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Cover crop effects on nitrogen mineralization and availability in conservation tillage cotton

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Abstract Understanding cover crop influences on N availability is important for developing N management strategies in conservation tillage systems. Two cover crops, cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.), were evaluated for effects on N availability to cotton (*Gossypium hirsutum* L.) in a Typic Kanhapludult soil at Watkinsville, Ga. Seed cotton yields following clover and rye were 882 kg ha^{-1} and 1,205 kg ha^{-1}, respectively, in 1997 and were 1,561 kg ha^{-1} and 2,352 kg ha^{-1}, respectively, in 1998. In 1997, cotton biomass, leaf area index, and N were greater on some dates following crimson clover than following rye but not in 1998. During 1997, net soil N mineralized increased with time in both systems, but a similar response was not observed in 1998. Net soil N mineralization rates following crimson clover and rye averaged, respectively, 0.58 kg and 0.34 kg N ha^{-1} day^{-1} in 1997 and 0.58 kg and 0.23 kg N ha^{-1} day^{-1} in 1998. Total soil N mineralized during the cotton growing season ranged from 60 kg ha^{-1} to 80 kg ha^{-1} following crimson clover and from 30 kg ha^{-1} to 50 kg ha^{-1} following rye. Soil N mineralization correlated positively with heat units and cumulative heat units. Net soil N mineralization rates were 0.023 kg ha^{-1} heat unit^{-1} once net mineralization began. Soil heat units appeared to be a useful tool for evaluating N mineralization potential. Nearly 40% of the rye and 60% of the clover biomass decomposed during the 6 weeks prior to cotton planting, with nearly 35 kg N ha^{-1} mineralized from clover.

Keywords Nitrogen mineralization · Heat units · Crop residue decomposition · Cotton growth

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Introduction

In the southeastern United States, both winter cereals and legumes are grown as cover crops in cotton (Reeves 1994). Cereals grow rapidly in the fall and reduce N losses from previous crops by scavenging residual soil N (McCracken et al. 1995). The high C/N ratio of cereals may reduce N availability through immobilization of soil N and reduce growth of subsequent crops (Reeves 1994). Legume cover crops fix atmospheric N in the range from 40 kg ha^{-1} to 200 kg ha^{-1} which can help reduce the amount of fertilizer N required for a subsequent crop (Reeves 1994). Management of N in cotton is critical because both under-fertilization and over-fertilization decrease the yield (Mullins and Burmester 1990). N deficiency reduces vegetative growth and yield while over-supply of N affects the transition of cotton from vegetative to reproductive growth and eventually influences crop yield.

Availability of N under cover crops depends on the quantity of N in the biomass, the resource quality or chemical composition of the plant residues, and the rate of N mineralization during decomposition. Long-term use of conservation tillage can result in a buildup of organic matter at the soil surface and stratification of nutrients (Hargrove 1986). Accumulation of surface residues in conservation tillage systems may reduce N availability through immobilization (Rice and Smith 1984) and denitrification (due to wet conditions; Aulakh et al. 1991). Decomposition and nutrient release from residues on or near the soil surface are influenced by significant fluctuations in climatic conditions (Douglas et al. 1980; Schomberg et al. 1994). In high residue systems, additional N may be needed to balance organic carbon sequestered during the formation of soil organic matter (Kuo et al. 1997). For a crop like cotton, with a relatively long growing season and a peak N demand occurring after mid-bloom, slowly available cover crop N in no-till systems may be a distinct advantage.

Efficient N management depends on understanding complex interactions between soil and site properties, crop

characteristics, climate, and biological processes influencing N dynamics. Cropping history and other management practices also affect N management strategies. The complexity of the interacting factors indicates that site-specific knowledge may be needed for best nutrient management. This could include regional estimates of residual N availability and soil organic N mineralization rates. The in situ soil core technique can be helpful in evaluating management effects on N availability and provide site-specific information needed for improved nutrient management (DiStefano and Gholz 1986; Raison et al. 1987; Kolberg et al. 1997).

Understanding cover crop effects on N cycling is important for developing appropriate N management strategies for cotton in conservation tillage systems. Because the response could be different in long-term conservation tillage systems, we were interested in comparing N dynamics between legume-based and cereal-based cover crop systems. We compared these systems to determine how cover crop differences influenced N availability, growth, and yield of cotton.

