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AGRONOMY AND SOILS

Cotton Production in Rotation with Summer Legumes

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ABSTRACT

Sunn hemp (*Crotolaria juncea*) is a fast growing tropical legume that can accumulate large amounts of biomass and N in a relatively short period of time during the summer in the southeast US. This study was conducted to evaluate the potential of using this legume as an N source for cotton (*Gossypium hirsutum* L.). A field study was conducted in 2004-2005 and 2006-2007. Treatments were summer legume [sunn hemp, cowpeas (*Vigna unguiculata*), and summer fallow] and fertilizer N rate applied to cotton (0, 45, 90, and 135 kg N ha^{-1}). The summer legumes were planted in mid-summer (July) and cotton was planted the following spring (May). Sunn hemp N accumulation at the first freeze in the fall was 204 kg ha^{-1} in 2004 and 98 kg ha^{-1} in 2006. Cowpeas accumulated 57 kg ha^{-1} in 2004 and 87 kg ha^{-1} in 2006. Soil NO_3-N was higher in the surface 90 cm following sunn hemp than either cowpeas or summer fallow during the winter in both years. Shortly after cotton planting in May, however; there was no difference among the three summer legume treatments in soil NO_3-N. Nitrogen concentrations of uppermost fully expanded leaves were greater in cotton following the legumes than following summer fallow at seven of nine weekly sampling dates in 2005, but there were no differences in 2007. In 2005, seedcotton yield following cowpeas and summer fallow increased with N rate, but seedcotton yield following sunn hemp was not significantly affected by fertilizer N. Drought conditions in 2007 limited cotton yield, and yield decreased with increasing N rates due to the severe stress conditions. Sunn hemp has the potential for providing substantial biomass and N for cropping systems on the low organic matter soils of the southeast US. Further research is needed on the fate of the N in the residues during the winter for cotton rotations.

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Legumes have been used for millennia as an N source in crop rotations. In the southeast US, winter legumes can provide substantial amounts of N to a succeeding cotton crop (Bauer et al., 1993; Touchton et al., 1984). The amount of N provided by a winter legume to a subsequent summer crop is dependent on a number of factors including the legume species, growth stage at desiccation, and weather conditions during the growth of the legume. These factors, along with relatively inexpensive commercial N fertilizers and the added cost and management of planting and desiccating the legume, are some of the reasons that conventional growers in the region are not widely using winter legumes as an N source.

Summer legumes, grown during late summer the season before a cash crop, may help overcome the problems associated with winter legumes and still provide N and organic matter for soil improvement. Mansoer et al. (1997) evaluated growing a sunn hemp cover crop late in the summer. In a three-year study, they found that within a 9-12 wk growing period, sunn hemp accumulation averaged 5.9 Mg ha^{-1} of biomass and 120 kg ha^{-1} of N. Subsequently, Balkcom and Reeves (2005) reported that a fall grown sunn hemp cover crop provided 58 kg ha^{-1} of N to a spring-planted corn (*Zea mays*) crop. More recently, Cherr et al. (2006) reported similar results for sweet corn following sunn hemp grown the previous summer.

Cotton requires less N than corn and 60 kg N ha^{-1} comprises a large portion of the recommended rate of N for a rainfed cotton crop in the southeast USA cotton growing areas. On the other hand, N accumulation by cotton occurs later than corn because corn planting in the southeast occurs about 30 days before cotton planting and significant N accumulation by cotton does not begin until about 50 days after planting. The extra time available for residue decomposition and N mineralization may result in more soil N losses to leaching.

The objectives of this experiment were 1) compare biomass and N accumulation of sunn hemp to cowpea, a common summer legume when planted in late summer, and 2) assess N response of cotton following these summer legumes.

MATERIALS AND METHODS

The study was conducted near Florence, SC from late July through the following October in 2004-2005 and 2006-2007. An experiment was established in 2005-2006, but dry soil conditions following summer legume planting resulted in poor cover crop stands. Treatments in the study were summer legume cover crop [fallow, sunn hemp (cv. 'Tropic Sunn'), and cowpeas (cv. 'Iron-Clay')] and four N fertilizer rates to the cotton (0, 45, 90, and 135 kg N ha^{-1}). Experimental design was split-plot with summer legumes as main plots and N rates as subplots. Subplot size was 12 m wide by 15 m long in 2004-2005 and 4 m wide by 15 m long in 2006-2007. The experiments were conducted on a Nobocco loamy fine sand (fine loamy, siliceous, thermic Typic Paleudult) in 2004-2005 and a Bonneau sand (loamy, siliceous, thermic Arenic Paleudult) in 2006-2007.

