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AGRONOMY & SOILS

Cotton Response to Nitrogen Derived from Leguminous Cover Crops and Urea Ammonium Nitrate

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ABSTRACT

The use of legumes as a winter cover crop and green manure for subsequent summer annual crops in the southeastern U.S. has been limited due to relatively inexpensive sources of nitrogen. However, the cost of synthetic nitrogen has nearly tripled in the last 11 years, stimulating growers to reconsider the use of legumes as a cost-effective source of nitrogen. Selecting an appropriate legume species, timing of cover crop termination, and timing of summer crop planting can be adjusted to supply total season nitrogen needs of cotton (*Gossypium hirsutum* L.) in North Carolina. Crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth) were used as green manures in cotton as a sole source of nitrogen in field experiments conducted in North Carolina during 2010 and 2011. The highest cotton yield and biomass were noted when cover crops were terminated by a single broadcast herbicide application at 10 days before cotton planting. Lint yield of cotton following crimson clover and hairy vetch equaled lint yield of cotton without cover crops plus 70 kg N ha^{-1} of liquid urea ammonium nitrate. Net return of the legume cover crop/cotton system equaled net return of the cotton liquid nitrogen system and ranged from 1,240 to 1,650 \$ ha^{-1}.

The cost of nitrogen (N) to growers remained fairly uniform from 1974 to 2000, at an average cost of \$0.48 kg^{-1} N^{-1} in a 30% solution of liquid urea ammonium nitrate (UAN) (USDA-ERS, 2012b). Since 2001, however, the cost of N increased. The average cost from 2006 to 2011 was \$1.20 kg^{-1} N^{-1} (Crozier et al., 2012; Edmisten, 2012c; USDA-ERS, 2012b). Recommended N rates for rain-fed cotton (*Gossypium hirsutum* L.) grown in North Carolina typically range from 60 kg ha^{-1} to 90 kg ha^{-1} accounting for 14% of the total variable production cost (Bullen and Edmisten, 2012; Crozier et al., 2012). To minimize N cost, cotton producers must consider more efficient ways to use their N sources, such as precision agriculture or less costly sources such as animal and municipal wastes. Legume cover crops are often overlooked due to the establishment cost. However, faced with increasing N prices, cover crops might offer a cost effective alternative to other N sources.

Fall planted legumes have been used as a winter cover crop to prevent soil erosion and as green manure for a succeeding summer annual crop. Examples include alfalfa (*Medicago sativa* L.), Austrian winter pea (*Pisium sativum* L.), crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth), and common vetch (*Vicia sativa* L.) (Bauer et al., 1993; Frye et al., 1985). Legume cover crops can provide additional benefits as well, such as early season weed suppression, improved soil structure, reduced water runoff, increased soil organic matter, reduced N fertilization requirement, and reduced potential N leaching (Bauer et al., 1993; Entry et al., 1996; Millhollon and Braud, 1999; Möller and Reents, 2009; Norsworthy et al., 2010; Reddy, 2001; Rochester et al., 2001; Sankaranarayanan et al., 2010).

Previous work in North Carolina involving winter legumes indicated shoot biomass N content often exceeded 100 kg N ha^{-1} in crimson clover and 150 kg N ha^{-1} in hairy vetch (Crozier et al., 1994; Ranells and Wagger, 1996). In Pennsylvania, Cook et al. (2010) found hairy vetch shoot biomass contained at least 200 kg N ha^{-1} when terminated in late May. They found that shoot biomass N content was directly proportional to growing degree days (GDD) and, therefore, sensitive to termination date. These results suggest that crimson clover and hairy vetch might be useful as green manure in North Carolina because they have the potential to supply total season N needs to annual summer crops if they are allowed

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to grow into late spring. Crimson clover and hairy vetch might also be good cover crops because they release N rapidly after desiccation, due to their relatively low carbon-to-nitrogen ratio (C/N) (Nakhone and Tabatabai, 2008). North Carolina experiences relatively high soil temperature adding to N availability (Sankaranarayanan et al., 2010).