Materials and methods

The study was conducted during 1997 and 1998 on two adjacent 1.3-ha fields at the J. Phil Campbell Sr. Natural Resource Conservation Center (USDA Agricultural Research Service, Watkinsville, Ga.; 33°59′N, 83°27′W). The fields, instrumented with flumes and refrigerated samplers, are used to determine cropping system effects on sediment and nutrient losses on a typical soil in the Southern Piedmont landscape (Cecil sandy clay loam, fine, kaolinitic, thermic Typic Kanhapludult, with 2–3% slope). They were no-till cropped to cotton following a cover crop from 1994 to 1998. The cover crops were cereal rye in one field and crimson clover in the other. Soil C and N concentrations measured in May 1997 were, respectively, 10.1 g kg^{-1} and 0.70 g kg^{-1} in the cotton–crimson clover soil and 10.4 g kg^{-1} and 0.73 g kg^{-1} in the cotton–rye soil. Cover crops were planted into cotton residues in late October using a no-till grain drill (Great Plains Manufacturing, Salinas, Kan.). Cotton was planted on 26 May in 1997 and 1998 into cover crop residues with a four-row no-till planter (Allis Chalmers, now Deutz-Allis, Norcross, Ga.). N, as NH_4NO_3, was applied to cotton at 34 kg and 67 kg N ha^{-1} following crimson clover and rye, respectively, and 56 kg N ha^{-1} to the rye each fall, using a drop spreader. In 1997, clover was near maturity at cotton planting and was not killed, to allow for natural reseeding; but in 1998 clover was killed with glyphosate [*N*-(phosphonomethyl)glycine] prior to planting cotton, as was rye in both years.

Crop growth and yield

Nine sub-areas in each field were selected for both crop growth and soil N mineralization measurements. Distances between sub-areas (>30 m) were considered great enough to constitute replications (Mahmoudjafari et al. 1997; Stenger et al. 1998). On each sample date, 6–8 cotton plants were collected randomly from an area within a 5-m radius of the soil N mineralization tubes (see below) for determining growth parameters. A subsample of the collected plants was used, with the number being reduced as the growing season progressed to accommodate the labor required to complete leaf area measurements. Plants were separated into leaves, stems, and fruit. Leaf area was determined with a flatbed scanner (Delta T Devices, Cambridge, UK). The leaf area index (LAI) was determined by dividing the leaf area by the estimated area occupied by the number of plants in the sample. Plant height, number of nodes, and plant populations were estimated at each date. Leaves, stems, and immature fruit were dried, weighed, and ground to pass a 2-mm sieve. Total N was determined for plant fractions using a CNS 2000 analyzer (LECO, St Joseph, Mich.). Mature fruit were not analyzed for total N.

Soil N mineralization

N mineralization during the cotton-growing season was measured for each of the nine sub-areas (30–35 m apart), by incubating undisturbed soil cores in situ for 2–5 weeks (DiStefano and Gholz 1986; Kolberg et al. 1997). Cores were placed between crop rows in areas without growing plants. The first set of cores was established one day following planting and fertilizer operations in 1997 (two in each of the nine locations) and 1998 (one per location) by driving an aluminum cylinder (110 mm depth, 50 mm diam.) into the ground. The cylinder was removed from the ground with the soil intact and the lower 10 mm of soil was excavated using a 19-mm wide chisel (a 60-mm length of square steel rod was attached 10 mm from the end to ensure uniform depth). A Nylon mesh bag containing approximately 15 g (25 ml) of a 50:50 mixture of anion and cation exchange resins (Sybron Ionac ASB-1, C-249) sufficient to fill the 10-mm excavated area was placed in the cavity. The resin mixture served to capture both NO_3^- and NH_4^+ leaching from the soil core (DiStefano and Gholz 1986; Kolberg et al. 1997). The aluminum cylinder containing the intact soil core with the resin bag was returned to the same hole. Each time a set of in situ soil cores was established, an additional soil core was collected at each location to determine current soil inorganic N content (ambient soil N) for use in estimating N mineralized during the subsequent incubation period. New cores were established on the same day that incubated cores were removed from the field.

At the end of each incubation period, soil and resin bags were removed from the cylinder and placed in separate clean plastic bags. Samples were kept in a cooler in the field and were transported to the laboratory within 2–3 h, where they were stored at 3°C and extracted within 3–5 days. Soils were passed through a 6.35-mm screen and thoroughly mixed. A 10-g subsample was added to 50 ml

of 1 M KCl and placed on a flatbed shaker for 1 h. The extract was filtered through pre-washed filter paper and used to determine both NH_4^+ and NO_3^-. Resin bags were extracted three successive times following shaking for 20 min with 20 ml of KCl. Three extractions consistently recovered more than 85% of the N in the resin bags. An automated analysis system was used for determining NH_4^+ and NO_3^- (Technicon Industrial Systems 1977a, b).