In mid-July of 2004 and 2006, lime and P and K fertilizer was applied based on soil test results and recommendations for cotton based on Clemson University Extension (Clemson University Extension Service, 2001). The soil was then disked twice and smoothed with an S-tined harrow. The legumes were planted on 22 July 2004 and 28 July 2006 with a grain drill in rows spaced 19 cm apart. Seeding rates were 56 kg seed ha^{-1} for both species. Biomass and N content of the legumes were determined by collecting 0.57 m^2 areas within each plot at 26 August, 1 October, and 5 November 2004 and on 30 August, 29 September, and 25 October 2006. The last biomass collection of each season was made following the first killing freeze of the fall. After collection, samples were placed in a 65 °C oven until dry and then weighed. A portion of each sample was then ground for total combustible N analysis.

Soil samples for NO_3-N analysis were collected in 30-cm increments to a depth of 90 cm three times from first frost to cotton planting. In 2004-2005, samples were collected on 8 December, 2 February, and 24 May. In 2006-2007, samples were collected on 4 December, 28 February, and 25 May. At the first and second sampling dates in each season, five subsamples were collected and combined from each main plot. In the May sampling each season, soil samples were collected after the N was applied to the cotton so samples were collected from only the 0 kg N ha^{-1} subplots. All soil samples were dried on greenhouse benches and then ground prior to analysis.

A burndown application of glyphosate (1.12 kg a.i. ha^{-1}) was made to the experimental areas in April of each season. Cotton (cv. 'DPL 449 Bt/RR') was planted using conservation tillage (the only tillage was in-row subsoiling just prior to planting) on 10 May 2005 and on 7 May 2006. Row spacing was 1-m and seeding rates were approximately twelve seeds per meter of row. The nitrogen fertilizer treatments were applied within one week of planting the cotton. Liquid urea-ammonium nitrate was dribble-applied at treatment rates approximately 15-cm to the side of each row. Weeds were controlled with a combination of herbicides and hand-weeding. Insect pests were scouted regularly and insecticides applied as needed. At the end of the season, cotton was defoliated with thidiazuron, tribuphos, and ethephon at recommended rates. A spindle picker was used to harvest two interior rows of each subplot on 14 October 2005 and 3 October 2007.

Ten uppermost fully expanded cotton leaves were collected from the center rows of each plot for N analysis each year. Weekly collections were made in 2005 from 23 June through 17 August. In 2007, samples were collected three times from 22 June through 4 August. Samples were not collected in mid-August of 2007 because of the severe water deficit stress that year. After collection, samples were placed in a 65 °C oven until dry and then ground.

Total combustible N (TCN) of the legume and cotton plant tissues was determined by dry combustion using a LECO-2000CNS analyzer (LECO Corp., Chicago, IL). Nitrate was extracted from the soil samples with 1M KCl and total nitrate in the extract was determined using a Lachat QuickChem 8000 analyzer (Latchat Instruments, Milwaukee, WI).

Data were analyzed by year using the MIXED procedure of SAS (Littell et al., 1996). Replicates and the replicate X summer legume interaction were considered random effects, while all others were considered fixed. Summer legume means were separated using the pdiff mean separation technique. The REG procedure (SAS, 1985) was used to evaluate seedcotton yield responses to N. Linear, quadratic, and cubic regression equations were evaluated. Only the linear equations were significant ($P \leq 0.05$) in either year.

RESULTS AND DISCUSSION

Biomass and N accumulation for the summer legumes are shown in Table 1. Long-term average cumulative precipitation at Florence is about 32 cm for the months of August, September, and October. The two years of this study represented years that were above normal (2004) and below normal (2006). In 2004, rainfall accumulation totaled 56 cm from August through October with an exceptionally wet August (August precipitation was 33 cm). The sunn hemp grew well that year, accumulating almost 11000 kg ha^{-1} of biomass and over 200 kg ha^{-1} of N in the aboveground plant parts by the first freeze. The biomass of the cowpeas nearly doubled between one and two months after planting in 2004, but N content did not increase much during this time. At the last sampling time (first freeze), there were only a few cowpea plants so they were not sampled. Rainfall during the summer legume growing time was less in 2006 than in 2004. Total accumulation in 2006 was only 22 cm and 15 cm of that occurred in August. The limited precipitation, together with the experiment being conducted on a more droughty soil in 2006 than in 2004, resulted in lower total biomass and N accumulation than in 2004. Neither legume accumulated much biomass between 2 and 3 months after planting in 2006 (Table 1) because of the lack of precipitation. The reduction in total N content in the aboveground plant parts between 2 and 3 months after planting is probably due to loss of leaves that shed due to the water-deficit stress conditions.

