp cultivation in the southeast is currently limited to Florida (Wunderlin and Hansen, 2002). Historically, 'Tropic Sun' has been grown in Hawaii (Rotar and Joy, 1983) and naturalized within the area (Evenhuis and Miller, 1997). The U.S. territories of Puerto Rico (Loigier, 1994) and the Virgin Islands (Britton and Wilson, 1926) had sunn hemp naturalization after its introduction for agricultural purposes. However, no accounts of weediness within these areas have been noted. Sunn hemp seedling vulnerability to mechanical damage (Yost and Evans, 1988) could reduce the likelihood of it becoming an agricultural weed in conventional tillage systems. With the exception of the recently developed temperate cultivar ‘Selection PBU’, tropical sunn hemp is unable to produce viable seed at latitudes above 28° N, reducing its weed potential as it is unable to complete a successful lifecycle (Wang and McSorley, 2004). Outside of the U.S., no other documentation of sunn hemp invasiveness was found. Within the U.S., Arkansas has a state law banning introducing *Crotalaria* spp. due to noxious congeneric weeds (Arkansas State Plant Board, 1997).

Biology/Ecology Literature

Section 4: Undesirable Traits

Some *Crotalaria* spp. excrete monocrotaline, a plant-parasitic nematicide (Gommers and Bakker, 1988; Fassuliotis and Skucas, 1969) and many *Crotalaria* spp. seeds contain toxic pyrrolizidine alkaloids (Cook and White, 1996; Ji et al., 2005). Trichodesmine was identified as the principle sunn hemp toxic alkaloid (Zhang, 1985). Leather and Forrence (1990) found sunn hemp seed extract inhibited leafy spurge (*Euphorbia esula* L.) and restrained germination in some small seeded weeds (Alder and Chase, 2007).

Unlike most congeners (Yost and Evans, 1988; Valenzuela and Smith, 2002), ‘Tropic Sun’ is deemed non-toxic (USDA, 1999). Reddy et al. (1999) reported sheep (*Ovis aries*) may be fed up to 45% sunn hemp hay without serious illness. Hess and Mosjidis (2008) found broiler (*Gallus domesticus*) performance was reduced with elevated levels of ‘Selection PBU’ seed in feed (5%), but mortality was unaffected. *Crotalaria* spp. seed toxicity is due to pyrrolizidine alkaloids (Cook and White, 1996) which oxidases in the liver convert to powerful toxins (Mattocks, 1978). Alkaloid contents may vary by sunn hemp maturity at termination and cultivar selection, thus resulting in the conflicting results found among sunn hemp poisoning studies. Sunn hemp seed alkaloids have been attributed to poisoning and decreased performance in pigs (*Sus scofa domesticus*) (Duke, 1981; Zhang, 1985), horses (*Equus caballus*) (Nobre et al., 1994), and other livestock (McKee et al., 1946; Russell et al., 1997) when fed seeds. However others found sunn hemp seed had no alkaloid toxicity as a feed to swine and horses (Purseglove, 1981), or cattle (*Bos taurus*) and sheep (Anonymous, 1921; Timon, 1929). Agricultural Research Services Poisonous Plant Laboratory and the University of Hawaii also determined 'Tropic Sun' seeds were not toxic to livestock (Rotar and Joy, 1983). When grazed, fresh sunn hemp had limited palatability to animals and drying sunn hemp to make hay is suggested to increase palatability (Duke, 1981). 'Tropic Sun' has been deemed palatable to livestock (Rotar and Joy, 1983). Morris and Kays (2005) suggested sunn hemp as a dietary fiber source using a variety low in phytochemicals.

Sunn hemp demonstrates nematode resistance, including sedentary plant-parasites (McKee et al., 1946; Rotar and Joy, 1983; Wang and McSorley, 2004). It is a non- or poor host and produces some allelopathic chemicals, including the nematicide monocrotaline (Valenzuela and Smith, 2002), to stop reniform (*Rotylenchulus reniformis* Linford and Olivera), root-knot (*Meloidogyne* spp.), and soybean cyst (*Heterodera glycines* Ichinohe) nematodes (Wang et al., 2002), which are agronomic pests in the Southeast. During its reproductive stage, sunn hemp harbors high densities of the western tarnished plant bug (*Lygus hesperus* Knight), a cotton (*Gossypium* spp.) pest in the western U.S., specifically California (M. Van Horn pers. comm. to SAREP). In Hawaii, sunn hemp was a host to the stink bug (*Nezara viridula*), a common insect pest (Davis, 1964). Within the Southeast, no published reports of sunn hemp harboring local pests or pathogens are published.

Sunn hemp is not extensive across southeastern ecosystems and presents little risk as a fire hazard. Sunn hemp has an up-right cylindrical stalk lacking sharp structures such as burrs, spines, or thorns (Cook and White, 1996). Its production is optimized with 14 h day lengths (Pandey and Sinha, 1979) and plants typically flower in response to shortening day-length (Yost and Evans, 1988). Indian accessions are shade intolerant; reducing light availability decreases sunn hemp growth (Pandey and Sinha, 1979).

Sunn hemp grows in infertile areas (McKee, 1946; Duke, 1981; Miller et al., 1989) and sandy soils (McKee et al., 1946; Yost and Evans, 1988). Well-drained (McKee et al., 1946) and acidic soils (McLeod, 1982; Miller et al., 1989) are preferred. Sunn hemp has low salinity tolerance (Duke, 1981; Yost and Evans, 1988). Due to its adaptability on less than desirable soils, sunn hemp has been used as a soil improving crop (Cook and White, 1996). Furthermore, sunn hemp is the quickest growing of its genus and smothers weeds (Burnside and Williams, 1968; Yost and Evans, 1988).

Section 5: Plant Type

Sunn hemp is a terrestrial herbaceous legume unable to tolerate wet lands (McLeod, 1982; Yost and Evans, 1988). As a legume, sunn hemp forms symbiotic relationships with *Rhizobia* spp. on its roots and fixes N. Sunn hemp is non-geophytic and has a strong taproot on which nodules reaching 2.5 cm diameter form (Duke, 1981). Plants grow erect up to 3 m and do not climb. It is found very rarely as a perennial shrub outside of cultivation (White and Haun, 1965). Within the Southeast, ‘Tropic Sun’ has been cultivated in field rotations as a summer annual.

Section 6: Reproduction

Sunn hemp is usually photoperiod sensitive and most cultivars, including ‘Tropic Sun’ and ‘Selection PBU’, flower in response to shortening day-length (White and Haun, 1965). Sunn hemp racemes have showy yellow flowers which develop into fruiting pods. Sunn hemp cross-pollinates, however self-pollination may occur after insect or mechanical stimulation of the stigma (Kundu, 1964; Purseglove, 1968). Sunn hemp is reportedly self-incompatible (Cook and White, 1996), but self-compatible breeding efforts have been made to assist in developing pure lines (Ribeiro et al., 1977; Miranda, 1991).

Sunn hemp production has occurred in southern Texas and Florida on a small scale (Cook and White, 1996). ‘Selection PBU’ is the only known variety able to produce viable seed above 28° N latitude (Mosjidis, 2006; Mosjidis, 2007), increasing the risk of naturalizing ‘Selection PBU’ if not managed. Sunn hemp reproduces by seed, and no evidence of reproduction by vegetative fragmentation has been observed. Sunn hemp maturity occurs quickly, within several weeks after planting in the correct environment (Duke, 1981; Yost and Evans, 1988). Viable seed production is dependent on environmental conditions (McKee et al., 1946).

Section 7: Dispersal Mechanisms

Sunn hemp historically has been introduced intentionally as a soil amending plant, fiber source, and fodder supply (Rotar and Joy, 1983). *Crotalaria* spp. seed is a contaminant by USDA grain standards as their size is similar to that of soybean (*Glycine max* L.) making cleaning more difficult (USDA, 1999). McKee et al. (1946) found sunn hemp “although blooming freely, produces very little seed”. A sunn hemp seed measures up to 6 mm in length and seed weight varies by cultivar and environmental effect (t’Mannetje, 1988). Pods contain an average of 6 flattened, kidney-shaped seeds which have a smooth thick coat (Dempsey, 1975;

Cook and White, 1996). Sunn hemp seed is spread naturally by the pod opening and dropping the seed. Wind dispersal is unlikely as the seed is sizable and has smooth surfaces. Dispersal by animal is also unlikely as sunn hemp is often unpalatable. In the event of ingestion, the coat of sunn hemp heightens viability likelihood in the event the propagule passes through digestive systems.

Section 8: Persistence Attributes

Sunn hemp is able to volunteer in cultivated fields over a number of years, possibly providing a propagule bank (McKee et al., 1946). Although sunn hemp seedlings are vulnerable to mechanical damage (Yost and Evans, 1988), cutting sunn hemp at 90 cm 100 d after planting increased biomass production and flowering (Abdul-baki et al., 2001). Similarly, Potter et al. (2007) planted tropical sunn hemp in May, mowed at 100 cm, and found it regrew to 150 cm by October. Although sunn hemp has no registered herbicides (Cook and White, 1996), unwanted tropical sunn hemp is effectively controlled by 2,4-D (2,4-dichlorophenoxyacetic acid) application (Duke, 1981). The natural enemies of sunn hemp present in southeastern U.S. include the lima bean pod borer (*Etiella zinckenella* Treit.) and bella moth (*Utetheisa bella* L.), which feed on pods (Seale et al., 1957). Fall armyworms (*Spodoptera exigua*) have also been found to suppress sunn hemp growth in the region. Numerous fungi, bacteria, and viruses are also present in the area which attack sunn hemp leaves, stems, and pods (McKee et al., 1946; Kundu, 1964; Duke, 1981; Cook and White, 1996; Valenzuela and Smith, 2002).

Discussion

The Pheloung (1995) weed risk assessment system indicated the weed potential of tropical sunn hemp was minimal. Lodge et al. (2006) highlighted the benefits of focusing on 4 aspects (environmental matching, propagule pressure, species characteristics, and expert opinion). Areas of exploration for the Pheloung (1995) weed risk assessment of tropical sunn hemp matched these recommendations, with the exception of expert opinion as literature was substituted. ‘Tropic Sun’ has already been introduced as an experimental or limited acreage crop in the Southeast with no reports of weediness. This is due to an inability of tropical sunn hemp to complete a life cycle and produce viable seed above 28° N latitude. The ability of sunn hemp to fix N from the soil may provide a competitive advantage over nonleguminous plants (Fogarty and Facelli, 1999.) A competitive advantage of sunn hemp is its intentional introduction by humans due to leguminous properties. Mulvaney (2001) found naturalization likelihood significantly increased when planting frequency rose. Beyond cultivation, the physical distribution of sunn hemp is limited despite its suitability to natural areas and introduced areas. This could be attributed to the dispersal mechanism of sunn hemp seed, which is limited to gravity scattering seed after the pod splits open; thus most seed falls directly under the plant. This trait is common to *Crotalaria* spp. Furthermore, the unpalatability of sunn hemp and seed alkaloid toxicity (common to *Crotalaria* spp.) would not contribute to natural spread via bird or animal.

Using the Pheloung (1995) weed risk assessment, overall results indicated introducing tropical sunn hemp to the southeastern region of the U.S. is low risk. Beyond this assessment, accurate predictions of weediness would be to observe further experimental responses of the temperate sunn hemp cultivar, ‘Selection PBU’ in the Southeast. ‘Selection PBU’ has been limited to controlled field experiments, thus its capabilities were measured to ensure invasion potential is limited.

Maximum WRA climate match values have been made. The climatic suitability in a large area of the southeastern U.S. may cause potential sunn hemp naturalization if ‘Selection PBU’ is unattended. This is due to the ability of ‘Selection PBU’ to produce viable seed in temperate areas; tropical sunn hemp cultivars are unable to produce viable seed above 28° N latitude. ‘Selection PBU’ adaptability in the region is heightened by its versatility in a wide range of soil conditions. Temperate ‘Selection PBU’ may last longer within the Southeast than its tropical peers and effective chemical termination has been found. Mosjidis and Wehtje (2010) achieved consistent weed control and adequate ‘Selection PBU’ performance in Alabama with pre-emergent pendimethalin (*N*-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine) and imazethapyr (2-(4,5-dihydro-4-methyl-4-(1-methltheyl)-5-oxo-1H-imidazol-2-yl)-5-ethyl-3-pyridinecarboxylic acid). Post-emergent ‘Selection PBU’ control (termination) is reported with glyphosate (*N*-(phosphonomethyl) glycine). Managing ‘Selection PBU’ within southeastern conditions will aid in addressing best management practices of the temperate cultivar.