Net N mineralization and quantity of N leached were calculated as per Raison et al. (1987). N mineralized ($N\min_t$) during each period (t) was calculated as follows:

$$N\min_t = N\text{core}_t + N\text{resin}_t + N\text{soil}_t$$

where $N\text{core}_t$ is inorganic N in the soil core at the end of period t, $N\text{resin}_t$ is inorganic N in the resin bag at the end of period t, and $N\text{soil}_t$ is inorganic N in the soil core collected at the beginning of period t. Inorganic N recovered in the resin bag would be the inorganic N that was leached from the soil core and is composed of initial N and any N that mineralized during the incubation period. The $N\text{core}_t$ is composed of the initial inorganic N and N mineralized during the incubation period. The soil water content of the soil cores was determined gravimetrically by drying a 10-g subsample for 48 h at 60°C. The bulk density was determined from the volume and the mass of the soil core was adjusted for water content (Blake and Hartge 1982) and used in converting data to an areal basis.

Cover crop decomposition

In 1998, mass and N remaining in decomposing cover crop residues were determined by placing bags of residue in nine sub-areas used to measure in situ soil net N mineralization. Cover crop residues were collected 1 day before applying herbicides and dried in a forced draft oven at 35°C for 24 h to produce a uniform water content but not remove all water. Residues were weighed to give an effective loading rate of 2.2 Mg ha^{-1} (13.75 g dry weight, 48 h at 70°C) and placed in bags (25×25 mm^2) having 1-mm mesh opening. The bags of residue were placed in the field on 21 April and collected after 2, 4, 8, 16, and 24 weeks. Residue remaining in each bag was dried at 60°C for 72 h, weighed, ground, and analyzed for total N using a LECO CNS 2000 analyzer. N remaining in residue was calculated by multiplying total N concentration by residue dry matter weight. No correction was made for soil on residues, because very little soil was present on the residues at any sampling date.

Climatic measurements

Rainfall, air temperature, and soil temperature at 5 cm under mixed tall fescue (*Festuca arundinacea* L.) and Bermudagrass (*Cynodon dactylon* (L.) Pers.) sod were measured with an automated weather station less than 300 m from the cotton cropping systems. Temperature data were used to estimate growing degree days (GDD, based on a 15.6°C base) and soil heat units at 5 cm below the soil surface (HU5cm; Honeycutt et al. 1988) for comparing thermal environments between years. Volumetric soil water content in the watersheds was measured at 0–15, 15–30, 30–60, 60–90, and 90–120 cm, with the time–domain reflectometry (TDR)-based MoisturePoint system (Environmental Sensors, Victoria, British Columbia, Canada) at six locations per cotton cropping system, two to three times each week in 1997 and one to two times each week in 1998.

Data analysis

Because samples were collected from two paired field areas, a simple approach was taken for data analysis by considering the data to be collected from independent locations; and basic statistical procedures of confidence limits and t-tests were used to compare treatments (Der and Everitt 2001; Muller and Fetterman 2002). Sub-areas for sampling were randomly selected and were at least 30 m apart. Significance for t-tests was set at 90%, while confidence limits were estimated at the 95% level. All data analyses were conducted using procedures in SAS software release 8.2 (SAS Institute 2002). Both graphical and statistical methods were used to evaluate the normality and equality of variances for the data. Appropriate regressions (linear, quadratic) were fit to estimate residuals and predicted values. The Shapiro-Wilk statistic in the UNIVARIATE procedure was used to evaluate normality based on residuals. Where transformations were needed to meet normality assumptions, data were usually log-transformed. Treatment differences based on t-tests (TTEST procedure) were adjusted for unequal variances by calculating an approximate t-statistic; and Satterthwaite's approximation was used to calculate the degrees of freedom for the significance test. Confidence intervals for means or log-means were calculated using the MEANS procedure.