Table 1. Biomass and N content of sunn hemp and cowpeas at three harvest dates in 2004 and 2006 at Florence, SC. Sunn hemp and cowpeas were planted on 22 July 2004 and 28 July 2006.

		Biomass			N Content		
		Months After Planting					
Year	**Legume**	**1**	**2**	**3**	**1**	**2**	**3**
		------------------- kg ha^{-1} -------------------					
2004	**Sunn Hemp**	**2070**	**7891**	**10718**	**53**	**146**	**204**
	Cowpeas	**1628**	**3222**	**---**	**51**	**57**	**---**
	Prob.>F	**0.09**	**0.01**	**---**	**0.68**	**0.01**	**---**
2006	**Sunn Hemp**	**1266**	**6985**	**7265**	**33**	**134**	**98**
	Cowpeas	**1686**	**5516**	**5920**	**53**	**93**	**87**
	Prob.>F	**0.18**	**0.16**	**0.19**	**0.05**	**0.14**	**0.32**

The sunn hemp had higher biomass and N content than the cowpeas at 2 months after planting in 2004. In 2006, there was no significant difference in biomass for the two species at any sampling time. Cowpeas had higher N concentration than the sunn hemp at all sampling dates (data not shown) which resulted in that legume having higher N accumulation at one month after planting in 2006 ($P \leq 0.05$).

Schomberg et al. (2007) developed prediction equations for biomass and N accumulation of sunn hemp based on cumulative growing degree days and/or cumulative solar irradiation across a number of environments. These prediction equations were developed with experiments in which sunn hemp was grown under irrigated conditions at seeding rates of 13 kg seed ha^{-1} in wide rows ($\geq$76 cm). The data from the two years of this study is plotted against the Schomberg et al. (2007) equations in Figures 1 and 2. Temperature and solar irradiation data used for this analysis were collected at a weather station approximately 8 km from the experiment. The equations underestimated biomass accumulation and N content in high rainfall year of 2004. This is likely because of the higher seeding rate and narrow row spacing in this study. This is similar to what Schomberg et al. (2007) found when comparing their equation to the data collected by Mansoer et al. (1997) which was grown with production practices similar to this study. In limited rainfall environment of 2006, the biomass and N content of the sunn hemp in this study were quite close to the predicted values. Overall, these results confirm the usefulness of the equations for growers in predicting sunn hemp biomass and N at different desiccation times, especially for short-term rotations.

The accumulated N by the two legumes did have a small impact on soil NO_3-N in the surface 90-cm both years (Table 2). Soil NO_3-N was higher following sunn hemp than following either fallow or cowpeas at the February sampling time in the 2004-2005 season and both the December and February sampling times in the 2006-2007 season. Since the legumes did accumulate substantial N, it is likely that a large portion of the N in the legume biomass mineralized and leached deeper than 90-cm that we measured. This is not surprising since the coastal plain region has a high potential for NO_3-N leaching through winter months (Nelson and Uhland, 1955) and fall-applying N fertilizer for spring-planted crops is not recommended.