The challenge with any green manure used as an N source for summer annual crops is to manipulate the cover crop termination and/or the crop planting date so that peak biomass N production, legume termination, and subsequent N release and mineralization occur before peak crop needs. Unfortunately, many summer annual crops must be planted before cover crops achieve maximum biomass N due to other agronomic constraints, such as avoidance of late season insect damage and shortened growing season. When this happens, the cover crop must be terminated early and supplemental N applied to achieve high crop yields. Cook et al. (2010) found that peak corn (*Zea mays* L.) yield resulted from a mid-May hairy vetch termination date, even though peak biomass N had not yet been achieved; they estimated that late-May terminated hairy vetch produced 100 kg ha^{-1} more N than mid-May terminated hairy vetch, but delayed planting of the subsequent corn crop resulted in insufficient GDD to produce higher yield.

In North Carolina, cotton is a perennial plant grown as a summer annual crop that is well suited to utilize the N supplied by crimson clover and hairy vetch. Cotton is planted as early as soil temperature, soil moisture, and weather conditions allow; however, maximum yield is usually achieved when planted before the end of May (Edmisten, 2012c). Cotton N requirement above what is naturally supplied by the soil is typically less than 90 kg N ha^{-1} and high N uptake does not take place until first bloom, often during the first week in July, or at approximately eight weeks after planting (WAP). If crimson clover and hairy vetch are to be used as an N source, mineralization of the cover crop N must occur by first bloom, but not so early that nitrate (NO_3^-) is susceptible to leaching. Cover crop studies in North Carolina indicated that termination of crimson clover and hairy vetch near optimum cotton planting dates might provide sufficient N for high cotton yield. Ranells and Wagger (1996) estimated that N released from crimson clover and hairy vetch cover crop residues left on the soil surface released 60 and 108 kg N ha^{-1}, respectively, after eight weeks of field decomposition. Parr et al. (2011) found that crimson clover peak biomass N content occured in mid to late April and hairy vetch peak biomass N content occured between early and late May.

Strip tillage and the use of herbicide resistant cotton cultivars have become common practices in North Carolina; at least 96% of the cotton ha is herbicide tolerant and 38% of the cotton acreage is reduced tilled, primarily strip tilled (USDA-ERS, 2007, 2012a). These two practices might improve the efficiency of legume cover crops because they allow for effective late cover crop termination. The postemergence and relatively nonselective herbicides glufosinate and glyphosate have made it possible to terminate cover crops after cotton emergence. Strip tillage makes it feasible to prepare a seedbed without disturbing the cover crop situated between the cotton rows. In this scenario, the cover crops become living mulches. However, problems might arise in North Carolina when terminating cover crops in May; the cover crops might become difficult to kill after anthesis and soils might become excessively dry and reduce cotton seedling emergence (Clark et al., 1995; Price et al., 2009).

Previous economic studies involving legume cover crops and cotton have concluded that synthetic N sources were more cost effective than green manures, and green manures did not provide enough N by themselves to achieve high lint yield (Thompson et al., 1997). However, most of these economic studies were conducted prior to 2000 before rapid increases in N cost and widespread adoption of strip-tillage equipment. Although N prices are at least three-fold higher than 2000 prices and with the widespread adoption of herbicide-tolerant cotton, more flexibility in designing winter legume/summer annual cropping system exists.

Research was conducted to evaluate crimson clover and hairy vetch as winter cover crops capable of supplying total season cotton N needs. Four cover crop termination dates were employed using a combination of herbicide strip and herbicide broadcast applications to maximize N supplied to the cotton. Conventional plots with increasing levels of fertilizer N were used to determine the N equivalency rate of the cover crop management strategy. Cover crop biomass, lint yield, and cotton morphological response were measured to compare cover crop termination strategies and cover crop species. An economic estimate of net return to the system also was conducted to compare termination strategy, cover crop species, and synthetic N response.