Evaluating areas of ‘Selection PBU’ usage is also key. ‘Selection PBU’ population evaluation suggests its cover cropping N contributions may be substantial and depend on planting date. As a feed, broilers ingesting ‘Selection PBU’ seed for 21 d had no fatality or unusual pathology (Hess and Mosjidis, 2008). Hess and Mosjidis (2008) observed lower than control bird weight after 5% ‘Selection PBU’ seed inclusion in diet and control-similar bird weight at 0.5% ‘Selection PBU’ contamination level. Hess and Mosjidis (2008) reported lower feed conversion when ‘Selection PBU’ seed was included in broiler diet, suggesting less palatability. Mosjidis and Sladden (2006) analytically evaluated ‘Selection PBU’ as fodder and reported fair fodder quality with leaves and stems, excellent fodder quality with leaves, and poor fodder quality with stems.

‘Selection PBU’ is well-suited for southeastern production. Southeastern regional evaluation per worst case scenario using WRA found ‘Selection PBU’ to be low-risk introduction (Table 1.03). With increased availability, higher intentional human dispersal is likely; however, volunteer 'Selection PBU' is treatable as chemicals are available to prevent unwanted growth. The invasive potential of 'Selection PBU' is small, as it has limited dispersal mechanisms and low palatability. Within Pheloung (1995) classification, the score of 'Selection PBU' (Table 1.03) is low and survey classification places it within "non-weed" category (Table 1.04).

Conclusion

Tropical sunn hemp and temperate cultivar 'Selection PBU' should not be considered risky introductions to the southeastern U.S. region. Historically sunn hemp has limited weed history elsewhere despite short generative time and soil tolerance. Interest in sunn hemp for its abilities as a soil amender contributes to its wide distribution by people for agricultural purposes. 'Selection PBU' and 'Tropic Sun' sunn hemp cultivars have already been introduced as a crop in the Southeast. However, poor natural dispersal mechanisms and the limited region of viable seed production (excluding cultivar 'Selection PBU') contribute to reduced WRA and reduced impact area beyond cultivation. 'Selection PBU', despite producing seed, is not a threat due to aforementioned literature and a low-risk introduction using the Pheloung (1995) system.

Panetta et al. (2001) found the Pheloung (1995) system more effective at identifying agricultural weeds than environmental and this assessment found similar results (Table 1.02). Agriculturally and environmentally, 'Selection PBU' will likely not be a threat to the southeastern U.S. Assessment for introduction to the region is important to provide agricultural communities with usage guidelines and to increase relevant knowledge exposure. Public interest in 'Selection PBU' and sunn hemp overall is unlikely to decrease, especially as the environmental impacts of nonnative introductions receive heightened attention.

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Table 1.01. Results for Pheloung (1995) weed risk assessment of sunn hemp.

Section	Question	Answer	Score
1.01	Is the species highly domesticated?	No	0
1.02	Has the species become naturalized where grown?	No	0
1.03	Does the species have weedy races?	No	0
2.01	Species suited to southeastern US climate	Medium	1
2.02	Quality of climate match (0-low, 1-medium, 2-high)	Medium	1
2.03	Broad climate suitability (Environmental versatility)	No	0
2.04	Native/naturalized in similar regions	Yes	1
2.05	Repeated introductions outside of its natural range	Yes	-2
3.01	Naturalized beyond native range	No	0
3.02	Garden/amenity/disturbance weed	No	0
3.03	Agricultural/forestry/horticultural weed	No	0
3.04	Environmental weed	No	0
3.05	Congeneric weed	Yes	1
4.01	Produces spines, thorns, or burrs	No	0
4.02	Allelopathic	Yes	1
4.03	Parasitic	No	0
4.04	Unpalatable to grazing animals	Yes	1
4.05	Toxic to animals	No	0
4.06	Host for local recognized pests and pathogens	No	0
4.07	Causes allergies or otherwise toxic to humans	No	0
4.08	Creates a fire hazard in natural ecosystems	No	0
4.09	Is shade tolerant at some stage of its life cycle	No	0
4.10	Grows on infertile soils	Yes	1
4.11	Climbing or smothering growth habit	No	0
4.12	Forms dense thickets	No	0
5.01	Aquatic	No	0
5.02	Grass	No	0
5.03	Nitrogen fixing woody plant	No	0
5.04	Geophyte	No	0
6.01	Evidence of substantial reproductive failure	Yes	0
6.02	Produces viable seed	No	0
6.03	Hybridizes naturally	No	-1
6.04	Self-compatible or apomictic	No	0
6.05	Requires specialist pollinators	No	0
6.06	Reproduction by vegetative fragmentation	No	-1
6.07	Minimum generative time (years)	1 year	1
7.01	Propagules likely to be dispersed unintentionally	No	-1
7.02	Propagules dispersed intentionally by people	Yes	1
7.03	Propagules likely to disperse as produce contaminant	No	-1
7.04	Propagules adapted to wind dispersal	No	-1
7.05	Propagules buoyant	No	-1
7.06	Propagules bird dispersed	No	-1
7.07	Propagules dispersed by other animals (externally)	No	-1
7.08	Propagules dispersed by other animals (internally)	No	0
8.01	Prolific seed production (> 1000 m^2)	No	0
8.02	Persistant propagule bank is formed (> 1 yr)	Yes	1
8.03	Well controlled by herbicides	Yes	-1
8.04	Tolerates or benefits from mutilation/cultivation/fire	Yes	1
8.05	Effective natural enemies present locally	Yes	-1
	WEED RISK ASSESSMENT RESULT	Low risk	-1

Table 1.02. Frequency of sunn hemp weed aspect classification based on Pheloung (1995) weed risk assessment.

Section		Aspect			Answer	
Biographical/Historical		Agriculture	Environment	Nuisance	Yes	No
1. Domestication	1.01	■				X
	1.02	■	●	▲		X
	1.03	■	●	▲		X
2. Climate/Distribution	2.03	■	●	▲		X
	2.04	■	●	▲	X	
3. Weed elsewhere	3.01	■	●	▲		X
	3.02			▲		X
	3.03	■				X
	3.04		●			X
Biology/Ecology						
4. Undesirable traits	4.01	■				X
	4.02	■	●	▲	X	
	4.03	■	●	▲		X
	4.04	■			X	
	4.05	■	●	▲		X
	4.06	■	●	▲		X
	4.07			▲		X
	4.08		●			X
	4.09		●			X
	4.10		●		X	
	4.11		●			X
	4.12		●			X
5. Plant type	5.01		●			X
	5.02	■	●	▲		X
	5.03		●			X
	5.04	■	●	▲		X
6. Reproduction	6.01	■	●	▲		X
	6.02	■	●	▲	X	
	6.03	■	●	▲		X
	6.04	■	●	▲		X
	6.05	■	●	▲		X
	6.06	■	●	▲		X
	6.07	■	●	▲		X
7. Dispersal mechanisms	7.01	■				X
	7.02	■	●	▲	X	
	7.03	■				X
	7.04	■	●	▲		X
	7.05		●			X
	7.06		●			X
	7.07	■	●	▲		X
	7.08	■	●	▲		X
8. Persistence attributes	8.01	■	●	▲		X
	8.02	■			X	
	8.03	■			X	
	8.04	■			X	
	8.05		●		X	

Weediness Aspect	Frequency‡
Agriculture	8
Environment	6
Nuisance	4

† ■ = Agricultural aspect question; ● = Environmental aspect question; ▲ = Nuisance aspect question
‡ Frequency is the number of yes responses for the aspect

Table 1.03. Results for Pheloung (1995) weed risk assessment of sunn hemp cultivar ‘Selection PBU’.

Section	Question	Answer	Score
1.01	Is the species highly domesticated?	No	0
1.02	Has the species become naturalized where grown?	No	0
1.03	Does the species have weedy races?	No	0
2.01	Species suited to southeastern US climate	High	2
2.02	Quality of climate match (0-low, 1-medium, 2-high)	High	2
2.03	Broad climate suitability (Environmental versatility)	No	0
2.04	Native/naturalized in similar regions	Yes	1
2.05	Repeated introductions outside of its natural range	Yes	-2
3.01	Naturalized beyond native range	No	0
3.02	Garden/amenity/disturbance weed	No	0
3.03	Agricultural/forestry/horticultural weed	No	0
3.04	Environmental weed	No	0
3.05	Congeneric weed	Yes	1
4.01	Produces spines, thorns, or burrs	No	0
4.02	Allelopathic	Yes	1
4.03	Parasitic	No	0
4.04	Unpalatable to grazing animals	Yes	1
4.05	Toxic to animals	No	0
4.06	Host for local recognized pests and pathogens	No	0
4.07	Causes allergies or otherwise toxic to humans	No	0
4.08	Creates a fire hazard in natural ecosystems	No	0
4.09	Is shade tolerant at some stage of its life cycle	No	0
4.10	Grows on infertile soils	Yes	1
4.11	Climbing or smothering growth habit	No	0
4.12	Forms dense thickets	No	0
5.01	Aquatic	No	0
5.02	Grass	No	0
5.03	Nitrogen fixing woody plant	No	0
5.04	Geophyte	No	0
6.01	Evidence of substantial reproductive failure	No	0
6.02	Produces viable seed	Yes	1
6.03	Hybridizes naturally	No	-1
6.04	Self-compatible or apomictic	No	0
6.05	Requires specialist pollinators	No	0
6.06	Reproduction by vegetative fragmentation	No	-1
6.07	Minimum generative time (years)	1 year	1
7.01	Propagules likely to be dispersed unintentionally	No	-1
7.02	Propagules dispersed intentionally by people	Yes	1
7.03	Propagules likely to disperse as produce contaminant	No	-1
7.04	Propagules adapted to wind dispersal	No	-1
7.05	Propagules buoyant	No	-1
7.06	Propagules bird dispersed	No	-1
7.07	Propagules dispersed by other animals (externally)	No	-1
7.08	Propagules dispersed by other animals (internally)	No	0
8.01	Prolific seed production (> 2000 m^{-2})	No	0
8.02	Persistant propagule bank is formed (> 1 yr)	Yes	1
8.03	Well controlled by herbicides	Yes	-1
8.04	Tolerates or benefits from mutilation/cultivation/fire	Yes	1
8.05	Effective natural enemies present locally	Yes	-1
	WEED RISK ASSESSMENT RESULT	Low risk	1

Table 1.04. Partitioning species by Pheloung (1995) weed risk assessment score and survey classification.

Score	Serious Weeds	Minor Weeds	Non-weeds
		Accept	
-14			*Camellia japonica*
-13			*Cedrus atlantica*
-12			*Magnolia campbelli*
-11			*Chamaecyparis pisifera*
-10			*Acer palmatum*
-9			*Antirrhinum majus*
-8			*Stapelia nobilis*
-7		*Buddleia crispa*	*Lupinus albus*
-6		*Cistus ladanifer*	*Raphanus sativus*
-5		*Aristolochia elegans*	*Secale cereale*
-4		*Buddleia davidii*	*Triticum aestivum*
-3		*Chamaecyparis lawsoniana*	*Fagopyrum spp.*
-2		*Melilotus alba*	*Lupinus* "Russell" hybrids
-1		*Phleum pratense*	*Trifolium hirtum, Crotalaria juncea*
0		*Poa trivialis*	*Vicia villosa*
		Evaluate	
1	*Salix babylonica*	*Homeria elegans*	*Avena sativa, Crotalaria juncea cv. Selection PBU*
2	*Olea europea*	*Agrostis stolonifera*	*Glycine max, Zea mays*
3	*Gleditis triacanthos*	*Festuca arundinacea*	*Sorghum bicolor*
4	*Cucumis myriocarpus*	*Arundo donax*	*Vigna luteola*
5	*Datura stramonium*	*Cynodon dactylon*	*Pueraria phaseoloides*
6	*Echium vulgare*	*Lolium perenne*	*Stenotaphrum secundatum*
		Reject	
7	*Cenchrus ciliaris*	*Xanthium strumarium*	*Vigna unguiculata*
8	*Cardaria draba*	*Leucanthemum vulgare*	
9	*Pueraria thunbergiana*	*Paspalum dilatatum*	
10	*Cyperus rotundus*	*Paspalum notatum*	
11	*Hypericum perforatum*	*Pennisetum pedicellatum*	*Dactyloctenium aegyptium*
12	*Orobanche ramose*	*Pennisetum clandestinum*	*Stylosanthes guianensis*
13	*Brachiaria mutica*	*Andropogon virginicus*	
14	*Ageratina adenophora*	*Pennisetum polystachion*	
15	*Solanum elaeagnifolium*	*Pennisetum macrourum*	
16	*Carduus nutans*	*Typha latifolia*	
17	*Centaurea solstitialis*	*Anthemis cotula*	
18	*Pistia stratiotes*	*Genista monspessulana*	
19	*Allium vineale*		
20	*Acroptilon repens*	*Hydrilla verticillata*	
21	*Cirsium arvense*	*Allium triquetrum*	
22	*Cuscuta campestris*		
23	*Elodea canadensis*		
24	*Onopordum acanthium*		
25	*Sagittaria montevidensis*		
26	*Ageratina riparia*		

III. ‘Selection PBU’ Sunn Hemp Biomass and Nitrogen Production Across Planting Dates and Seeding Rates

Abstract

Sunn hemp (*Crotalaria juncea* L.) is a tropical legume capable of producing considerable biomass in a short period of time. The objectives of this study were to assess the performance of ‘Selection PBU’, a new sunn hemp cultivar, for 2 planting dates (immediately after harvest or 2 wk after harvest) following corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) harvest across different sunn hemp seeding rates (17, 34, 50, and 67 kg ha^{-1}) and to determine how a cereal rye (*Secale cereale* L. cv. Elbon) cover crop responds to different ‘Selection PBU’ biomass levels and nitrogen (N) contents. Field experiments were conducted during the 2007-2008 and 2008-2009 growing seasons in east-central Alabama. Results for planting dates were not consistent and appeared to be influenced by year. Seeding rates had little effect on ‘Selection PBU’ productivity. The effect of ‘Selection PBU’ planting date on a rye cover crop was noted, with planting ‘Selection PBU’ 2 wk after corn harvest resulted in more rye biomass during the 2008-2009 growing season. Rye biomass N content increased when ‘Selection PBU’ was planted 2 wk after corn harvest in 2008-2009. ‘Selection PBU’ quickly produced biomass and N within a limited growing window in southeastern rotations under the conditions of this study; however, ‘Selection PBU’ performance was not maximized due to its limited biomass production. Due to the negative effect of short day-length on ‘Selection PBU’ biomass production, earlier planting

times are suggested when using lower seeding rates (17 to 34 kg ha^{-1}). Alternatively, producers could increase ‘Selection PBU’ seeding rate after corn harvest to counter reduced day-length.