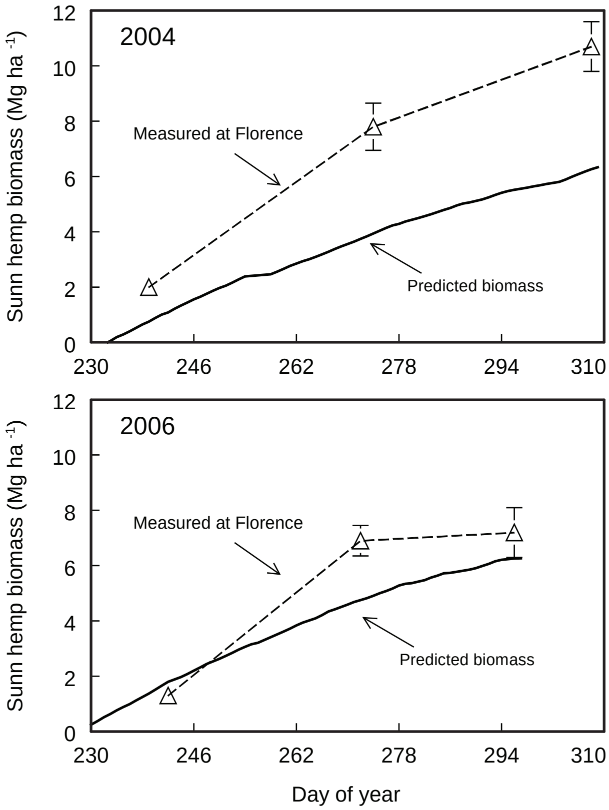

Figure 1. Sunn hemp aboveground biomass accumulation in 2004 and 2006 at Florence SC compared to prediction equation developed by Schomberg et al. (2007) [accumulated biomass = -2.77 + (0.0060*cumulative growing degree days) + (0.0014*cumulative solar irradiation). Error bars are ± one standard error.

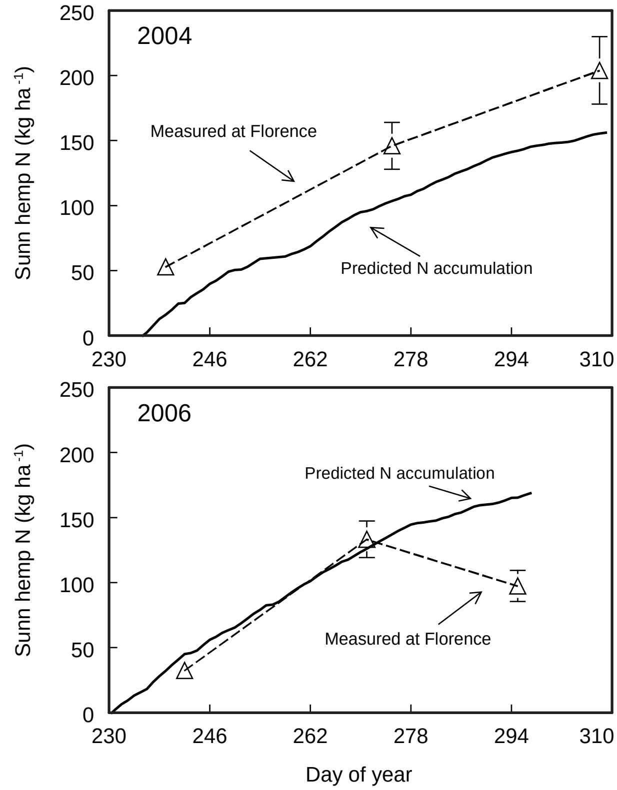

Figure 2. Sunn hemp aboveground N accumulation in 2004 and 2006 at Florence SC compared to predicted N accumulation using equation developed by Schomberg et al. (2007) [accumulated N = -115.5 + (0.2634*cumulative solar irradiation) - (0.000052*cumulative solar irradiation^2). Error bars are ± one standard error.

Table 2. Soil NO_3-N in the surface 90-cm of the soil at three sampling times during the winter/spring in 2004-05 and 2006-07 at Florence, SC. Soil NO_3-N is the sum of the three depths.

		Soil NO_3-N Sampling Time†		
Year	Legume	December	February	May
		kg ha^{-1}		
2004-05	Sunn Hemp	5.3	50.8a‡	48.6
	Cowpeas	6.0	14.8b	33.5
	Fallow	3.6	8.9b	28.2
2006-07	Sunn Hemp	41.1a	15.9a	20.0
	Cowpeas	22.5b	10.1b	18.1
	Fallow	18.5b	5.4b	20.0

†Sampling dates in 2004-2005 were 8 December 2004, 2 February 2005, and 24 May 2005. Dates in 2006-2007 were December 2006, 28 February 2007, and 25 May 2007.

‡ Means followed by different letters are significantly different ($P<0.05$) using the pdiff procedure in SAS.