MATERIALS AND METHODS

The experiment was conducted in North Carolina during 2010 on a Goldsboro fine sandy loam soil (fine-loamy, siliceous, thermic, Aquic Paleudults) near Rocky Mount and during 2011 on a Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Paleadults) near Clayton. Treatments included five cover crop termination strategies applied to two cover crop species, plus five bare cover plots with increasing levels of nitrogen (UAN) to establish nitrogen response curves.

Crimsom clover (*Trifolium incarnatum*, cv. Dixie) and hairy vetch (*Vicia villosa*, cv. Hairy) were overseeded into standing cotton the previous year on 30 September 2009 and 17 September 2010, immediately prior to defoliation. Cover crops were seeded using a hand spreader calibrated to spread 28 kg ha^{-1} of true live seed. Cotton was defoliated using a combination of ethephon (Prep™ 6, Bayer CropScience, Research Triangle Park, NC) at 1.12 kg ai ha^{-1}, phosphorotrithiate (Def® 6, Bayer CropScience, Research Triangle Park, NC) at 1.34 kg ai ha^{-1}, and thidiazuron (Dropp®SC, Bayer CropScience, Research Triangle Park, NC) at 0.11 kg ai ha^{-1}. Cover crop germination was determined by counting live plants inside a 0.25-m^2 template randomly placed inside each plot within 12 wk of overseeding.

Cover crops were terminated in the spring prior to cotton planting using the following strategies: 1) broadcast application of glyphosate (Roundup WeatherMax®, Monsanto, St. Louis, MO) at 0.84 kg ae ha^{-1} plus dicamba (Clarity®, BASF, Research Triangle Park, NC) at 0.28 kg ae ha^{-1} 30 d before planting (DBP); 2) broadcast application of paraquat (Gramoxone Inteon®, Syngenta, Greensboro, NC) at 1.12 kg ai ha^{-1} plus diuron (Direx® 4L, Makhteshim Agan of North America, Raleigh, NC) at 0.90 kg ai ha^{-1} 10 DBP; 3) banded application (30-cm width) of glyphosate plus dicamba over the center of the cotton rows using rates described previously at 30 DBP followed by a broadcast application of paraquat plus diuron 10 DBP using rates described previously; 4) banded application (30-cm width) of glyphosate plus dicamba at 30 DBP over the center of the cotton rows using rates applied previously plus a broadcast application of paraquat plus diuron at cotton planting using rates applied previously; and 5) banded application (30-cm width) of glyphosate plus dicamba over the center of the cotton rows at rates described previously at 30 DBP, plus a broadcast application of glyphosate over the top of cotton at 1.12 kg ai ha^{-1} applied 2 wk after planting (WAP). Glyphosate at 1.12 kg ha^{-1} was applied to all plots during both years at 4 WAP to control any remaining cover crop and to control emerged summer weeds.

Cover crop shoot biomass for each termination strategy from two randomly placed 0.25-m^2 templates was collected from each plot immediately before the final broadcast application of herbicide. When plots contained previously killed strips, biomass samples were obtained from the middle two rows between the kill strips so that actual dry weights per unit area were adjusted to account for the desiccated area; actual dry weights per unit area were calculated by multiplying the obtained dry weights by 0.666. Biomass samples were placed in cloth bags, forced-air dried at 66 °C for 72 h, and weighed.

Plot size was 9.1 m long and 3.7 m wide containing four rows of cotton spaced at 0.91 m. Tillage of all plots was performed using a strip-till implement (KMC 2-36, Kelley Manufacturing Co., Tifton, GA) immediately before cotton planting. Four rows of the cotton variety 'PHY 485 WRF' (Dow Agrosciences, Indianapolis, IN) were planted on 7 May 2010 and 11 May 2011 at 13 seeds per m on 91-cm rows. At planting, all plots were treated with lambda-cyhalothrin (Karate®, Syngenta Crop Protection, Greensboro, NC) at 0.0219 kg ha^{-1} to minimize the risk of cutworm (*Agrotis* spp.) damage to seedlings. All plots were replicated four times.