Introduction

Due to the volatility of nitrogen (N) fertilizer costs, alternative sources of N, such as legumes, have received renewed interest. Winter legume benefits as an N source for corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and grain sorghum (*Sorghum bicolor* L.) have been previously examined (Mitchell and Teel, 1977; Ebelhar et al, 1984; Hargrove, 1986). However, when using legumes as N sources, N accumulation and biomass production are highly variable based on environment, planting and termination date, legume selection, growth stage, and management strategy (Touchton et al., 1984; Holderbaum et al., 1990; Reeves, 1994; Odhiambo and Bomke, 2001; Balkcom and Reeves, 2005; Cherr et al., 2006). Biomass production may be reduced in field situations with little rainfall, extreme temperatures, late planting dates, and early termination dates. Nitrogen availability is dependent on factors such as partitioning within the plant, plant N concentration, and carbon to nitrogen ratios (C:N) of the plant parts (Marshall et al., 2002).

Total legume biomass production is a major determining factor in N contribution (Fribourg and Johnson, 1955; Holderbaum et al., 1990; Hartwig and Ammon, 2002). Winter annual legumes such as crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth), and lupin (*Lupinus pilosus* L.) are commonly incorporated into rotations across the Southeast and are noted for biomass and N content (Gallaher, 1991; Ranells and Wagger, 1996; Sainju and Singh, 2001); however, in these studies legume growth time was over the traditional winter fallow period (~24 wk). Summer legumes such as cowpea (*Vigna unguiculata* L.) utilize a shorter time frame, yet still produce notable levels of dry matter and N content (Jeranyama et al., 2000). Sunn hemp (*Crotalaria juncea* L.) is a tropical legume contributing 134-145 kg N ha^{-1} in 9 to 12 wk (Rotar and Joy, 1983; Mansoer et al., 1997). Due to its ability to produce large amounts of biomass within a short time frame, sunn hemp could serve as a summer cover crop in rotations after warm-season cash crops harvest and prior to cool-season crop planting. Sunn hemp cannot tolerate temperatures below -4° C (Cherr et al., 2006); thus, early freezes would effectively terminate sunn hemp, leaving N from decomposing biomass available to a subsequent crop.

The most commonly studied cultivar of sunn hemp is 'Tropic Sun'. In Alabama, 'Tropic Sun' produces 5.9 Mg ha^{-1} biomass in 9 to 12 wk (Mansoer et al., 1997); however, it has limited availability due to an inability to produce viable seed above 28° N latitude (USDA, 2009). In the U.S., areas of possible production based on sunn hemp growing conditions are Hawaii, south Texas, and south Florida. Available 'Tropic Sun' seed is expensive due to limited production. By increasing production, more available seed would come at a lower cost to producers and could raise interest in sunn hemp.

Recent breeding efforts at Auburn University, AL have produced a new sunn hemp variety which produces viable seed in southeastern growing conditions. 'Selection PBU' was developed using tropical 'PI 322377', a Brazilian cultivar notable for southern root-knot (*Meloidogyne incognita*) and reniform (*Rotylenchulus reniformis*) nematode suppression, at the Plant Breeding Unit (PBU) of the E.V. Smith Research Center near Tallassee, AL (Mosjidis, 2006; Mosjidis, 2007; Marla et al., 2008). Unlike tropical sunn hemp cultivars, 'Selection PBU' completes its lifecycle within temperate environments. Temperate 'Selection PBU' may last longer within the Southeast than its tropical peers and effective chemical termination has been found. 'Selection PBU' is tolerant of pre-emergent pendimethalin (*N*-(1-ethylpropyl)-2,6-dinitro-

3,4-xylidine) and imazethapyr (2-(4,5-dihydro-4-methyl-4-(1-methltheyl)-5-oxo-1H-imidazol-2-yl)-5-ethyl-3-pyridinecarboxylic acid), but it is effectively controlled by post-emergent application of glyphosate (*N*-(phosphonomethyl) glycine) or 2,4-D (2,4-Dichlorophenoxyacetic acid) (Mosjidis and Wehtje, 2010). Managing ‘Selection PBU’ within southeastern conditions will aid in addressing best management practices of the new cultivar.

Bhardwaj et al. (2005) found ‘Tropic Sun’ production was impacted by changes in planting date. As a short-day plant (White and Haun, 1965), biomass yields of sunn hemp are higher when planted early in the growing season (Kundu, 1964). Cook and Scott (1998) found seeding rate affected the quality of ‘Tropic Sun’ and PI248491 (cv. Guizo de Cascavel) as a fiber sources, yet little research has been conducted observing the effect of seeding rate on sunn hemp quality as an N supplying cover crop.

It is important to synchronize biomass N release with N uptake of subsequent crops. Nitrogen release is influenced by manner of residue incorporation and placement (Huntington et al., 1985; Muller et al., 1988). Decay rate studies of ‘Tropic Sun’ in Alabama found leaves had lower ratios (<20:1) than stems (>20:1) 3 WAP (Mansoer et al, 1997). Mansoer et al. (1997) also reported N from ‘Tropic Sun’ biomass decreased from 126 kg N ha^{-1} at time of termination 12 WAP to 45 kg N ha^{-1} left available to corn after overwintering (16 wk after kill date). The N available from the decomposing sunn hemp was subject to denitrification and leaching losses during the winter months when rainfall is typically more prevalent.

One way to exploit the N available from decomposing sunn hemp biomass includes a winter cover crop used to sequester N (Balkcom and Reeves, 2005). Rye (*Secale cereale* L.) is often used as a winter cover crop in the Southeast due to its ability to produce large amounts of biomass and its ability to scavenge residual soil N with its extensive root system (Bruce et al., 1995; Ranells and Wagger, 1997; Dabney et al., 2001). ‘Elbon’ rye is a popular cover crop choice for conservation systems because biomass production provides good ground cover. In most instances, the naturally low fertility soils in the Southeast produce limited rye biomass. Planting rye in November is common in the Southeast, despite later planting date reducing rye dry matter accumulation (Bauer and Reeves, 1999); however, augmenting N levels with a summer legume could improve rye biomass production. Additionally, planting rye after sunn hemp termination would potentially hold N which is otherwise subject to loss from denitrification and leaching (Aulakh et al., 1991; McKenney et al, 1995).

Prior to cultivar release, ‘Selection PBU’ best management practices should be determined. Recommended ‘Selection PBU’ seeding rates need to be established and planting windows affirmed. Thus, the study objectives were to (i) assess the performance of ‘Selection PBU’ for two planting dates (immediately after harvest or two wk after harvest) following corn and wheat harvest across different sunn hemp seeding rates (17, 34, 50, and 67 kg ha^{-1}) and (ii) to determine how a cereal rye cover crop responds to subsequent ‘Selection PBU’ biomass levels and N contents.

Materials and Methods

This experiment was conducted during the 2007-2008 and 2008-2009 growing seasons at the Plant Breeding Unit (PBU) of the E.V. Smith Research and Extension Center near Tallassee, AL. The soil series was a Wickham sandy loam (fine-loamy, mixed, semiactive, thermic Typic Hapludults). The experimental design was a randomized complete block with a split-plot treatment restriction in four replicates. The plot dimensions were 2.2 by 6.7 m during 2007-2008 and 2.2 by 10 m during 2008-2009. Soil samples were collected to 20 cm depth using a 1.9 cm diameter probe and compositing 20 cores by replication before each field was planted with sunn hemp. Initial nutrient levels were measured at the Auburn University Soil Testing Laboratory (Cope et al., 1983) with Mehlich-1 method (Mehlich, 1953). Inorganic soil N averaged 1.9 mg kg^{-1} NH_4-N and 2.7 mg kg^{-1} NO_3-N during 2007-2008. In 2008-2009, the field location changed and NH_4-N and NO_3-N concentrations were 5.7 and 7.3 mg kg^{-1}. Recommended rates of nutrients excluding N were applied during the duration of the experiment. During 2007-2008, 45 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} were applied to the corn field and 39 kg P_2O_5 ha^{-1} and 27 kg K_2O ha^{-1} were applied to the wheat field. During 2008-2009, 59 kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1} were applied to the corn field and 48 kg P_2O_5 ha^{-1} and 22 kg K_2O ha^{-1} were applied to the wheat field.

Each experiment was established in two separate fields, following corn and wheat harvest. Main plot treatments were ‘Selection PBU’ planting dates; immediately after cash crop harvest (PD1) or two wk after cash crop harvest (PD2). Subplot treatments were ‘Selection PBU’ seeding rates (17, 34, 50, and 67 kg ha^{-1}). The range of seeding rates for this experiment was based around the recommended seeding rate of ‘Tropic Sun’, which is 34 to 56 kg ha^{-1} (Rotar and Joy, 1983). Each year, ‘Selection PBU’ was seeded with a Great Plains® no-tillage drill (Great Plains Mfg., Salina, KS) with an 18-cm row spacing into existing summer crop residue. ‘Selection PBU’ planting dates and harvest dates following each crop are presented in Table 2.01. In 2007, there was an outbreak of fall armyworms (*Spodoptera frugiperda* (J.E. Smith)) (FAW) discovered on 10 September, and Karate® 2.08 Z (lambda-cyhalothrin) insecticide was applied. However, insecticide application did not prevent leaf defoliation by the insects during ‘Selection PBU’ early growth stages, which impacted the results from this experimental year.

Plant populations were measured 4 wk after planting (WAP) by counting all emerged ‘Selection PBU’ in one 0.25 m^2 quadrant from each subplot. Heights from 10 plants were measured at random by subplot also at this sample date. Twelve WAP, final heights were collected and stem diameter was measured at a point 0.33 m aboveground from 10 random plants by subplot. Aboveground ‘Selection PBU’ biomass was also collected at random from two 0.25 m^2 quadrants and plants were then terminated at mid-bloom stage by applying glyphosate (*N*-(phosphonomethyl) glycine). ‘Selection PBU’ biomass was dried in a forced air oven at 55° C for 72 h, weighed, and ground using Wiley (Thomas Scientific, Swedesboro, NJ) and cyclone (UDY Corp., Fort Collins, CO) sample mills to pass a 1-mm screen. Subsamples were analyzed for total C and N by dry combustion using a LECO TruSpec CN analyzer (LECO Corp., St. Joseph, MI). Aboveground N content of ‘Selection PBU’ was the product of average dry matter (kg ha^{-1}) and average total N concentration (g kg^{-1}).

On 13 November 2007 and 10 November 2008, 101 kg ha^{-1} ‘Elbon’ rye was drilled into terminated standing sunn hemp biomass using the same equipment utilized in sunn hemp planting. Additional rye was drilled into alleys (8.7 by 10 m in 2007-2008, 8.7 by 13.3 m in 2008-2009) to provide a control that would estimate rye production with no influence from sunn hemp. Aboveground rye biomass was cut at random from two 0.25 m^2 quadrants on 11 April 2008 and 23 April 2009. These dates were selected to reflect cover crop termination 3 wk prior to cotton planting. Rye biomass was dried in a forced air oven at 55°C for 72 h, weighed, and ground using Wiley (Thomas Scientific, Swedesboro, NJ) and cyclone (UDY Corp., Fort Collins, CO) sample mills to pass a 1-mm screen. Subsamples were analyzed for total C and N by dry combustion using a LECO TruSpec CN analyzer (LECO Corp., St. Joseph, MI). Aboveground N content of rye was the product of average dry matter (kg ha^{-1}) and average total N concentration (g kg^{-1}).