Results

Climatic conditions

Daily average temperatures and rainfall during 1997 and 1998 cotton-growing seasons are presented in Fig. 1a,b. Temperatures during the 1997 growing season ranged from 0.3°C to 2.6°C below long-term monthly averages. Monthly rainfall during this period was 30 mm above normal. The summer of 1998 was dryer and hotter than long-term averages. Average monthly temperatures during this period were 1–2°C above long-term averages, while monthly rain was below average with several long periods with no rainfall (Fig. 1b,d). Soil HU5cm and GDD also indicated that the growing season was warmer in 1998

than in 1997 (Fig. 1c). Rainfall during the spring of 1998 prior to cotton planting resulted in substantial stored soil water. Rainfall during the two cotton and cover crop seasons was insufficient to produce runoff from either field. During the 1997 growing season, the soil water contents did not indicate significant depletion below 60 cm (data not shown). Soil water profiles reflected fluctuations associated with short drying periods between rainfall events. During 1998, water use extended deeper into the soil profile with significant declines in soil water contents down to 1.2 m during July and August. Soil water extraction from lower depths of the profile appeared to be greater in the rye system than the crimson clover system, with net changes in soil water content of −11.73 cm and −10.28 cm for the two systems, respectively.

Yield, biomass, and inorganic N

In 1997 and 1998, respectively, clover biomass was 6.2 Mg ha^{-1} and 5.4 Mg ha^{-1}; and rye biomass was 11.3 Mg ha^{-1} and 5.2 Mg ha^{-1}. Averaged for 1997 and 1998, the respective C and N contents of clover residue were 42.4% and 2.3% and of rye residue were 43.5% and 1.4%. N contained in the above ground biomass for the 2 years, respectively, was 142.6 kg ha^{-1} and 124.2 kg ha^{-1} for crimson clover and was 158.2 kg ha^{-1} and 72.8 kg ha^{-1} for rye. The lower amount of N in rye during 1998 was probably due to the later fall planting date and lower biomass accumulation.

Seed cotton yields (seed + lint) following clover and rye were 882 kg ha^{-1} and 1,205 kg ha^{-1}, respectively, in 1997 and were 1,561 kg ha^{-1} and 2,352 kg ha^{-1}, respectively, in 1998. Slow accumulation of GDD limited yields in 1997 compared with 1998, even though rainfall was less during the growing season in 1998. Significant rain fell in the spring of 1998, which provided stored soil water during the early growing season. Soil C and N contents measured in May 1997 were, respectively, 10.1 g kg^{-1} and 0.70 g kg^{-1} in the cotton–crimson clover and 10.4 g kg^{-1} and 0.73 g kg^{-1} in the cotton–rye soil.

In 1997, cotton growth early in the growing season was similar on the two cotton-cropping systems (Table 1). There was a trend beginning at the early bloom period (59 days after planting; DAP) for greater biomass following crimson clover. A significant difference was observed at 99 DAP. Similar results were observed for N content. Leaf area index was greater for cotton grown following crimson clover on four dates. Measurements of greater LAI correspond to the trend for greater biomass and N contents. Plant height was greater at the final two sampling dates for cotton grown following crimson clover. Cotton development as indicated by number of nodes, however, showed little difference during the 1997 growing season.

In 1998, fewer differences in cotton growth were observed between the two cotton-cropping systems (Table 2). At the first sampling date, just after first bloom, the number of nodes and plant height were greater for cotton following rye. Cotton biomass at the first sampling date was not different between the two systems and total N content of cotton was similar following the two cover crops. No differences in crop growth parameters were observed at the second sampling date, 77 DAP, which corresponded to mid-bloom. Cotton samples collected just prior to defoliation and harvest, 132 DAP, indicated differences in total N and number of nodes per plant. However, these data were influenced by the lateness of sample collection. Some loss of cotton leaves and bolls was noted at this date. An attempt was made to compensate for this by collecting leaves and bolls that had fallen to the ground, but some loss of material probably occurred. At this date, values for total N were greater for cotton grown following crimson clover compared with cotton following rye, but this difference should be considered with caution.