Urea-NH_4NO_3 liquid nitrogen (32% UAN) was applied in stream 10 cm away from cotton rows to the no-cover crop plots at 0, 28, 56, 84, and 112 kg N ha^{-1} during the first week of bloom immediately after the first petiole collection using a CO_2-pressurized two-row hand-held boom with XR8004 (TeeJet, Wheaton, IL). The nozzles were aligned parallel to the row to minimize splash on the cotton. All other cotton production and pest management practices were conducted in accordance with North Carolina Cooperative Extension Service recommendations (Bacheler, 2012; Crozier et al., 2012; Edmisten, 2012a, 2012b, 2012c; York, 2012).

Leaf petiole samples were removed during the first week of bloom and the fifth week of bloom, forced-air dried at 66 °C for 72 h, and submitted to the North Carolina Department of Agriculture and Consumer Services for nitrate (NO_3^-) concentration analysis. Nitrate concentration was determined with an ion-sensitive electrode (Orion Model 93-07; Thermo Fisher Scientific Inc., Waltham, MA) following an $Al_2(SO_4)_3$ extraction (Baker and Thompson, 1992). Prior to cotton defoliation, nodes above cracked boll (NACB) were taken from 20 randomly selected plants from the middle two rows. Plant height, total nodes, and number of total bolls were collected from six plants randomly selected from the middle two rows prior to harvest. The center two rows of each plot were harvested with a two-row spindle picker, weighed, and 1-kg subsamples of seed cotton were extracted for high volume instrument testing for fiber length, fiber length uniformity, micronaire, fiber strength, and lint percentage using a saw-type mini-gin. Cotton was harvested on 16 September 2010 and 26 October 2011 at Rocky Mount and Clayton, respectively.

The experimental design was a split plot with cover crop species (crimson clover, hairy vetch, or none) serving as the whole plot units, with cover crop termination strategy serving as subplot units within the cover crop plots. Subplot units were replicated four times. Data collected from cover crop germination, cover crop biomass, NACB, height, total nodes, total bolls, petiole NO_3-, cotton yield, and gin turnout were subjected to analysis of variance (ANOVA) using the general linear model in SAS (Version 9.2, SAS Institute, Cary, NC) for a two (combination of field and year) by two (clover and vetch) by five (cover crop termination strategy) treatment structure. Means of significant main effects and interaction were performed using Fisher's Protected LSD at $p \leq 0.05$. The no-cover crop plots were treated with five levels of N. In these plots, lint yield versus applied N was subjected to curve fit regression, second order polynomial, using the regression procedure in SAS to determine optimal level of UAN to apply to achieve maximum cotton yield.

Economic analysis was based on North Carolina Cooperative Extension Service Enterprise Budgets to compare treatments. Cost associated with cover crop seed, insecticide, herbicide, N, ginning, hauling, and cotton seed gin payments were removed from the budget to establish a base production cost of \$1,047 ha^{-1} for strip-tilled cotton (Bullen and Edmisten, 2012). Cost of cover crop seed regardless of the species varied considerably, from \$2.75 kg^{-1} to \$4.40 kg^{-1} depending on cultivar, presence of inoculant coating, and supplier. Therefore, the seed plus inoculant plus application cost was set at \$89 ha^{-1} and \$136 ha^{-1} representing the lowest and highest range of seed cost. Cost of herbicide strips at 30 DBP, broadcast herbicide application at 30 DBP, broadcast herbicide application at 0 and 10 DBP, and broadcast application at 14 DAP were set at \$8.52 ha^{-1}, \$17.67 ha^{-1}, \$24.20 ha^{-1}, and \$11.94 ha^{-1}, respectively. Cost of N (32 % UAN) was set at \$122 ha^{-1} based on an N rate of 84 kg ha^{-1}. Ginning cost, payment received for ginned seed, and lint price were set at \$0.23 kg^{-1} lint, \$0.20 kg^{-1} seed, and \$1.98 kg^{-1} lint, respectively. Economic return for cover crop and termination strategy was compared to the no-cover plots at 0 and 84 kg N ha^{-1}rate and subjected to ANOVA using the general linear model in SAS. Means of net return by termination strategy were separated using Fisher's Protected LSD at $p \leq 0.05$. In a separate economic analysis, economic return of legume cover crop system terminated at 10 DBP was compared to the no-cover crop system, with 84 kg ha^{-1} of liquid N applied at first bloom using the general linear model in SAS.