Data were analyzed by field and year using the MIXED procedure in Statistical Analysis System (SAS) software (SAS Inst., Cary, NC). Replication was considered random, while planting date, seeding rate and interactions were considered fixed. Protected least significant differences (LSD) at 5% probability ($\alpha = 0.05$) were determined to compare treatment means when measured traits had significant F-tests ($P \leq 0.05$). Traits analyzed were sunn hemp population, sunn hemp height, sunn hemp stem diameter, sunn hemp biomass, sunn hemp N concentration, sunn hemp N content, rye biomass, rye N concentration, and rye N content.

Results and Discussion

Daily maximum and minimum air temperatures and precipitation came from the AWIS Weather Services, Inc., Auburn, AL, 'E.V. Smith' monitoring station located 6 km from the experiment (Alabama Mesonet Weather Data, 2009). No weather data records were available prior to 1999, so a 10-yr average was calculated to estimate a "normal" growing season. Weather conditions in the area were generally favorable. Temperatures from June to November during 2007 and 2008 were near the 10-yr average (data not shown). The location received below average precipitation in 2007 during the time sunn hemp was grown (Table 2.02). In 2008, the experimental area received greater than average rainfall, especially during an exceptionally wet August. 'Selection PBU' growing degree days (GDD) were calculated by month until time of termination. Accumulation of GDD from planting to termination of 'Selection PBU' was more rapid during 2007 than 2008 (Table 2.02). However, days in the field averaged 15% more during 2007 than 2008 (Table 2.01).

Sunn Hemp Following Wheat

Planting immediately after wheat harvest resulted in greater sunn hemp emergence 4 WAP during 2007 (p = 0.0578) (Table 2.03). However, PD2 had greater emergence 4 WAP in the following growing season ($p = 0.0145$) (Table 2.03). During 2007, higher seeding rates resulted in higher seedling emergence ($p = 0.0001$) (Table 2.03). Sunn hemp population 4 WAP increased seeding rates during 2008 ($p < 0.0001$) (Table 2.03). Higher populations were seen in 2008 than 2007 (Table 2.03). Increased precipitation (Table 2.01) and subsequent water retention due to wheat residue could have contributed to greater soil moisture during seed germination and seedling establishment, which improved sunn hemp emergence in 2008.

In 2008, planting date influenced height 4 WAP ($p = 0.0004$) (Table 2.03). Sunn hemp planted 2 wk after wheat harvest had nearly 50% taller plants than PD1 in 2008 (Table 2.03). The effect of seeding rate on sunn hemp plant height 4 WAP was significant during both 2007 ($p = 0.0011$) and 2008 ($p = 0.0086$) growing seasons (Table 2.03). Higher seeding rates produced taller plants. Cook et al. (1998) found sunn hemp height was “positively and consistently related to stalk yield”. Although plant height did not significantly impact ‘Selection PBU’ biomass levels, greater yield was observed from plots with early planting dates, hence taller plants. Final plant heights measured 12 WAP were not affected by seeding rate, while planting date ($p = 0.0015$) was significant only during the 2007 growing season (Table 2.03). In 2007 planting immediately after wheat harvest resulted in sunn hemp that was 16% taller than PD2 at time of termination (Table 2.03).

During the 2007 growing season, neither planting date nor seeding rate influenced the diameter of sunn hemp at time of termination (Table 2.03). However, PD1 resulted in sunn hemp stem diameters that were 18% greater than corresponding PD2 stem diameters during 2008 ($p = 0.0344$) (Table 2.03). Cook et al. (1998) also found that stem girth was greater when sunn hemp was sown at earlier planting dates. In 2008, lower sunn hemp seeding rates had stem diameters that were significantly thicker than observed at higher seeding rates ($p = 0.0025$) (Table 2.03).

In 2007 and 2008, only the effect of planting date after wheat harvest had any significance on the aboveground ‘Selection PBU’ dry matter production (Table 2.04). Cook et al. (1998) found planting ‘Tropic Sun’ and PI248491 (cv. Guizo de Cascavel) in Texas during late March and mid-April increased biomass production over that of late April and mid May. Similar to Cook et al. (1998) receiving better dry matter yield with earlier planting dates, there was a 51% increase in biomass production observed when ‘Selection PBU’ was planted at PD1 rather than PD2 in 2007 ($p = 0.0026$). Conversely when ‘Selection PBU’ was planted during the 2008 season, PD2 produced 32% more biomass than PD1 ($p = 0.0035$). Increased sunn hemp biomass corresponded to planting dates following wheat with the greatest accumulations of GDD (Table 2.02). Dry weather in the summer of 2007 contributed to limited ‘Selection PBU’ biomass production.

During both growing seasons, aboveground ‘Selection PBU’ N concentration was elevated in dry matter collected from PD1; however, planting date was significant only in 2008 (Table 2.04). During that year, PD2 had 48% lower N concentration than PD1 ($p = 0.0006$) (Table 2.04). Also in 2008, the lower ‘Selection PBU’ seeding rates exceeded the N concentration of higher ‘Selection PBU’ seeding rates ($p = 0.0285$) (Table 2.04). Aboveground biomass N content varied among planting date in 2007 (Table 2.04). Planting immediately after wheat harvest resulted in 66% greater sunn hemp N content at termination than sunn hemp planted 2 wk after wheat harvest ($p < 0.0001$) (Table 2.04). During 2008, neither planting date ($p = 0.1351$) nor seeding rate ($p = 0.3815$) affected ‘Selection PBU’ N content (Table 2.04). Higher biomass yields and N concentrations did result in greater ‘Selection PBU’ N content following wheat harvest in 2008 (Table 2.04).

Sunn Hemp Following Corn

Planting 'Selection PBU' immediately after corn harvest resulted in 88% more plants emerging 4 WAP ($p = 0.0122$) (Table 2.05). As with the wheat field study (Table 2.03), higher seeding rates resulted in higher seedling emergence both seasons. Sunn hemp population 4 WAP averaged 62% higher across all seeding rates in 2008 than 2007 (Table 2.05).

In 2007, sunn hemp plant heights from PD2 were 40% taller than PD1 at 12 WAP, although this difference was not significant (Table 2.05). Final height of sunn hemp during 2008 was significantly influenced by planting date ($p < 0.0001$) (Table 2.05). In 2008, sunn hemp planted immediately after corn harvest was 30% taller than PD2. Seeding rate was only significant 4 WAP in 2008 ($p = 0.0151$), however there was no clear trend (Table 2.05). As with the wheat study, neither planting date ($p = 0.5620$) nor seeding rate ($p = 0.9474$) influenced the diameter of sunn hemp at time of termination in 2007 (Table 2.05). However, seeding rate influenced stem girth in 2008 ($p = 0.0065$) (Table 2.05). As seeding rate increased, there was a 26% decrease in sunn hemp stem diameter (Table 2.05). Cook et al. (1998) reported that stem diameter had an "often erratic and nonsignificant" relationship with biomass yield. Increasing population had little effect on sunn hemp plant height, but was associated with decreasing sunn hemp stem diameter, which was similar to observations in our study.

In 2007 and 2008, planting date affected aboveground 'Selection PBU' dry matter production (Table 2.06). There was a 96% increase in biomass production when sunn hemp was planted at PD2 rather than PD1 in 2007 ($p = 0.0261$) (Table 2.06). However, reduced yields for PD1 were affected by FAW damage early in the season. Seedlings from PD2 had less FAW damage due to delayed emergence. When sunn hemp planting had a two week delay following corn during 2008, there was 54% less dry matter produced than when planted immediately after corn harvest ($p < 0.0001$) (Table 2.06). Higher 'Selection PBU' seeding rates are needed to counter limiting day length and maximize biomass production.

'Selection PBU' biomass average yields of 0.79 (PD1) and 1.55 (PD2) Mg ha^{-1} were extremely poor in 2007. Other southeastern studies reported biomass yields of 4.4-6.8 Mg ha^{-1} in Georgia (mid-April to mid-July planting) (Schomberg et al., 2007), 4.5 Mg ha^{-1} in Florida (early August planting) (Cherr et al., 2006), and 4.6-6.0 Mg ha^{-1} in Alabama (mid-August planting) (Mansoer et al., 1997). In these studies, 'Tropic Sun' was in the field 60 d.

Planting date affected 'Selection PBU' biomass N concentration both growing seasons (Table 2.06). During 2008, PD1 resulted in 36% greater N concentration than PD2 ($p = 0.0008$) (Table 2.06). 'Selection PBU' biomass N content also varied by seeding rate ($p = 0.0385$) during 2008 (Table 2.06), but appeared to be more related to biomass production. 'Selection PBU' planted after corn had much lower N content than other studies conducted in the South over the same growth period (Mansoer et al., 1997; Balkcom and Reeves, 2005; Cherr et al., 2006). However, this variation could be attributed to different cultivars being used.

Effect of Sunn Hemp on Rye Cover Crop

Precipitation received from December 2007 to February 2008 and during April 2008 was near average rainfall; however, during March 2008, very low precipitation levels were nearly half of average (Table 2.02). Overall, rye received less than average rainfall during the 2007-2008 growing season. As stated before, during 2007-2008 inorganic soil N averaged 1.9 mg kg^{-1} NH_4-N and 2.7 mg kg^{-1} NO_3-N. Low amounts of 'Selection PBU' biomass provided little supplemental N (Table 2.04, 2.06) for rye during the 2007-2008 growing season. Rye collected from control areas had less N content than areas where sunn hemp was planted on wheat during

2007-2008 (Table 2.07). ‘Selection PBU’ N contribution appeared dependent on biomass production.

Rainfall was below average soon after rye planting during December 2008 and January 2009, but fields received above average spring precipitation, especially during March, until rye termination in April 2009 (Table 2.02). In 2009, no rye yield differences were observed between control treatment and ‘Selection PBU’ treatment (Table 2.07, 2.08). This was attributed to higher inorganic N levels observed in the soil tests. During 2008-2009, NH_4-N and NO_3-N concentrations were 5.7 and 7.3 mg kg^{-1} respectively. Higher rye yields and lower N concentrations were observed where soil had higher inorganic N levels. Rye collected from control areas had less N content than areas where ‘Selection PBU’ was planted on wheat and corn during 2008-2009. Rye N concentration was similar for both control treatment and sunn hemp treatment for the in 2009 (Table 2.07, 2.08).

Less average rye biomass was produced in 2008 (2.1 Mg ha^{-1}) than 2009 (5.2 Mg ha^{-1}) (Table 2.07, 2.08); however, similar levels of rye biomass were reported in other southeastern (Vaughn and Evanylo, 1999) and midwestern (Odhiambo and Bomke, 2001; Ruffo et al., 2004) studies. In addition, overall rye N concentrations were 2 times lower in 2009 (6.7 g kg^{-1}) than 2008 (14.2 g kg^{-1}) (Table 2.07, 2.08). The suggested time of ‘Selection PBU’ planting is immediately after cash crop harvest if maximum sunn hemp biomass production is sought. This recommendation is supported by studies which found detrimental yield results when sunn hemp planting was delayed (Kundu, 1964; White and Haun, 1965; Cook et al., 1998).

Rye Cover after Wheat-Sunn Hemp

During both growing seasons, rye following wheat-sunn hemp had higher amounts of dry matter than rye behind a wheat-sunn hemp rotation (Table 2.07, 2.08). Rye planting occurred after ‘Selection PBU’ had begun losing leaves, which contain considerable N and decompose quickly due to low C:N ratios. Marshall et al. (2002) found lost leaves are 10 to 15% of ‘Tropic Sun’ biomass. The contribution of the leaves was unaccounted for prior to ‘Selection PBU’ biomass collection. The majority of ‘Tropic Sun’ N is concentrated in its leaves fraction, which has a low C:N ratio (Mansoer et al, 1997). In 2008, control treatment rye yield (1.45 Mg ha^{-1}) was 33% lower than sunn hemp treatment rye yield (2.15 Mg ha^{-1}). Sunn hemp treatment (7.41 Mg ha^{-1}) resulted in 25% more rye yield than control treatment (5.55 Mg ha^{-1}) in 2009. During 2008-2009, planting sunn hemp 2 wk after wheat harvest ($p = 0.0019$) increased rye biomass yields (Table 2.07). Rye biomass levels were 22.4% less in areas where sunn hemp was planted immediately after wheat harvest (6.47 Mg ha^{-1}) than 2 wk after wheat harvest (8.34 Mg ha^{-1}). This effect was attributed to less ‘Selection PBU’ residue in plots planted immediately after wheat harvest during 2008-2009 (Table 2.04).