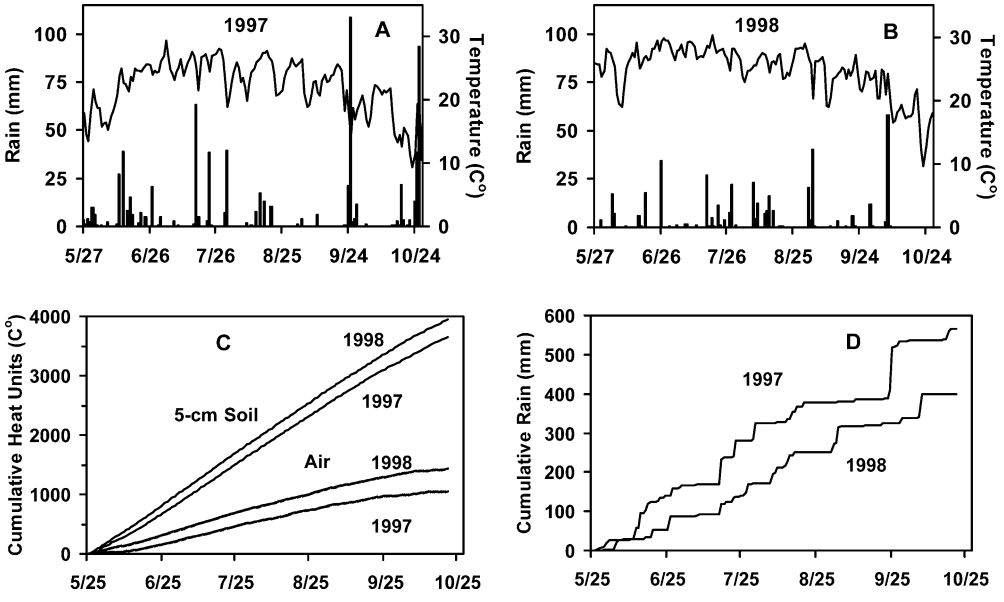

Fig. 1 Daily average temperatures and rainfall **a**,**b**, cumulative heat units **c** and cumulative rainfall **d** for the 1997 and 1998 cotton growing seasons at Watkinsville, Ga.

Table 1 Mean above-ground biomass, total N accumulated in above-ground biomass, LAI, plant height, and number of nodes during the 1997 cotton-growing season following crimson clover and rye cover crops. Biomass, total N, and LAI values are geometric means. Values in parentheses indicate ±95% confidence limits. * Significant difference between clover and rye values at the same DAP, based on *t*-test at $P<0.10$

Cover crop	DAP	Biomass (Mg ha^{-1})	Total N (kg ha^{-1})	LAI (m^{2}m^{-2})	Height (m)	Nodes (*n*)
Clover	51	0.08* (0.02)	2.26 (0.8)	0.8 (0.2)	0.43* (0.02)	9.0* (0.9)
Rye	51	0.09 (0.01)	2.68 (0.7)	0.8 (0.1)	0.48 (0.05)	10.6 (0.5)
Clover	59	0.14 (0.03)	3.75 (1.3)	1.3 (0.4)	0.53 (0.05)	11.6 (0.5)
Rye	59	0.12 (0.03)	3.04 (1.1)	1.2 (0.3)	0.58 (0.06)	11.4 (1.2)
Clover	64	0.23 (0.39)	6.51 (1.2)	2.0* (0.3)	0.66 (0.02)	13.5 (0.6)
Rye	64	0.20 (0.39)	5.16 (1.9)	1.6 (0.3)	0.69 (0.07)	13.4 (0.6)
Clover	79	0.40 (0.24)	7.68 (4.8)	2.8 (1.3)	0.84 (0.12)	16.3 (1.3)
Rye	79	0.37 (0.12)	6.55 (2.0)	2.8 (0.5)	0.94 (0.05)	17.1 (0.6)
Clover	85	0.71 (0.19)	15.16 (4.7)	4.3* (1.0)	0.98 (0.07)	18.4 (0.9)
Rye	85	0.60 (0.23)	11.77 (6.5)	3.1 (0.8)	1.01 (0.07)	18.4 (0.9)
Clover	99	1.22* (0.25)	23.90* (8.0)	4.5* (1.2)	1.19* (0.07)[d]	21.1 (1.4)
Rye	99	0.90 (0.35)	16.95 (6.8)	3.1 (1.5)	0.98 (0.14)	19.6 (1.3)
Clover	120	2.48 (0.47)	44.35 (8.7)	6.2* (1.4)	1.24* (0.06)	22.2 (0.7)
Rye	120	2.09 (0.57)	36.29 (13.4)	4.7 (1.6)	1.15 (0.09)	21.1 (1.5)

Table 2 Mean above-ground biomass, total N accumulated in above-ground biomass, plant height, and number of nodes at three dates during the 1998 cotton-growing season following crimson clover and rye cover crops

Cover crop	DAP	Biomass (Mg ha^{-1})	Total N (kg ha^{-1})	Height (m)	Nodes (*n*)
Crimson clover	55	0.46 (0.7)	8.5 (1.5)	0.53* (0.04)	14.1* (0.9)
Rye		0.52 (0.6)	8.4 (1.6)	0.60 (0.02)	15.0 (0.5)
Crimson clover	77	1.26 (0.2)	24.0 (4.5)	0.75 (0.04)	17.2 (2.5)
Rye		1.41 (0.2)	26.0 (3.3)	0.76 (0.04)	17.9 (1.6)
Crimson clover	132	1.10 (0.2)	16.2* (3.5)	0.84 (0.08)	22.5* (1.0)
Rye		0.90 (0.2)	11.0 (2.6)	0.80 (0.04)	20.7 (1.0)