RESULTS AND DISCUSSION

Density of crimson clover and hairy vetch at Rocky Mount was 319,870 and 364,860 plants m^{-2}, respectively, when termination of cover crops was initiated. At Clayton, these respective cover crops had densities of 264,900 and 304,880 plants m^{-2}. Although the defoliants used at these locations indicate that adequate stand establishment might not occur, companion research to the current experiment suggests that thidiazuron does not affect density of these cover crops or biomass (Foote, 2012). Cover crop dry weight was affected by termination strategy and the interaction of year-soil series and cover crop (Table 1). The highest dry weights were obtained when cover crops were terminated by a single broadcast herbicide application at 10 DBP in contrast to a broadcast herbicide application at 30 DBP, which produced the lowest biomass (Table 2). Dry matter accumulation more than quadrupled in the 20 d between these two termination dates. Termination strategies involving a strip kill at 30 DBP, regardless of the final termination date (10 and 0 DBP and 14 DAP), resulted in dry weights that were approximately half that of the single broadcast termination at 10 DBP. Therefore, any termination strategy involving an early strip kill should be avoided to maximize cover crop dry weight. High cover crop biomass is critical to the success of a legume cover crop system to maximize soil N supply and early season weed suppression (Cook et al., 2010; Parr et al., 2011; Reddy, 2001).

Table 1. Probability of a greater F value for cover crop dry weight, cotton plant height, total bolls per plant, total nodes per plant, nodes above cracked boll (NACB), and petiole nitrate (NO3-) at first week of bloom (1 WAB) and fifth week of bloom (5 WAB).

Treatment factor	Dry weight	Plant height	Total bolls	Total nodes	NACB	Petiole NO_3^- 1 WAB	Petiole NO_3^- 5 WAB
	-------------------	-------------------	-------------------	*p* value	-------------------	-------------------	-------------------
Year	0.9391	0.5164	0.9369	0.7728	$\leq$ 0.0001	0.0845	0.8597
Termination Strategy (Term)	$\leq$ 0.0001	0.0007	0.0226	$\leq$ 0.0001	0.0193	0.0597	0.6600
Year x Term	0.7235	0.8900	0.1413	0.1006	0.0085	0.1704	0.5662
Cover Crop Species (Cover)	0.5237	0.3318	0.9143	0.8006	0.3391	0.0459	0.4597
Year x Cover	0.0009	0.0783	0.0596	0.0094	0.0284	0.0077	0.2005
Term x Cover	0.1219	0.6892	0.5117	0.5620	0.1585	0.0504	0.3380
Year x Term x Cover	0.7444	0.1932	0.7604	0.1699	0.7833	0.0121	0.0827
Coefficient of variation (%)	36	9	21	4	29	51	70

Table 2. Cover crop dry weight, cotton plant height, total bolls per plant, and total nodes per plant as influenced by cover crop termination strategy and nodes above cracked boll as influenced by site and termination strategy.

Cover crop termination strategy		Cover crop dry weight[z]	Cotton plant height[z]	Total bolls[z]	Total nodes[z]	Nodes above cracked boll[y]	
Strip kill at 30 d before planting (DBP)	Termination date relative to cotton planting					2010	2011
	days	kg ha^{-1}	cm	bolls plant^{-1}	nodes plant^{-1}	------------ no.	------------
No	-30	930 c	60 c	7.1 bc	13.8 b	2.8 c	1.3 a
No	-10	4,420 a	69 a	8.6 a	14.8 a	3.2 bc	1.8 a
Yes	-10	2,350 b	66 bc	6.9 c	14.2 b	3.0 bc	1.2 a
Yes	0	2,460 b	66 ab	8.2 ab	14.7 a	3.7 b	1.7 a
Yes	+14	2,050 b	67 ab	8.1 ab	14.9 a	4.3 a	1.2 a