Average biomass C:N ratios were significantly influenced by sunn hemp planting date, with the exception of wheat-sunn hemp in 2007 (Table 2.09). Planting sunn hemp immediately after wheat harvest in 2008-2009 significantly lowered ($p < 0.0001$) sunn hemp C:N, contributing to N mineralization and enhancing its availability to rye (Table 2.09). In 2007-2008, average C:N ratios of the sunn hemp biomass were 31:1 when planted immediately after wheat harvest and 41:1 for sunn hemp planted 2 wk after wheat harvest (Table 2.09). It is widely accepted that quicker decomposition occurs at or below 30:1.

Rye Cover after Corn-Sunn Hemp

‘Selection PBU’ did not affect rye biomass yield or rye N concentration in 2008 (Table 2.07). Despite no treatment differences, 20% greater rye yields and 9% greater N concentration were observed where sunn hemp was planted 2 wk after corn harvest in 2008 (Table 2.08). Due to FAW damage, less sunn hemp was in this area, but PD2 sunn hemp had less damage and produced more biomass (1.55 Mg ha^{-1}) to contribute N for rye production than PD1 sunn hemp (0.79 Mg ha^{-1}) (Table 2.06). In 2009 sunn hemp preceding rye resulted in a 2% rye yield increases over control treatment (Table 2.08). Planting sunn hemp 2 wk after corn harvest in 2008-2009 notably increased N contents of rye biomass by 15% ($p = 0.0017$) (Table 8). Nonwithstanding, sunn hemp planting date and sunn hemp seeding rate had no significant effects on rye biomass N content during the experiment with the exception of rye N concentration ($p = 0.0071$) in 2009 increasing by 16% when sunn hemp was planted 2 wk after corn harvest (Table 2.08). Nitrogen accumulation in rye biomass was a measure of N removal from soil—whether the N mineralizing from residue was subject to leaching or productive utilization by rye cover cropping—and also inorganic N.

Sunn hemp planted at PD1 had a 32% lower C:N than PD2 ($p < 0.0001$) (Table 2.09). However, both planting dates had sunn hemp C:N ratios below 30:1 contributing to N mineralization (Table 2.09). Planting sunn hemp immediately after corn harvest significantly raised the sunn hemp C:N ratio ($p < 0.0001$) in 2008 (Table 2.09). With the exception of sunn hemp planted after corn during 2008, sunn hemp C:N ratio increased with maturity as expected (Odhiambo and Bomke, 2001) and standing biomass decreased the rate of residue decomposition. Both factors may lower N mineralization from 'Selection PBU' to rye.

Conclusions

This experiment demonstrated that high 'Selection PBU' seeding rates were not necessary and lower seeding rates from 17 to 34 kg ha^{-1} can perform as well, in some cases, as higher seeding rates up to 67 kg ha^{-1}. During this study, 'Selection PBU' was in the field for 70 d or less. 'Selection PBU' biomass yield performance seemed to be reduced when compared to the biomass production of other sunn hemp cultivars in other southeastern studies (Mansoer et al., 1997; Balkcom and Reeves, 2005). However, this reduction in ‘Selection PBU’ biomass production is attributed to energy partitioning toward producing viable seeds.

Day-length affects ‘Selection PBU’ vegetation production, as seen in sunn hemp biomass yields between wheat harvest and corn harvest. Higher ‘Selection PBU’ seeding rate are recommended with use after corn harvest to counter shorter day-length and promote increases in ‘Selection PBU’ biomass yield. As a short-day plant, extending the amount of time in the field might be beneficial in increasing ‘Selection PBU’ N content; therefore, planting ‘Selection PBU’ immediately after cash crop harvest is advised to improve biomass N content.

Rye is widely known as a nutrient scavenger and appeared efficient in up-taking residual N from ‘Selection PBU’. When compared to control treatment, ‘Selection PBU’ produced higher rye biomass yields in 3 of 4 growing seasons. These rye biomass amounts provide evidence that ‘Selection PBU’ N could be utilized and sequestered through periods where it would otherwise be subject to loss (Balkcom and Reeves, 2005).

The ability of ‘Selection PBU’ to provide increased N availability pooled with additional advantages, such as erosion control and soil organic matter augmentation, would provide benefits to conservation systems. Southeastern producers looking to reap N additions with limited rotational windows should consider ‘Selection PBU’ an option if availability increases and seed cost falls below that of other cultivars.

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Table 2.01. Sunn hemp field calendars for 2007 and 2008 at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL.

	Wheat		Corn	
Sunn hemp data	PD1†	PD2†	PD1	PD2
	2007 harvest			
Planting date	8 June	22 June	17 Aug.	31 Aug.
Termination date	15 Aug.	24 Aug.	26 Oct.	5 Nov.
Growing days	68	63	70	66
	2008 harvest			
Planting date	11 June	26 June	22 Aug.	5 Sep.
Termination date	31 June	21 Aug.	23 Oct.	4 Nov.
Growing days	50	56	62	60

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.02. Average monthly precipitation with growing degree days of sunn hemp at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007 and 2008.

	Precipitation†			Sunn hemp growing degree days (GDD)‡							
				Wheat				Corn			
				2007		2008		2007		2008	
Month	2007	2008	Average§	PD1¶	PD2¶	PD1	PD2	PD1	PD2	PD1	PD2
	------------mm------------			--------------------------------GDD-----------------------------							
June	30	51	99	622	246	534	139	---	---	---	---
July	172	127	112	890	890	869	869	---	---	---	---
Aug.	84	251	104	449	720	---	589	447	30	282	---
Sep.	56	18	86	---	---	---	---	777	777	755	636
Oct.	76	84	71	---	---	---	---	541	595	424	487
Nov.	56	94	107	---	---	---	---	---	72	---	49
Total	474	625	579	1961	1856	1403	1597	1765	1474	1461	1172
Dec.	95	82	97								
Jan.	111	52	96								
Feb.	102	112	92								
Mar.	77	244	146								
Apr.	101	109	98								
Total	486	599	529								

† Source: Alabama Mesonet Weather Data. E.V. Smith, AL weather station (32.45 N, 85.88 W).

‡ Growing degree days (base 10°C) accumulated until termination date. Daily growing degree days were calculated as: [(daily maximum temp. + daily minimum temp.)/2] – 10°C.

§ 1999-2009 means. Data was not available prior to 1998.

¶ Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.03. Sunn hemp population, plant height, and stem diameter for planting date (main plots) and seeding rate (subplots) when planted after wheat harvest at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007 and 2008.

	Population		Height				Stem diameter	
			4 WAP		12 WAP			
Treatment	2007	2008	2007	2008	2007	2008	2007	2008
	-----plant m^{-2}-----		------------------cm------------------				-------mm-------	
Planting date								
PD1†	73.8	80.5	27.7	48.3	155.2	173.3	4.84	6.61
PD2†	52.8	107.0	26.7	72.9	131.7	180.0	4.18	5.61
$LSD_{0.05}$	15.0	25.1	7.4	9.5	15.1	13.1	0.63	0.93
Seeding rate, kg ha^{-1}								
17	31.5	46.0	25.6	57.6	145.5	172.4	4.77	6.97
34	48.5	66.0	24.1	55.3	141.5	174.5	4.66	6.33
50	77.5	102.5	32.0	64.9	149.1	183.3	4.38	6.07
67	95.5	160.5	26.9	64.6	138.0	176.4	4.22	5.07
$LSD_{0.05}$	24.4	17.0	3.6	6.3	12.2	9.1	0.76	0.89
			Analysis of variance ($P > F$)					
Planting date	0.0578	0.0145	0.7845	0.0004	0.0015	0.3461	0.0831	0.0344
Seeding rate	0.0001	<0.0001	0.0011	0.0086	0.2877	0.1017	0.4230	0.0025
PD × SR	0.6086	0.6070	0.1000	0.7570	0.1650	0.6300	0.9620	0.8520

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.04. Sunn hemp biomass yield, N concentration, and N content for planting date (main plots) and seeding rate (subplots) when planted after wheat harvest at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007 and 2008.

Treatment	Biomass yield 2007	Biomass yield 2008	N concentration 2007	N concentration 2008	N content 2007	N content 2008
	-------Mg ha^{-1}-------		--------g kg^{-1}--------		-------kg ha^{-1}-------	
Planting date						
PD1†	3.97	4.50	15.6	26.5	56.0	104.0
PD2†	1.54	6.62	11.5	13.8	19.2	78.9
$LSD_{0.05}$	1.24	1.23	6.7	4.4	20.3	31.1
Seeding rate, kg ha^{-1}						
17	2.52	5.49	13.6	24.6	31.8	106.0
34	2.92	4.92	13.9	22.0	38.6	86.7
50	3.18	5.95	13.4	17.8	39.8	92.9
67	3.20	5.86	13.4	16.4	40.1	81.2
$LSD_{0.05}$	0.89	1.17	3.5	5.7	20.2	31.5
			Analysis of variance ($P > F$)			
Planting date	0.0026	0.0035	0.1291	0.0006	<0.0001	0.1351
Seeding rate	0.3701	0.2657	0.9884	0.0285	0.8053	0.3815
PD × SR	0.5462	0.1410	0.4831	0.3227	0.9221	0.8427

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.05. Sunn hemp population, plant height, and stem diameter for planting date (main plots) and seeding rate (subplots) when planted after corn harvest at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007 and 2008.

	Population		Height				Stem diameter	
			4 WAP		12 WAP			
Treatment	2007	2008	2007	2008	2007	2008	2007	2008
	----plant m^{-2}----		--------------------cm-------------------				-------mm------	
Planting date								
PD1†	51.0	80.5	21.7	50.7	76.8	145.7	3.68	4.41
PD2†	27.3	106.2	15.5	51.5	93.7	111.8	3.85	4.39
$LSD_{0.05}$	24.0	18.8	6.0	4.9	31.0	1.8	1.10	1.09
Seeding rate, kg ha^{-1}								
17	24.0	47.6	17.9	50.0	82.5	127.3	3.77	4.96
34	27.0	68.0	18.3	47.4	84.7	129.0	3.82	4.48
50	44.0	105.3	18.2	52.7	84.3	128.8	3.65	4.24
67	61.5	158.2	19.9	54.2	89.4	129.8	3.81	3.94
$LSD_{0.05}$	18.7	15.2	3.7	4.1	11.6	7.9	0.68	0.54
			Analysis of variance ($P > F$)					
Planting date	0.0122	0.1233	0.0136	0.6990	0.0912	<0.0001	0.5620	0.9474
Seeding rate	0.0017	<0.0001	0.6979	0.0151	0.6395	0.9263	0.9543	0.0065
PD × SR	0.4090	0.5087	0.6011	0.9653	0.6849	0.6787	0.2144	0.7882

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.06. Sunn hemp biomass yield, N concentration, and N content for planting date (main plots) and seeding rate (subplots) when planted after corn harvest at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007 and 2008.

	Biomass yield		N concentration		N content	
Treatment	2007	2008	2007	2008	2007	2008
	-----Mg ha^{-1}-----		--------g kg^{-1}--------		-------kg ha^{-1}-------	
Planting date						
PD1†	0.79	4.93	36.2	13.9	25.0	60.6
PD2†	1.55	2.28	25.8	19.9	35.9	38.9
$LSD_{0.05}$	1.00	0.82	5.8	4.2	22.9	12.6
Seeding rate, kg ha^{-1}						
17	1.28	2.93	31.2	16.5	33.3	37.8
34	1.32	3.79	30.7	18.5	33.5	58.1
50	0.93	3.61	28.8	16.0	22.4	44.6
67	1.17	4.09	33.3	16.7	32.7	58.5
$LSD_{0.05}$	0.31	1.11	4.9	4.4	9.7	17.8
		Analysis of variance ($P > F$)				
Planting date	0.0261	<0.0001	<0.0001	0.0003	0.1740	0.0008
Seeding rate	0.0607	0.1475	0.2654	0.6067	0.0725	0.0385
PD × SR	0.1945	0.9346	0.8048	0.4688	0.6759	0.7082

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

Table 2.07. Rye biomass yield and N concentration for planting date (main plots) and seeding rate (subplots) when planted after wheat-sunn hemp at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2008 and 2009.

	Biomass yield		N concentration		N content	
Treatment	2008	2009	2008	2009	2008	2009
	-----Mg ha^{-1}-----		--------g kg^{-1}--------		------kg ha^{-1}------	
Planting date						
PD1†	2.22	6.47	13.7	6.9	29.0	46.2
PD2†	2.08	8.34	13.7	6.5	27.7	54.3
$LSD_{0.05}$	0.36	1.58	2.2	0.8	2.3	10.0
Seeding rate, kg ha^{-1}						
17	2.16	7.09	13.7	6.8	28.4	49.9
34	2.34	6.88	14.0	6.6	31.5	45.4
50	2.01	8.37	13.6	7.1	27.1	58.6
67	2.07	7.28	13.4	6.3	26.3	46.8
$LSD_{0.05}$	0.58	2.24	3.1	1.2	7.0	14.7
Control‡	1.45	5.55	16.7	8.1	24.4	42.6
			Analysis of variance ($P > F$)			
Planting date	0.4609	0.0019	0.9594	0.2538	0.7652	0.2360
Seeding rate	0.6249	0.2268	0.9168	0.5542	0.4386	0.2845
PD × SR	0.7682	0.5163	0.4847	0.6488	0.6585	0.7584

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

‡ Collected from areas fallow prior to rye planting and not included in statistics.