The amount of net soil N mineralized during 1997 increased with the growing season in both cover crop systems, but there was no clear trend in 1998 (data not shown). Net soil N mineralization rates for the crimson clover and rye systems averaged, respectively, 0.58 kg and 0.34 kg N ha^{-1} day^{-1} in 1997 and 0.58 kg and 0.23 kg N ha^{-1} day^{-1} in 1998. Cumulative net soil N mineralized increased following both cover crops in 1997, but did not increase initially following rye in 1998 (Fig. 2). The changes in inorganic N levels were near zero or negative in the rye system during the first 30–60 days in 1997 and 30–90 days in 1998. If the initial large amount of inorganic N measured in the soil following crimson clover in 1998 is not considered, total amounts of soil N mineralized were similar for the 2 years and ranged from 60 kg ha^{-1} to 80 kg ha^{-1} in soil following crimson clover and from 30 kg ha^{-1} to 50 kg ha^{-1} in soil following rye.

Correlation coefficients were used to investigate climatic influences on soil N mineralization (Table 3). In 1997, the correlations between soil N mineralized in each period and climatic factors were similar following the two cover crops with the exception of correlations with cumulative rainfall (PPT). Correlations for soil N mineralized each incubation period were similar for DAP, HU5cm, sum of HU5cm (ΣHU5cm) and sum of cumulative rainfall (ΣPPT). Combinations of rain and temperature (either additive or multiplicative) did not substantially increase the correlations over that of DAP or HU5cm. In 1998, soil N mineralized in a period negatively correlated with DAP for crimson clover but there was no correlation for rye. The most influential climatic factor for N mineralized was HU5cm for both the rye and crimson clover systems. Addition of rain did not improve the correlations. A similar result was observed for cumulative N mineralization and cumulative HU5cm, as would be expected. Again, addition of rain did not significantly improve the correlations.

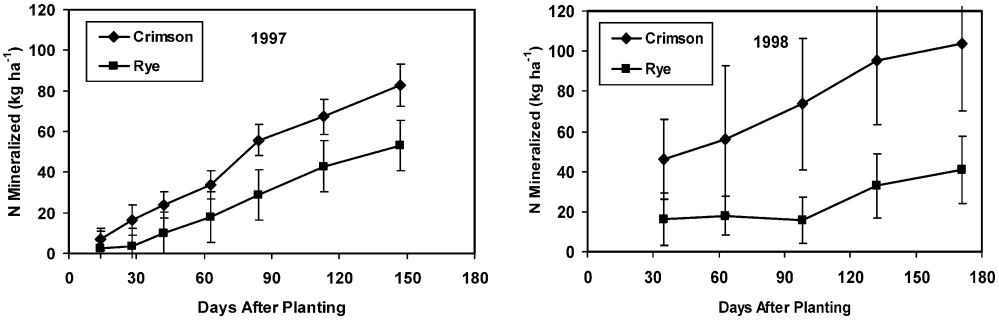

Fig. 2 Cumulative net soil N mineralized during the 1997 and 1998 cotton growing seasons in Watkinsville, Ga. (*vertical lines* indicate 95% confidence limits for means)

Table 3 Correlation between soil N mineralized in each period, cumulative soil N mineralized, and climate variables. *Corr* Pearson correlation coefficient, *P* significance level for Pearson correlation coefficient, *R* rainfall, *T* temperature, $T \times R$ multiplicative interaction of temperature and rainfall