Cotton following sunn hemp, cowpeas, and summer fallow had similar responses to fertilizer N rates for uppermost fully expanded leaf N concentration at all sampling dates in both years. Therefore, means in Table 3 are averaged over all N rates. Cotton grown following both summer legumes had higher leaf N concentration through early bloom (59 days after planting) in 2005. During mid-bloom (66 and 73 days after planting), cotton grown following the legumes did not differ in leaf N from cotton grown following summer fallow. After mid-bloom, leaf N was higher from the cotton grown following the legumes compared to cotton grown following summer fallow (Table 3). The higher leaf N concentrations late in the season may have been due to cotton roots expanding deeper into the soil and recovering leached N. In 2007, there was no influence of the previous crop on leaf N at any sampling date (Table 3).

Table 3. Cotton leaf N content in 2005 and 2007 averaged over all N rates

Year	Days After Planting	Sunn Hemp	Cowpeas	Fallow
		------------------ g N kg^{-1}	-----------------	
2005	44	42.8a†	41.8a	39.6b
	52	49.3a	49.4a	45.3b
	59	41.4a	41.1a	37.9b
	66	34.4	33.5	32.8
	73	33.0	32.9	32.3
	80	34.2a	34.1a	30.6b
	87	36.0a	35.6a	30.6b
	92	38.4a	36.8a	32.0b
	99	34.1a	33.5a	30.4b
2007	46	49.9	49.5	48.4
	58	35.8	36.2	36.3
	77	38.6	38.8	37.7

† Means followed by the same letter within a row are not significantly different ($P \leq 0.05$) using the pdiff procedure. Means without letters indicate the legume effect was not significant ($P \leq 0.05$) from analysis of variance.

Seedcotton yield following the legumes was higher than cotton following summer fallow at the low N rates in 2005 (Table 4). Following sunn hemp, yield was not significantly influenced by N fertilizer rate (Table 4). Seedcotton yield increased with N application rate for the cotton following cowpeas and following summer fallow (Table 4). Although the quadratic regression was not significant for yield in the cotton following cowpeas, the largest numerical increase occurred between 0 and 45 kg N ha^{-1}. Growing conditions were better for cotton in 2005 than in 2007. The 2007 cotton growing season had 20 cm less precipitation than the 2005 season. The severity of plant stress during July and August of that year resulted in very low yield. Yields decreased with increasing N rate (Table 4), presumably because the cotton fertilized with higher N rates had more leaf area earlier in the season which led to more rapid depletion of stored soil water. With the severe stress, there was no difference in yield among cotton grown after sunn hemp, cotton grown after cowpeas, and cotton grown after summer fallow.

In summary, our data are in agreement with previous reports (Balkcom and Reeves, 2005; Schomberg et al., 2007) on the potential of using sunn hemp to provide biomass and N for cropping systems on the low organic matter soils of the southeast US. Using the Schomberg et al. (2007) equations that predict biomass and N from solar irradiation, growers can manage this legume for optimal N and biomass for their production system. The high N content potential of the legume makes this a questionable rotation for cotton production because of environmental concerns with N losses through the winter. One solution may be to grow a winter cereal cover crop following the summer legume to sequester the N as suggested by Balkcom and Reeves (2005); however, this does not overcome the limitation of having to manage a cover crop in the spring before cotton planting. In cases where this is a concern, using winter legumes for soil improvement and N for the subsequent crop appears preferable.

DISCLAIMER:

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Table 4. Effect of summer legume and N rate on seedcotton yield.

Year	Legume	N Fertilizer Rate (kg ha^{-1}) 0	45	90	135	Regression Equation
					kg ha^{-1}	
2005	Sunn Hemp	2311	2552	2534	2795	$Y=2337 + 3.5N^{ns}$
	Cowpeas	1767	2585	2529	2877	$Y=1997 + 7.4N^{*}$; $r^2=0.36$
	Fallow	1495	1868	2776	3002	$Y=1466 + 13.6N^{**}$; $r^2=0.65$
2007	Sunn Hemp	964	902	891	796	$Y=965 - 1.3N^{†}$; $r^2=0.22$
	Cowpeas	1036	998	785	845	$Y=1034 - 2.0N^{*}$; $r^2=0.32$
	Fallow	988	875	897	795	$Y=972 - 1.4N^{ns}$

†, *, ** indicate regression was significant at $P \leq 0.10$, 0.05, and 0.01, respectively while ns indicates slope not significantly different from zero.

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