Table 2.08. Rye biomass yield and N concentration for planting date (main plots) and seeding rate (subplots) when planted after corn-sunn hemp at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2008 and 2009.

	Biomass yield		N concentration		N content	
Treatment	2008	2009	2008	2009	2008	2009
	-----Mg ha^{-1}-----		--------g kg^{-1}--------		-------kg ha^{-1}-------	
Planting date						
PD1†	1.84	3.50	13.2	6.1	24.1	46.2
PD2†	2.31	3.09	14.5	7.3	34.0	49.5
$LSD_{0.05}$	0.73	1.09	3.3	0.9	14.2	13.5
Seeding rate, kg ha^{-1}						
17	1.96	2.75	12.7	6.8	24.8	46.1
34	1.93	3.47	14.3	6.8	27.9	46.3
50	2.12	3.53	14.4	6.6	31.2	55.6
67	2.28	3.42	13.8	6.6	32.5	43.4
$LSD_{0.05}$	1.04	1.54	4.7	1.3	10.5	16.5
Control‡	2.29	3.22	15.8	6.7	36.2	18.8
			Analysis of variance ($P > F$)			
Planting date	0.1382	0.3088	0.3093	0.0071	0.0484	0.6090
Seeding rate	0.5589	0.4765	0.2080	0.9662	0.4296	0.4969
PD × SR	0.5038	0.2104	0.2725	0.1992	0.3398	0.9761

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

‡ Collected from areas fallow prior to rye planting and not included in statistics.

Table 2.09. Carbon to nitrogen ratios of sunn hemp by field planted at the Plant Breeding Unit of the E.V. Smith Research and Extension Center in Shorter, AL during 2007-2008 and 2008-2009 growing seasons.

	Wheat		Corn	
Treatment	2007	2008	2007	2008
	---------------------------------C:N---------------------------------			
Planting date				
PD1†	31.2	18.3	12.1	36.1
PD2†	41.0	36.5	17.9	23.7
$LSD_{0.05}$	19.3	1.8	3.5	10.8
Seeding rate, kg ha^{-1}				
17	38.2	22.8	15.1	31.1
34	34.8	23.5	15.1	25.7
50	35.7	29.2	16.0	33.1
67	35.7	34.1	13.8	29.8
$LSD_{0.05}$	11.3	11.3	2.4	8.5
	Analysis of variance (*P* > *F*)			
Planting date	0.1944	<0.0001	<0.0001	0.0002
Seeding rate	0.9302	0.3104	0.0953	0.3303
PD × SR	0.4752	0.8692	0.9230	0.2661

†Planting date of sunn hemp immediately after cash crop harvest (PD1) and planting date of sunn hemp 2 wk after cash crop harvest (PD2).

IV. Wheat Nitrogen Requirements Following Sunn Hemp in Alabama

Abstract

Alternative nitrogen (N) sources, such as legumes, have undergone resurgences in popularity during times of increasing N fertilizer costs. Sunn hemp (*Crotalaria juncea* L.) is a tropical legume capable of rapid biomass production as a cover crop. Recent breeding efforts at Auburn University, AL have produced ‘Selection PBU’, a sunn hemp cultivar capable of yielding seed above 28° N latitude. Improved availability could increase sunn hemp cover crop usage across the Southeast. This study was conducted to examine how ‘Selection PBU’ affects N requirements for winter wheat (*Triticum aestivum* L.). A randomized complete block design with a split-plot restriction and four replications was conducted at one site in 2008 and two sites in 2009 and 2010. Main plots were cover crop (‘Selection PBU’ and fallow) and subplots were N rates (0, 28, 56, 84, and 112 kg ha^{-1}) applied as ammonium nitrate in early to mid-February at Feekes 4 growth stage. Average ‘Selection PBU’ biomass production was greatest in 2008. Planting ‘Selection PBU’ prior to wheat significantly improved wheat grain yield in 2 of the 5 growing seasons. In 2008, overall wheat grain yields were extremely low, but ‘Selection PBU’ produced a 54% yield increase in harvested wheat grain compared to fallow plots. Nitrogen application improved wheat grain yields in 4 of the 5 growing seasons. Moving ‘Selection PBU’ planting date to before the dates used in this study may improve the benefits ‘Selection PBU’ can provide a winter wheat crop.

Introduction

During periods of escalating and unpredictable nitrogen (N) fertilizer prices, alternative N sources become more desirable to protect producers from high chemical costs and meet cash crop N needs. Cover crops are a traditional choice in crop management systems that provide ground cover and reduce nutrient, pesticide, or sediment losses from agricultural fields (Reeves, 1994; Dabney et al., 2001; Phatak et al., 2002). Legumes provide additional advantages as a cover crop including an ability to fix atmospheric N and extend N accruement periods during the spring compared to other cover crop types (Vaughn and Evanylo, 1998; Silva and Uchida, 2000; Cherr et al, 2006). The predominant cover crop selections in southeastern rotations are winter annuals (Schomberg et al., 2007). Tropical legumes provide an alternative to winter legumes and perform well in temperate climates, producing greater amounts of biomass in shorter periods than winter legumes (Yadvinder et al., 1992).

Sunn hemp (*Crotalaria juncea* L.) is a tropical legume notable for producing 5.9 Mg ha^{-1} biomass within a 9 to 12 wk span after August and mid-September planting in Alabama (Mansoer et al., 1997). ‘Tropic Sun’ is the most commonly used sunn hemp cultivar (Rotar and Joy, 1983). Southeastern studies have focused on ‘Tropic Sun’ as a cover crop preceding corn (*Zea mays* L.) planting (Mansoer et al., 1997; Balkcom and Reeves, 2005; Cherr et al, 2006). However, research suggests winter cereal crops would successfully utilize N mineralized from sunn hemp during the winter if planted immediately after sunn hemp termination (Mansoer et al., 1997; Dalal, 1988; Marshall et al., 2002; Balkcom and Reeves, 2005; Cherr et al., 2006). Sunn hemp accommodates the limited window between warm season harvest and cool season planting.

Unlike tropical sunn hemp cultivars, a recently developed cultivar from Auburn University, AL produces viable seed in temperate regions above 28° N latitude (Mosjidis, 2006;

Mosjidis, 2007). ‘Selection PBU’ was developed using tropical ‘PI 322377’, a Brazilian cultivar notable for southern root-knot (*Meloidogyne incognita*) and reniform (*Rotylenchulus reniformis*) nematode suppression, at the Plant Breeding Unit (PBU) of the E.V. Smith Research Center near Tallassee, AL (Marla et al., 2008). Increases in production area could decrease seed cost and increase availability. ‘Selection PBU’ planted in late summer is terminated before maturity by first frost or chemical means (Mosjidis and Wehtje, 2010). By terminating before maturity, ‘Selection PBU’ stems are still succulent and more easily planted into.

In 2008, 14.2 million bushels of wheat valued at 85 million dollars were produced in Alabama on 97 thousand hectares (NASS, 2009). Winter wheat is not new to Alabama and acreage has increased in recent years (NASS, 2009). A successful strategy of establishing wheat is by no-till planting into standing residue of prior crops, known as “stubbling-in” (Fowler, 2002). By planting ‘Selection PBU’ prior to wheat, Alabama producers may benefit from the ground cover and N available from ‘Selection PBU’ decomposition.

Carbon to nitrogen (C:N) ratios are presumed low at the early to mid-flowering stage, meaning that nutrients are more readily obtained (Marshall et al., 2002). Mansoer et al. (1997) observed ‘Tropic Sun’ biomass decomposition rate 3 wk after planting (WAP) and found stem C:N measured >20:1 and leaves were <20:1. It is widely accepted that quicker decomposition occurs at or below 30:1. Carbon to nitrogen ratios greater than 30:1 contribute to N immobilization where soil microbes out-compete plants for N (Allison, 1966). Marshall et al. (2002) found 80.6% of total N within ‘Tropic Sun’ is in the combined flower heads and leaves. Mansoer et al. (1997) observed that the overwinter ‘Tropic Sun’ biomass N release decreased from 126 kg N ha^{-1} at time of termination 12 WAP to 45 kg N ha^{-1} 16 wk later.

During this time, N is subject to denitrification and leaching losses unless methods of scavenging the released N are imposed. Nitrogen behavior from residue is of particular importance due to the N immobilization and prolonged mineralization (Aulakh et al, 1991; Maskina et al, 1993; McKenney et al., 1995; Mansoer et al., 1997; Medhdi et al., 1999). Thus, crop planting date following 'Selection PBU' should be planned to best use the nutrients released from the residue. Research is needed to determine the effect 'Selection PBU' has on N needs of a subsequent wheat cash crop. Therefore, the objective was to determine if 'Selection PBU' N accumulation would provide an alternative to winter wheat N fertilizer application in Alabama.

Materials and Methods

Five trials were conducted in Alabama from 2007 to 2010 to determine 'Selection PBU' suitability as an alternative N source for wheat. Two locations were used: Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center (WGS) in Headland, AL from 2007 to 2010 and Tennessee Valley Research and Extension Center (TVS) in Bella Mina, AL from 2008 to 2010. Soils were Dothan sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) at WGS and Rexor sandy loam (Fine-silty, siliceous, active, thermic Oxyaquic Hapludalfs) at TVS. The experimental design was a randomized complete block in 4 replicates with a split-plot restriction. Main plots were cover crop (sunn hemp and fallow) and subplots were N rates (0, 28, 56, 84, and 112 kg ha^{-1}) surface applied as ammonium nitrate by hand in early to mid-February at Feekes 4 growth stage. Subplot dimensions were 4 m wide and 13.3 m long at WGS and 3.3 m wide and 13.3 m long at TVS.

Initial soil samples were collected to 20 cm depth in each main plot with a 1.9 cm diameter probe by compositing 20 soil cores for routine soil analysis to measure nutrient levels and inorganic N. The Auburn University Soil Testing Laboratory analyzed samples using a

Mehlich-I extractant (Mehlich, 1953) to measure P, K, Mg, and Ca levels (Cope et al., 1983). Soil pH was measured in a 1:1 soil/water extract. Concentrations of NH_4-N and NO_3-N were measured using a microplate method with a 1:5 dilution (Nelson and Craft, 1992). Soil test results are presented in Table 3.01. Additional nutrients were applied, excluding N, to each experimental area as recommended by Auburn University Soil Testing Laboratory. During 2009-2010, 67 kg P_2O_5 ha^{-1} and 35 kg K_2O ha^{-1} was applied at TVS and 56 kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1} was applied at WGS.

‘Selection PBU’ was drilled using a Great Plains® no-till drill (Great Plains Mfg., Inc., Salina, KS) at 50 kg ha^{-1} 1.3 to 2.5 cm below the soil surface with 20 cm row spacing in early September (Table 3.02). Stand counts were determined by collecting all emerged plants in one 0.25 m^2 quadrant and plant heights from 10 random plants were recorded by subplot 4 weeks after planting (WAP). Prior to wheat planting, stem diameter at 30 cm aboveground was measured and final height measurements were recorded again from 10 random plants by subplot. Two 0.25 m^2 quadrants of biomass samples were collected by cutting all aboveground plant biomass. At this time, general soil samples were collected by subplot treatment in the same manner as initial soil samples for inorganic N (Table 1). ‘Selection PBU’ was terminated by applying glyphosate (*N*-(phosphonomethyl) glycine) immediately after biomass collection. No glyphosate was applied at TVS in 2008 due to 3 d of early frosts effectively killing ‘Selection PBU’. Chemicals were only applied to ‘Selection PBU’ plots. Aboveground plant biomass collected at termination was dried at 55°C for 72 h then weighed to estimate biomass of each subplot. Biomass was prepared for analysis by grinding a subsample in a Wiley mill (Thomas Scientific, Swedesboro, NJ) and cyclone (UDY Corp., Fort Collins, CO) sample mills to pass a 1-mm screen. Subsamples were measured for total C and N by dry combustion on a LECO

TruSpec C/N analyzer (LECO Corp., St. Joseph, MI). Biomass N content was the product of average dry matter (kg ha^{-1}) and average N concentration (g kg^{-1}).