Year	Climatic variable	Net N mineralized per period				Cumulative Net N			
		Clover		Rye		Clover		Rye	
		Corr	*P*	Corr	*P*	Corr	*P*	Corr	*P*
1997	DAP	0.33	0.0001	0.36	0.0001	0.86	0.0001	0.64	0.0001
	HU5cm	0.29	0.0001	0.39	0.0001	0.81	0.0001	0.61	0.0001
	ΣHU5cm	0.34	0.0001	0.36	0.0001	0.86	0.0001	0.64	0.0001
	PPT	0.23	0.0092	−0.02	0.8422	0.38	0.0001	0.26	0.0033
	ΣPPT	0.38	0.0001	0.33	0.0002	0.85	0.0001	0.62	0.0001
	$T \times R$	0.26	0.0032	0.09	0.2974	0.56	0.0001	0.41	0.0001
	$\Sigma T \times R$	0.36	0.0001	0.32	0.0003	0.84	0.0001	0.63	0.0001
	$T + R$	0.32	0.0003	0.33	0.0001	0.81	0.0001	0.61	0.0001
	$\Sigma T + R$	0.34	0.0001	0.36	0.0001	0.86	0.0001	0.64	0.0001
1998	DAP	−0.35	0.0208	0.02	0.9045	0.50	0.0005	0.48	0.0012
	HU5cm	0.52	0.0003	0.43	0.0056	−0.33	0.0289	−0.23	0.1348
	ΣHU5cm	−0.36	0.0168	0.01	0.9387	0.50	0.0005	0.48	0.0014
	PPT	0.15	0.3397	−0.25	0.1209	−0.36	0.0179	−0.31	0.0479
	ΣPPT	−0.38	0.0121	−0.02	0.8987	0.50	0.0006	0.47	0.0018
	$T \times R$	0.46	0.0019	0.16	0.3168	−0.44	0.0026	−0.35	0.0246
	$\Sigma T \times R$	−0.37	0.0128	−0.01	0.9407	0.50	0.0005	0.47	0.0018
	$T + R$	0.52	0.0003	0.40	0.0097	−0.35	0.019	−0.26	0.1029
	$\Sigma T + R$	−0.36	0.0162	0.01	0.9551	0.50	0.0005	0.48	0.0014

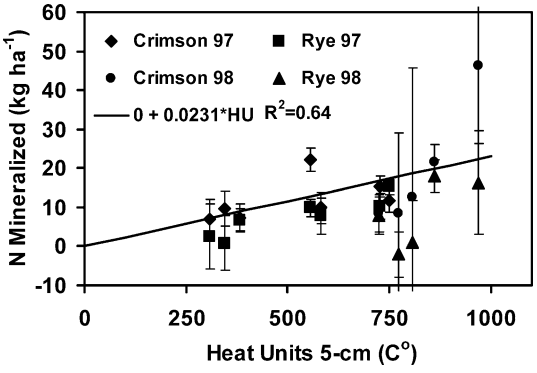

Fig. 3 Relationship between net soil N mineralization and HU5cm for two cover crop–cotton systems in Watkinsville, Ga. (*vertical lines* indicate 95% confidence limits for means)

The relationship between HU5cm and soil N mineralized during each period was evaluated with linear regression for the combined data from 1997 and 1998 and across the two cover crop–cotton systems (Fig. 3). Data from the rye–cotton system for two dates were not included in the regression because they indicated net N immobilization. The regression analysis indicated that net soil N mineralization rates were 0.023 kg ha^{-1} heat unit^{-1}.

The measurements of crimson clover and rye residue decomposition in 1998 indicated that the two cover crops decompose and mineralize N at different rates (Fig. 4). Losses of biomass and N were greater and faster for crimson clover than for rye. There was a 2-week delay in cotton planting due to wet weather, which resulted in a large amount of biomass and N loss from the cover crop residues prior to cotton planting (40% of rye biomass, 60% of clover biomass decomposed). N loss from the residues prior to cotton planting was nearly 35 kg ha^{-1} from crimson clover and near 15 kg ha^{-1} from rye.

Discussion

Weather factors had a key influence on cotton growth and contributed to the differences seen between the 2 years (Fig. 1). Cotton growth and yield, however, were not the same following the two cover crops and were probably related to short-term and long-term effects of the cover crops. Only small differences in soil water contents were observed following the two cover crops, which indicates that the differential response of cotton was mainly due to differences in N availability during the growing season. Although cotton biomass was greater on several sampling dates following crimson clover, yields were numerically lower than following rye (statistical comparison was not possible; yield determined from the entire 1.3 ha). Greater cotton growth following crimson clover apparently negatively influenced the transition to reproductive growth. Although we reduced fertilizer N inputs in the crimson clover system, it apparently was not reduced enough to avoid over-fertilization and reduction of cotton yields (Mullins and Burmester 1990; Touchton et al. 1984).