[z] Data are pooled over cover crop and site. Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[y] Data are pooled over cover crop. Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

Cover crop species affected dry weight differently depending on year-soil series. Crimson clover dry weight was higher during 2010 than hairy vetch dry weight, but the opposite was noted during 2011. Dry weight variability by year-soil series and species was attributed to variability of soil and climatic conditions. Hairy vetch biomass accumulation was higher in Clayton during 2011 where sandy soils prevail, but crimson clover performed better on soils containing more clay in Rocky Mount during 2010 (Table 3). Crozier et al. (2011) also reported that hairy vetch tends to be more winter-hardy and better adapted to coarser textured soils than crimson clover.

Regardless of cover crop species, cotton plant height and total bolls responded similarly to cover crop termination strategy (Table 1). The tallest plants with the highest number of bolls were found when the cover crop was terminated by a single broadcast herbicide application at 10 DBP (Table 2). The shortest plants with relatively low numbers of bolls were found in cotton when cover crops were terminated by a single broadcast herbicide application at 30 DBP. Plants with intermediate heights and boll numbers were noted when strip kill was applied at 30 DBP plus a later termination date was employed.

Total nodes were affected by termination strategy and by the interaction of cover crop by year-soil series (Table 1). Total nodes per plant were higher when cover crops were terminated by a single herbicide at 10 DBP, strip-killed plus termination at 0 DBP, or strip-killed plus termination 14 DAP, compared with early termination at 30 DBP and strip kill plus termination at 10 DBP (Table 2). Total nodes in Rocky Mount during 2010 were higher in clover plots than vetch, but the opposite was true in Clayton during 2011 (Table 3). Total nodes and cover crop dry weight responded similarly to the interaction of cover crop species by year-soil series; suggesting that cover crop biomass level is more important than legume species as a predictor of available soil N.

NACB was affected by termination strategy, interaction of termination and year-soil series, and interaction of site and cover crop species (Table 1). At Rocky Mount during 2010, NACB increased with later termination (Table 2). NACB was not affected by termination strategy in Clayton during 2011. In Clayton during 2011, cotton planted in hairy vetch exhibited higher NACB than cotton planted in crimson clover (Table 3).

Petiole nitrate during the first week of bloom (1 WAB) was affected by the interaction of year-soil series by cover crop by termination strategy (Table 1). Petiole nitrate was only affected in hairy vetch plots in Clayton during 2011 (Table 4). In these plots, petiole nitrate was generally responsive to termination date. The lowest nitrate levels were found when cover crops were terminated 30 DBP and the highest levels were found in cover plots terminated at planting. Cover plots terminated at 10 DBP regardless of the presence of strip plots had intermediate levels of nitrate. The cover plots terminated 14 DAP contained nitrate levels slightly less than cover plots terminated at planting (Table 4). By 5 WAB, there was no difference in petiole nitrate among sites, cover crops, or termination strategies with values ranging from 512 to 687 mg kg^{-1} (data not shown). Petiole nitrate levels might not have been an accurate indication of plant N status due to extended periods of low rainfall during the petiole sampling period at both sites (Crozier et al., 2012). Rocky Mount in July of 2010 and Clayton in July of 2011 received 3.1 cm and 5.0 cm of rain, respectively (10 and 8 cm below the 30-yr average monthly rainfall).