Wheat was planted utilizing a Great Plains® no-till drill with 20 cm drill spacing into erect desiccated sunn hemp (Table 3.02). Wheat variety ‘AGS2000’ was planted at 101 kg ha^{-1} in 2007, ‘USG3209’ was planted at 143 kg ha^{-1} in 2008, and ‘AGS2060’ was planted at 140 kg ha^{-1} in 2009 (Table 3.02). At WGS during the 2007-2008 growing season, chlorotic symptoms indicated a possible wheat N deficiency and 28 kg ha^{-1} ammonium nitrate was applied to all non-control plots on 4 January 2008. This early N fertilizer application was in addition to the latter assigned rates. Due to heavy rains after 15 February 2008, an additional 28 kg ha^{-1} was applied to plots—again excluding 0 kg ha^{-1} plots—to account for possible leaching. Wheat was harvested at each location in June (Table 3.02) with one pass through the center of each subplot using a small plot combine with a 2.4 m grain head. Wheat yields were adjusted to a moisture content of 135 g kg^{-1}. Harvested wheat grain was dried at 55°C for 72 h and prepared for analysis by grinding a subsample in a Wiley mill (Thomas Scientific, Swedesboro, NJ) and cyclone (UDY Corp., Fort Collins, CO) sample mills to pass a 1-mm screen. Grain subsamples were measured for total C and N by dry combustion on a LECO TruSpec C/N analyzer (LECO Corp., St. Joseph, MI). Wheat grain N content was the product of average dry matter (kg ha^{-1}) and average N concentration (g kg^{-1}). Wheat grain N use efficiency (NUE) was calculated using the difference method (Olson and Swallow, 1984). This formula is:

(Fertilized wheat N content – Unfertilized wheat N content)/Fertilizer application rate.

Traits examined in this experiment were sunn hemp population, sunn hemp height, sunn hemp stem diameter, sunn hemp biomass yield, sunn hemp N concentration, wheat grain yields, wheat grain N concentration, wheat grain N content and wheat grain NUE. Data were analyzed by year with analysis of variance (ANOVA) using the MIXED procedure in Statistical Analysis System (SAS) software (SAS Institute Inc., Cary, NC). Replication and interactions of cover crop with replication were considered random, while all others were considered fixed effects. Protected least significant differences (LSD) at 5% probability ($\alpha = 0.05$) were determined to compare treatment means when measured traits had significant F-tests ($P \leq 0.05$). Linear and quadratic regression equations were utilized to relate cover crop treatment and N rate with wheat grain yield and wheat grain concentration by selecting the highest R^2 statistic from the fit.

Results and Discussion

Climate

Daily maximum and minimum air temperatures and precipitation were obtained from the AWIS Weather Services, Inc., Auburn, AL (Alabama Mesonet Weather Data, 2009). At WGS, the monitoring station was located 2.9 km from the 2007-2008 experiment and 1.3 km from the 2008-2009 and 2009-2010 experiment. The monitoring station in Belle Mina was located 2.1 km from the TVS field during 2008-2009 and 2009-2010. No weather records were available prior to 1993, so an average was calculated from 1993-2010 data. With the exception of TVS in 2009, 'Selection PBU' was planted during a drier than average September at all locations (Table 3.03). Sunn hemp is considered drought tolerant (White and Haun, 1965); however, these dry conditions could have negatively impacted seedling vigor and emergence. Rainfall was below average for all field locations at time of wheat planting in November, but precipitation exceeded averages during the next month (Table 3). Rainfall was above average until N application in February then fell to below average until wheat harvest during June 2007-2008 (Table 3.03). During 2008-2009, wheat at both locations had drier winters then received greater than average rain from time of fertilization in February until harvest in June (Table 3.03). Rainfall during

2009-2010 was above average during January, dipped below average until May, and then remained above average until harvest in June at the two experimental areas.

Sunn Hemp Biomass and Nitrogen Production

Despite below average rainfall during 2007, ‘Selection PBU’ at WGS had higher stand counts than the 2008 and 2009 growth periods 4 WAP (Table 3.04). The increased emergence rate at WGS 2007 is attributed to more GDD accumulated 4 WAP (688 GDD) compared to the other years, 519 (WGS 2008) and 378 (WGS 2009) GDD, and locations, 511 (TVS 2009) and 378 (TVS 2010) GDD (Table 3.03). At the TVS location, 2008 and 2009 populations were both near 140 plants m^{-2} (Table 3.04). High soil inorganic N at TVS during the 2008-2009 experimental period was due to the presence of lupin (*Lupinus* spp.) in the field prior to sunn hemp planting. No lupin residue was left, but the inorganic N levels in the soil were high (Table 3.01).

At termination in November, ‘Selection PBU’ at WGS 2007 produced the tallest plants across all locations (Table 3.04). Although rainfall was below average during its growth period (Table 3.03), WGS 2007 ‘Selection PBU’ had considerable days in the field prior to termination (Table 3.02) and accumulated more GDD (Table 3.03). Below normal precipitation was measured at TVS and WGS in 2008 (Table 3.03). ‘Selection PBU’ at TVS 2008 and WGS 2008 had similar number of days in the field (Table 3.02) and GDD accumulation (Table 3.03); however, sunn hemp at TVS in 2008 was taller (Table 3.01). The 2009 sunn hemp growing period resulted in short plants (Table 3.04) despite above average rainfall (Table 3.03). The slighter taller plants at WGS in 2009 could be due to higher GDD accumulation (Table 3.03) and reduced competition due to lower stand numbers (Table 3.04).

Despite below average rainfall during the 2008 growing season, sunn hemp at TVS and WGS was 30% thicker than sunn hemp grown in 2009 at the same locations (Table 3.04). At termination, sunn hemp biomass averaged 3.5 Mg ha^{-1} at WGS in 2007, 1.7 and 0.9 Mg ha^{-1} in 2008 (TVS and WGS, respectively), and 0.8 and 0.9 Mg ha^{-1} in 2009 (TVS and WGS, respectively) (Table 3.04). Differences in 'Selection PBU' production were attributed to variability in GDD, with the exception of WGS in 2009 (Table 3.03). Despite receiving above average rainfall and high GDD accumulation overall (Table 3.03), 'Selection PBU' at WGS in 2009 was unable to rebound from slow growth early in the growing season (Table 3.03) resulting in low biomass production (Table 3.04). Throughout the experimental period, 'Selection PBU' biomass production was below the minimum rate of 4.5 Mg ha^{-1} (Table 3.04) reported for high residue conservation tillage systems in Alabama (Reiter et al., 2003). However when planted in late August and early September near Shorter, AL in 2008, 50 kg ha^{-1} 'Selection PBU' produced 3.6 Mg ha^{-1} biomass 8 WAP.

Sunn hemp N concentrations decreased when increased amounts of biomass were produced (Table 3.04). The total N content and potential N available from 'Selection PBU' averaged 84 kg N ha^{-1} in 2007 at WGS, 26 and 50 kg N ha^{-1} during 2008 (TVS and WGS, respectively), and 28 and 24 kg N ha^{-1} during 2009 (TVS and WGS, respectively). Average 'Selection PBU' C:N were below 30:1 (data not shown) during all growing seasons indicating the N would mineralize quickly.

Wheat Grain

The residual effects of 'Selection PBU' N mineralization were observed in wheat grain yields for two of the five growing seasons. Sunn hemp treatments resulted in significant wheat grain yield increases at WGS in 2008 ($p = 0.0501$) and 2009 ($p = 0.0278$) (Table 3.05). In 2008, sunn hemp biomass resulted in a 28% increase in wheat grain yield over fallow treatment (Table 3.05). Wheat grain yields were extremely low at WGS in 2008 (Table 3.05). In other field trials from the same year, the same wheat variety had yields at nearby locations of 3.7 Mg ha^{-1} (Quincy, FL) and 4.6 Mg ha^{-1} (Griffin, GA) when 78 kg N ha^{-1} was topdressed (Bockelman, 2008). The poor performance of wheat during 2008 was suspected, but not confirmed, to be due to residual herbicide injury. Despite having sufficient rainfall (Table 3.03) and more than adequate N (Table 3.01), wheat did not respond to treatment. During the following growing season, a 15% increase in wheat grain yield followed sunn hemp compared to the fallow treatment (Table 3.05). Grain yields responded to fertilizer application across all N treatments (Table 3.05). Wheat grain yields from the WGS location in 2009 demonstrated that high N fertilizer rates are not required following ‘Selection PBU’ when substantial biomass is produced (Table 3.05). During the experiment, 28 kg N ha^{-1} maximized grain yields at WGS and 56 kg N ha^{-1} maximized grain yields at TVS.

During the experiment wheat grain N concentration ranged from 1.7 to 2.5 g kg^{-1} (Table 3.06); this is similar to Debaeke et al. (1996) finding wheat grain N concentration ranges from 1.6 to 2.8 g kg^{-1}, rising with increasing fertilizer application rates. Wheat grain N contents at WGS in 2008 and 2009 increased by 38% (2008) and 17% (2009) following sunn hemp (Table 3.07). Due to soil moisture and N availability during wheat grain fill, reports found 8-50% of mature wheat N content is after anthesis (Austin et al., 1977; Spiertz and Ellen, 1978; Van Sanford and MacKown, 1987; Heitholt et al., 1990). Studies suggest wheat grain N contents and grain yields increase jointly (Austin et al., 1977; Debaeke et al., 1996). Wheat grain N content responses to fertilizer application at TVS in 2010 were linear for sunn hemp and quadratic for fallow (Table 3.08). Wheat grain N content responses were quadratic for sunn hemp and fallow at WGS in 2008 and 2010, and TVS in 2009 (Table 3.08). During 2009 at WGS, regressions were not significant (Table 3.08). The fertilizer equivalence values for wheat grain N content were 20.5 (2008), 99.6 (2009), and 3.4 (2010) kg N ha^{-1} at WGS, and <5 kg N ha^{-1} at TVS for both growing seasons.

Delogu et al. (1998) reported higher N fertilizer amounts are needed to optimize wheat yields due to the low NUE of wheat. Wheat NUE was calculated using wheat grain N content (Table 3.07). As expected, NUE decreased as fertilizer application increased across all locations during each growing season (Table 3.09). Estimated NUE averages were within the typical range of 30 to 35% for cereal production (Moll et al., 1982; Olson and Swallow, 1984; Sowers et al., 1994; Raun and Johnson, 1999). Some wheat grain NUE at the lower N application rates, especially at the WGS location during 2009, was greater than the established average (Table 3.09).

Regression equations relating wheat grain yields to fertilizer application within sunn hemp and fallow treatments were calculated (Table 3.10). The regression equations throughout this study were quadratic. Sunn hemp at WGS had 28 kg N ha^{-1} (2008) and 38 kg N ha^{-1} (2009) fertilizer equivalence on wheat grain yield. However, sunn hemp had <5 kg N ha^{-1} fertilizer equivalence at TVS in 2009 and at WGS and TVS in 2010. In Alabama, 'Tropic Sun' fertilizer equivalence had an average N fertilizer equivalence of 45 kg N ha^{-1} with mowed residue (Mansoer et al., 1997) and 58 kg N ha^{-1} with unmowed residue (Balkcom and Reeves, 2005) after decomposing during the winter prior to planting corn (*Zea mays* L.). Increased precipitation during early wheat growth may have contributed to N leaching from decomposing sunn hemp residue resulting in sunn hemp having no yield effect on the majority of wheat planted.

Conclusions

Wheat grain yields following 'Selection PBU' showed a response to N application. Wheat grain N contents were higher following 'Selection PBU' than fallow in 2 of the 5 site years. In 4 of the 5 site years, wheat grain yield and wheat grain N rose as N fertilizer applications increased. Wheat grain NUE decreased as N fertilizer application increased in 3 of the 5 growing periods.

'Selection PBU' contribution to wheat grain production was influenced by 'Selection PBU' biomass production. Despite somewhat promising results during 2008, evaluation of 'Selection PBU' biomass production was hindered by low biomass production in both northern and southern locations in 2009 and 2010. Moving the planting date of 'Selection PBU' to an earlier time in the rotation is suggested to improve GDD accrual and maximize biomass production. Increasing 'Selection PBU' biomass production is important to gain any benefit from including this sunn hemp cultivar in sunn hemp-wheat rotations. Increasing seeding rate may also be desirable; however, this option is dependent on seed availability and would increase costs. Results from this experiment suggest further exploration of 'Selection PBU' usage as a N source to reduce commercial fertilizer dependence is required.

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Table 3.01. Soil test results of top 20 cm from 2007 to 2010 at Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
Soil traits	2007	2008	2009	2008	2009
pH					
Fallow	5.9	6.4	6.4	6.4	6.1
Sunn hemp	5.9	6.4	6.4	6.5	6.1
CEC, cmol kg^{-1}					
Fallow	< 4.6	> 4.6 to 9.0	> 4.6	> 9.0	> 9.0
Sunn hemp	< 4.6	> 4.6 to 9.0	> 4.6	> 9.0	> 9.0
NH_4-N, mg kg^{-1}					
Fallow	0.5	1.8	1.0	2.6	2.7
Sunn hemp	0.4	2.7	2.0	9.5	2.7
Pre-cover	0.5	2.0	1.3	3.1	2.9
NO_3-N, mg kg^{-1}					
Fallow	1.2	3.0	0.8	22.2	4.2
Sunn Hemp	1.1	3.3	1.2	13.1	3.5
Pre-cover	1.1	4.2	1.0	23.7	4.3
Nutrient level†					
P	H	H	M‡	H	M‡
K	H	H	M§	VH	M§
Mg	H	H	H	H	H
Ca	H	H	H	H	H

† Same nutrient levels measured for pre-cover crop soil samples and post-cover crop soil samples.