Soil inorganic N levels were greater following crimson clover in both years, even though N applications following clover were one-half those following rye. The contrast between the two systems was quite striking, considering the N applications to the rye in the fall and to cotton in the spring for the rye-based system. Assuming N available from the above ground residues to be 25% (Ladd et al. 1981; Muller and Sundman 1988) we estimate that

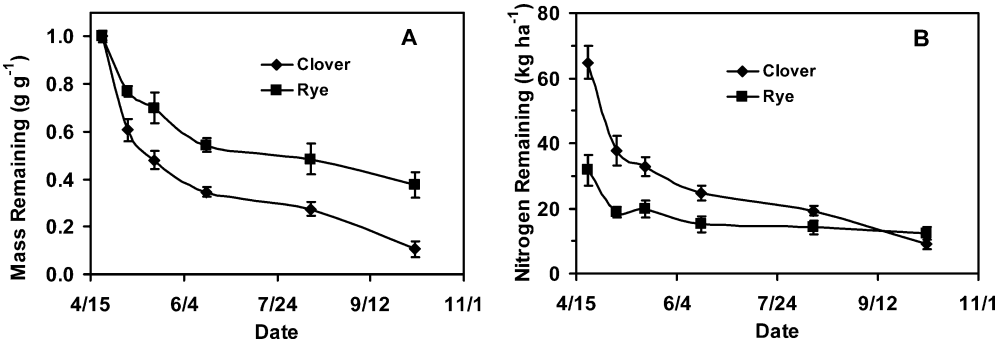

Fig. 4 Cover crop residue decomposition **a** and N loss **b** for the 1998 cotton-growing season at Watkinsville, Ga. (*vertical lines* indicate 95% confidence limits for means)

respectively 53 kg and 48 kg N ha^{-1} (50% fertilizer N + 25% clover residue N) of the applied N were available in the clover system for the 2 years and 73 kg and 51 kg N ha^{-1} were available in the rye system. However, the timing of N availability was obviously not the same in the two systems (Fig. 4) and was the result of multiple interacting processes: a more readily mineralizable pool of soil N in the crimson clover system along with rapid decomposition and loss of N from the clover residues, compared with a slower mineralizable pool of soil N in the rye system along with slower decomposition and immobilization of N by the microbial biomass associated with the rye residues (Hargrove 1986; Wagger 1989). Although we observed rapid decomposition of the crimson clover residues and large amounts of inorganic N in the soil following this cover crop, we do not know whether the observed soil inorganic N came directly from the clover residues. Other researchers using ^{15}N-labeled legume residues report less than 25% of legume N is found in subsequent crops, while the majority is recovered in the soil organic fraction (Ladd et al. 1981; Muller and Sundman 1988). Our N mineralization measurements were made in years 3 and 4 of the cropping systems study and appear to support conclusions by Ladd et al. (1981) that the value of legume residues as a source of N is long term, i.e., maintaining soil N concentrations at adequate levels.

Net soil N mineralization following rye in both 1997 and 1998 was less than that following crimson clover, which was not unexpected because N immobilization following small-grain residue incorporation is often reported in the literature. Early periods of N immobilization following rye in 1998 and low rates of N mineralization in 1997 apparently resulted in N availability being more closely synchronized to cotton development. The N need of cotton is greater during boll maturation later in the growing season and early-season N stress can result in an earlier transition to reproductive development.

The in situ soil core system provides a way to quantify soil N mineralization and evaluate soil N availability and could be used as an early season tool for determining the need for sidedress N applications for cotton. In 1998, N mineralization measurements for the first period indicated a large amount of inorganic N in the crimson clover system. Combining information like this along with knowledge about average soil N mineralization rates could be used to eliminate additional N applications (we did not apply sidedress N in this study, but it is a common practice with many cotton producers). Because of the lower yield observed following crimson clover, an early-season evaluation of soil N or plant N status appears to be warranted for more efficient N use, especially following legumes capable of supplying significant amounts of N. Early-season soil core data and long-term weather records could be useful in computer simulation models to help producers develop strategies for N applications later in the growing season (Schomberg and Cabrera 2001).

We found a strong relationship between HU5cm and the quantity of N mineralized during an incubation period (Fig. 3). By using HU5cm as a measure of thermal time, we were able to combine data from two different growing seasons and, after eliminating rye data indicating periods of net N immobilization, we could also combine data from two different types of cover crops. Surprisingly, our relationship was similar to one reported by Honeycutt et al. (1994) for a laboratory study of N mineralization in soil from a potato (*Solanum tuberosum* L.) field in Maine, USA. Although there was close correlation between DAP and HU5cm, the latter is based on the accumulation of thermal units and has proven an effective system for predicting crop development and activities of microorganisms in various environments. Honeycutt and co-workers demonstrated cumulative heat units were especially useful for identifying the point when net mineralization is positive for various crop residues, paper mill sludge, and animal manures (Doel et al. 1990; Honeycutt and Potaro 1990; Griffin and Honeycutt 2000; Honeycutt 1999). More work in other soils and climates may further refine the technique and define useful equations for N management across different cropping and management systems. The relationship between N mineralized each period and heat units may be a promising tool for use in N management.

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