In the no-cover crop plots, lint yield was affected by N rate ($p = 0.0015$), the quadratic best-fit curve peaked at 70 kg N ha^{-1} with a predicted lint yield of 1,110 kg ha^{-1} (Fig. 1). The cotton yield response curve is typical of rain-fed cotton grown on low organic soils in North Carolina; yields tend to fall off at high nitrogen rates due to excessive growth that is slow to fruit and late to mature. Cotton with excessive growth is also difficult to defoliate and more likely to develop boll rot and grade reductions (Crozier et al., 2012). Cover crop species had no effect on lint yield ($p = 0.7168$) regardless of termination strategy or year-soil series, but cover crop termination strategy affected lint yield (Table 5). For plots containing cover crops, the lowest yield was recorded when the cover crops were terminated at 30 DBP, and the highest yield was noted when the cover crops were terminated by a single herbicide application at 10 DBP. Intermediate cotton yield levels were noted in any termination strategy that utilized a strip kill at 30 DBP regardless of the final termination (Table 5). When comparing cover crop plots to no-cover crop plots, yield was higher for all cover crop treatments than no-cover crop with no N applied. However, cotton yield following all cover crop termination strategies were

Table 3. Cover crop dry weight, total nodes per plant, and nodes above cracked boll as influenced by cover crop and site.

Cover crop	Cover crop dry weight		Total nodes		Nodes above cracked boll	
	2010	2011	2010	2011	2010	2011
	----------- kg ha^{-1} -----------		--------- nodes $plant^{-1}$ ---------		------------ nodes ------------	
Crimson clover	2,980	2,070	15.0	13.9	1.5	3.2
Hairy vetch	1,870[z]	2,840[z]	14.1[z]	14.9[z]	1.3	3.7*

[z] Means within year significantly different at $p \leq 0.05$. Data are pooled over cover crop termination strategy.

Table 4. Leaf petiole NO_{3^-} at first week of bloom as influenced by cover crop termination strategy, cover crop species, and site.

Cover crop termination strategy		Petiole NO_3^- at first week of bloom		
Strip kill at 30 d before planting (DBP)	Termination date relative to cotton planting	Crimson clover cover crop[z]	Hairy vetch cover crop[y]	
			2010	2011
	days	---------------- mg kg^{-1} ----------------		
No	-30	860 a	425 a	2,075 c
No	-10	1,110 a	850 a	2,750 bc
Yes	-10	1,060 a	1,275 a	3,350 bc
Yes	0	1,210 a	775 a	5,225 a
Yes	+14	925 a	625 a	4,950 ab

[z] Data are pooled over years. Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[y] Means within a year followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

comparable to the predicted value of no-cover crop with 70 kg N ha^{-1} applied. Net return of cover crops regardless of species, termination strategy, or site was equivalent to net return of no-cover crop with 70 kg N ha^{-1} applied and higher than no-cover crop with no nitrogen applied (Table 5). No significant difference was found between the legume cover crop system terminated at 10 DBP and no-cover crop system with 84 kg N ha^{-1} applied at first bloom regardless of nitrogen cost or legume seed cost (Table 6). The net return of the cover crop system compares favorably with the no cover crop system when the price of cotton approaches \$1.98 kg^{-1} and nitrogen costs exceed \$1.10 kg^{-1}.

There were no differences in fiber quality parameters regardless of year-soil series, date of cover crop termination, or nitrogen rate (data not shown).

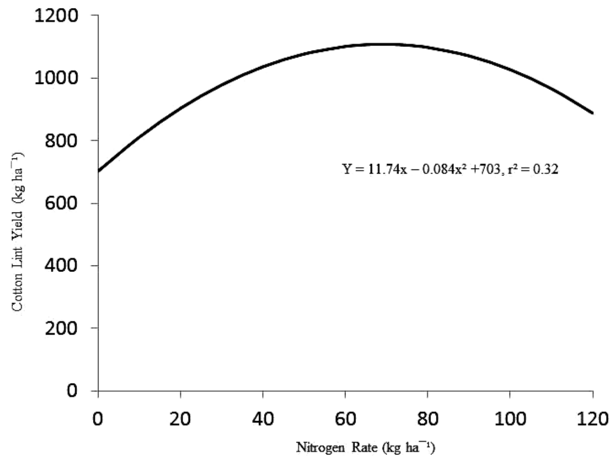

Figure 1. Predicted lint yield versus nitrogen rate.