‡ Applied 56 (WGS) and 67 (TVS) kg P_2O_5 ha^{-1} per wheat recommendation.

§ Applied 45 (WGS) and 35 (TVS) kg K_2O ha^{-1} per wheat recommendation.

Table 3.02. Sunn hemp and wheat field calendars from 2007 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
Field dates	2007-2008	2008-2009	2009-2010	2008-2009	2009-2010
	--------------------------------Sunn hemp data--------------------------------				
Planting date	5 Sep.	10 Sep.	18 Sep.	2 Sep.	9 Sep.
Termination date	12 Nov.	12 Nov.	30 Nov.	6 Nov.	5 Nov.
Growing days	68	63	73	65	57
	--------------------------------Wheat data--------------------------------------				
Variety	AGS2000	USG3209	AGS2060	USG3209	AGS2060
Planting date	23 Nov.	20 Nov.	30 Nov.	10 Nov.	16 Nov.
Fertilization date	15 Feb.†	20 Feb.	18 Feb.	20 Feb.	23 Feb.
Harvest date	3 June	17 June	8 June	17 June	25 June

† Additional fertilizer was applied on 4 January 2008 and 5 March 2008.

Table 3.03. Average monthly precipitation and growing degree days of sunn hemp from 2007 to 2010 at Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	Precipitation†							Growing degree days‡				
	WGS				TVS			WGS			TVS	
Month	2007-08	2008-09	2009-10	Average§	2007-08	2009-10	Average§	2007	2008	2009	2008	2009
	mm							Sunn hemp				
Sep.	88	32	89	111	21	118	97	688	519	378	648	511
Oct.	86	78	121	87	73	166	73	627	529	606	413	342
Nov.	0	6	57	18	0	0	16	146	138	252	70	16
Total	174	116	267	216	94	283	186	1461	1186	1236	1131	869
Nov.	82	42	---	75	33	74	86					
Dec.	208	159	265	104	253	178	121					
Jan.	109	53	224	101	90	128	118					
Feb.	155	50	97	102	66	82	108					
Mar.	55	183	55	113	128	105	113					
Apr.	104	146	61	103	125	62	94					
May	23	233	119	67	242	138	93					
June	2	0	43	16	28	32	44					
Total	738	866	864	681	965	800	777					

† Source: Alabama Mesonet Weather Data. Headland, AL (WGS), 31.35N 85.33W, and Belle Mina, AL (TVS), 34.70N 86.88W, weather stations.

‡ Growing degree days (base 10°C) accumulated until termination date. Daily growing degree days were calculated as: [(daily maximum temp. + daily minimum temp.)/2] – 10°C.

§ 1993-2009 means. Data was not available prior to 1993.

Table 3.04. Sunn hemp data collected from 2007 to 2009 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
	2007	2008	2009	2008	2009
Population†	---------------------------plants m^{-2}-------------------------------				
Average	133	104	97.4	141	138
Standard deviation	21.8	16.8	27.1	27.8	25.8
Height‡	------------------------------cm-----------------------------------				
Average	113	81.3	67.6	104	46.9
Standard deviation	8.85	5.15	6.25	6.46	3.44
Diameter‡§	------------------------------mm----------------------------------				
Average	---	3.78	2.99	3.76	2.80
Standard deviation	---	0.291	0.334	0.432	0.860
Biomass yield‡	----------------------------Mg ha^{-1}-------------------------------				
Average	3.45	0.872	0.933	1.68	0.843
Standard deviation	0.892	0.241	0.232	0.520	0.144
Biomass N concentration‡	------------------------------g kg^{-1}-------------------------------				
Average	24.1	29.4	26.0	29.3	33.2
Standard deviation	5.95	2.72	1.64	4.30	2.43

† Measured 4 WAP sunn hemp.

‡ Measured at time of sunn hemp termination.

§ Diameter data was not collected during 2007 sunn hemp growing season.

Table 3.05. Wheat yield data collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
Treatment	2008	2009	2010	2009	2010
	$Mg\ ha^{-1}$				
Cover crop					
Fallow	0.97	2.83	0.51	3.92	1.23
Sunn hemp	1.34	3.35	0.58	3.97	1.17
$LSD_{0.05}$	0.44	0.68	0.08	0.24	0.20
N rate, $kg\ ha^{-1}$					
0	0.56	3.55	0.25	3.11	0.77
28	1.29	3.17	0.82	4.16	1.12
56	1.26	3.23	0.67	4.33	1.25
84	1.30	2.44	0.50	4.18	1.36
112	1.35	3.08	0.48	3.94	1.49
$LSD_{0.05}$	0.18	0.80	0.10	0.33	0.18
	Analysis of variance ($P > F$)				
Cover crop	0.0501	0.0278	0.3421	0.6117	0.3785
N rate	<0.0001	0.0683	<0.0001	<0.0001	<0.0001
CC × N rate	0.3590	0.1177	0.4801	0.3340	0.6977

Table 3.06. Wheat grain nitrogen concentration data collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
	2008	2009	2010	2009	2010
	----------------------------------	----------------------------------	-g kg^{-1}-	----------------------------------	----------------------------------
Average	2.1	1.9	2.5	1.7	2.2
Standard deviation	0.40	0.20	0.30	0.11	0.26

Table 3.07. Wheat grain nitrogen content data collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
Treatment	2008	2009	2010	2009	2010
	---------------------------------kg ha^{-1}-------------------------------------				
Cover crop					
Fallow	20.7	54.4	12.3	68.6	27.5
Sunn hemp	28.6	63.4	14.4	66.6	26.6
$LSD_{0.05}$	7.2	7.7	2.3	9.4	3.1
N rate, kg ha^{-1}					
0	9.2	65.4	5.4	53.2	15.7
28	23.4	61.9	17.4	67.5	22.0
56	25.9	59.3	16.7	73.9	26.5
84	30.2	47.5	13.7	71.5	32.6
112	34.6	61.2	13.6	71.8	38.4
$LSD_{0.05}$	4.2	16.6	2.4	5.9	3.9
	Analysis of variance ($P > F$)				
Cover crop	0.0096	0.0543	0.2637	0.5017	0.5931
N rate	<0.0001	0.1752	<0.0001	<0.0001	<0.0001
CC × N rate	0.7233	0.1488	0.4046	0.4044	0.9318

Table 3.08. Regression equations for wheat grain N content collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and the Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

Location	Fallow			Sunn Hemp		
	Equation	R^2	Model $P > F$	Equation	R^2	Model $P > F$
WGS 2008	$y = 6.903 + 0.401x – 0.002x^2$	0.93	<0.0001	$y = 14.282 + 0.464x – 0.002x^2$	0.66	0.0001
WGS 2009	$y = 68.149 – 0.922x + 0.009x^2$	0.25	0.1010	$y = 65.564 + 0.144x – 0.003x^2$	0.19	0.1741
WGS 2010	$y = 6.456 + 0.318x – 0.003x^2$	0.46	0.0049	$y = 7.512 + 0.389x – 0.003x^2$	0.55	0.0011
TVS 2009	$y = 56.868 + 0.432x – 0.003x^2$	0.46	0.0052	$y = 58.401 + 0.187x – 0.001x^2$	0.33	0.0319
TVS 2010	$y = 16.038 + 0.212x +0.0002x^2$	0.84	<0.0001	$y = 15.862 + 0.215x$	0.84	<0.0001

Table 3.09. Wheat grain nitrogen use efficiency collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	WGS			TVS	
Treatment	2008	2009	2010	2009	2010
	--------------------------------------%--------------------------------------				
Cover crop					
Fallow	29.1	29.5	19.6	42.6	20.0
Sunn hemp	35.1	49.0	20.6	20.7	21.2
$LSD_{0.05}$	10.0	3.9	8.0	13.0	1.3
N rate, kg ha^{-1}					
0	-----	-----	-----	-----	-----
28	50.9	48.7	42.9	51.2	22.5
56	29.8	42.5	20.2	37.0	19.4
84	25.0	36.4	10.0	21.8	20.1
112	22.7	29.3	7.4	16.6	21.3
$LSD_{0.05}$	7.2	24.2	3.3	11.1	7.0
	Analysis of variance ($P > F$)				
Cover crop	0.1312	0.2052	0.8170	0.1053	0.7849
N rate	<0.0001	0.3602	<0.0001	<0.0001	0.7909
CC × N rate	0.4110	0.8045	0.3182	0.1904	0.9470

Table 3.10. Regression equations for wheat grain yields collected from 2008 to 2010 at the Wiregrass Research and Extension Center (WGS), Headland, AL and Tennessee Valley Research and Extension Center (TVS), Belle Mina, AL.

	Fallow			Sunn Hemp		
Location	Equation	R^2	Model $P > F$	Equation	R^2	Model $P > F$
WGS 2008	$y = 414.63 + 19.40x - 0.11x^2$	0.85	<0.0001	$y = 876.40 + 18.77x - 0.13x^2$	0.34	0.0286
WGS 2009	$y = 1552.05 + 30.93x - 0.09x^2$	0.78	<0.0001	$y = 2586.09 + 16.44x - 0.03x^2$	0.66	<0.0001
WGS 2010	$y = 313.09 + 12.42x - 0.11x^2$	0.41	0.0121	$y = 366.91 + 13.60x - 0.12x^2$	0.48	0.0039
TVS 2009	$y = 3253.88 + 29.09x - 0.03x^2$	0.53	0.0018	$y = 3132.69 + 42.21x - 0.32x^2$	0.78	<0.0001
TVS 2010	$y = 788.03 + 11.25x - 0.04x^2$	0.74	<0.0001	$y = 801.12 + 10.34x - 0.05x^2$	0.63	0.0002

V. Conclusions

After evaluating invasive potential using the Pheloung weed risk assessment system, ‘Selection PBU’ should not be considered a risky introduction to the Southeast. Historically, sunn hemp has limited weed history and cultivars have already been introduced as a crop in the Southeast. Interest in sunn hemp as a soil amender contributes to its wide distribution by people for agricultural purposes; however, poor natural dispersal mechanisms and the limited region of viable seed production, excluding cultivar ‘Selection PBU’, contribute to reduced weed risk assessment and reduced area of impact beyond cultivation. ‘Selection PBU’, despite producing seed, is not a threat due to aforementioned literature. Agronomic interest in sunn hemp cultivars, including ‘Selection PBU’, is unlikely to decrease, especially as the environmental impacts of nonnative introductions receive heightened attention.

Moderate ‘Selection PBU’ seeding rates provided decent results in a summer cover crop-winter cover crop rotation. Throughout the study, ‘Selection PBU’ was in the field for 70 d or less. Day-length affects vegetation production, as seen in ‘Selection PBU’ biomass yield differences between wheat harvest and corn harvest. High ‘Selection PBU’ seeding rates (50 and 67 kg ha^{-1}) were not necessary following wheat harvest, and lower seeding rates from 17 to 34 kg ha^{-1} can perform as well, in some cases, as higher seeding rates up to 67 kg ha^{-1}. Higher ‘Selection PBU’ seeding rates (50 and 67 kg ha^{-1}) are recommended after corn harvest to offset short-day effect and increase sunn hemp biomass yield. Prolonging growing days by planting

‘Selection PBU’ immediately after corn harvest might be beneficial for increasing the N content of biomass. ‘Selection PBU’ biomass production seemed to be inferior compared to biomass production of other sunn hemp cultivars in prior southeastern studies (Mansoer et al., 1997; Balkcom and Reeves, 2005); however, the reduced ‘Selection PBU’ biomass levels are attributed to day-length effect. ‘Selection PBU’ produced higher rye biomass yields in 3 of 4 growing seasons compared to fallow treatment. Rye biomass production demonstrates that N from ‘Selection PBU’ could be utilized and sequestered through periods where it would otherwise be subject to loss.

By planting ‘Selection PBU’ as a cover crop during September, grain N contents were higher following cover crop than fallow in 2 of the 5 site years. In 4 of the 5 site years, grain yield and grain N rose as N fertilizer applications increased. Wheat grain yields after ‘Selection PBU’ cover responded to N application. Wheat grain NUE decreased as N fertilizer application increased in 3 of the 5 growing periods. ‘Selection PBU’ contribution to wheat grain production was influenced by cover crop biomass production.

This research indicates planting ‘Selection PBU’ earlier in Alabama field rotations would potential maximize biomass production. Increasing ‘Selection PBU’ seeding rate may also be desirable; however, this option is dependent on seed availability and would increase costs. Results from this work suggest further exploration of ‘Selection PBU’ usage as a N source to reduce commercial fertilizer dependence.