Table 5. Lint yield and net return when cover crop seed cost is \$4.40 kg^{-1} and \$2.75 kg^{-1} as influenced by cover crop termination strategy and nitrogen applied to no cover plots[z].

Cover crop termination strategy		Nitrogen applied	Lint yield	Net return	
Strip kill at 30 d before planting	Termination date relative to cotton planting			Cover crop seed cost = \$4.40 kg^{-1}	Cover crop seed cost = \$2.75 kg^{-1}
	days	kg ha^{-1}	kg ha^{-1}	------------------- \$ ha^{-1} -------------------	
No	-30	-	1,000 b	1,240 a	1,290 a
No	-10	-	1,190 a	1,610 a	1,650 a
Yes	-10	-	1,060 ab	1,340 a	1,390 a
Yes	0	-	1,140 ab	1,560 a	1,610 a
Yes	+14	-	1,110 ab	1,490 a	1,540 a
------------- No cover crop -------------		0	700 c	630 b	630 b
------------- No cover crop -------------		70[y]	1,110	1,550	1,550
p-value		-	$\leq$ 0.0001	0.0006	0.0004

[z] Data are pooled over cover crop and year. Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[y] Calculated from regression analysis using N rates of 0, 28, 56, 84, and 112 kg N ha^{-1}. Data for predicted yield and net return are not included in the analysis of variance.

Table 6. System net return comparison, legume cover crop system versus no-cover crop system with 84 kg N ha^{-1} UAN, at various nitrogen and cover crop costs[z].

Nitrogen cost	System net return					
	Cover crop seed = \$2.20 kg^{-1}		Cover crop seed = \$4.40 kg^{-1}		Cover crop seed = \$6.60 kg^{-1}	
	Legume cover crop killed 10 DBP (no nitrogen)	No-cover crop, 84 kg N ha^{-1} (UAN)	Legume cover crop killed 10 DBP (no nitrogen)	No-cover crop, 84 kg N ha^{-1} (UAN)	Legume cover crop killed 10 DBP (no nitrogen)	No-cover crop, 84 kg N ha^{-1} (UAN)
\$ kg N^{-1}	-- \$ ha^{-1} --					
1.10	1,670 a	1,580 a	1,610 a	1,580 a	1,550 a[y]	1,580 a[y]
1.43	1,670 a	1,550 a	1,610 a	1,550 a	1,550 a	1,550 a
1.76	1,670 a	1,520 a	1,610 a	1,520 a	1,550 a	1,520 a
2.09	1,670 a	1,500 a	1,610 a	1,500 a	1,550 a	1,500 a

[z] Not significant at $p \leq 0.05$, at all nitrogen and seed cost levels.

[y] No cover crop system net return numerically higher than legume cover crop system.

SUMMARY

In this experiment, it was important to establish high cover crop biomass before termination to determine if adequate N was present to optimize cotton yield. This was best accomplished by killing the cover crops with a single herbicide application at 10 DBP. This strategy produced the highest yield, highest cover crop biomass, tallest plants, highest boll populations, and a net return equal to no-cover crop plots with 84 kg N ha^{-1} applied. High biomass level was critical to the success of this winter legume/summer annual cropping system, although cover crop species had no effect on yield and net returns. Cover crop species selection should be based on suitability to soil characteristics to ensure ease of establishment and high biomass level (Crozier et al., 2011).

The price of cotton, cost of N, cost of cover crop seed, and expected yield justify the use of crimson clover and hairy vetch as a sole source of N. Yield with legume cover crops equaled that of no-cover cotton with supplemental N applications, but additional benefits derived from using cover crops give growers added incentive to adopt their use. Early season suppression of weeds, increased organic matter with long-term use, and reduced water runoff through increased soil infiltration are examples of benefits that are difficult to quantify economically, but still provide value to agricultural production systems (Mischler et al., 2010; Reddy, 2001; Reddy and Koger, 2004; Rochester et al., 2001; Sankaranarayanan et al., 2010).

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