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Timing Nitrogen Applications for Corn in a Winter Legume Conservation-Tillage System

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ABSTRACT

Fertilizer N efficiency of corn (*Zea mays* L.) in conervation-tillage systems with winter legumes such as crimson clover (*Trifolium incarnatum* L) can possibly be improved by better synchronization of legume-N release, fertilizer-N application time, and crop demand for N. The objective of this 3-yr (1986-1988) field experiment was to determine the effect of N application time on dry matter accumulation, N uptake, and grain yield of corn grown in a winter legume conservation-tillage system. Corn was planted with unit planters into crimson clover residue following in-row subsoiling. The clover was killed at midbloom every year. Treatments were a factorial arrangement or fertilizer N rates and application time. Nitrogen as NH_4NO_3 was broadcast at rates of 34, 67, and 134 kg ha^{-1}. Zero-N checks were also included in both clover and rye (*Secale cereal* L) plots. Application times were at planting, or 3, 6, or 9 wk later. In addition, split applications (1/3 at planting and the remainder 6 wk later) of the 67 and 134 kg N ha^{-1} rates were included. In 2 of 3 yr, dry matter accumulation was not affected by N application time. In 1987, however, dry matter production was greater when N was applied at planting compared to split applications or applications later than 3 wk after planting. Application time affected N uptake patterns during the growing season, but generally did not affect total N uptake at the end of the season. With the exception of the first year, split N applications resulted in equivalent or reduced N uptake compared to application of all N at planting. Based on linear regression models, maximum field was obtained with 134, 116, and 93 kg N ha^{-1} in 1987, 1988, and 1989, respectively. After the first year, applying N later than 6 wk after planting reduced grain yield and split applications of N were not effective in increasing pin yield. These results suggest that the fertilizer N requirement of corn grown in winter legume conservation-tillage systems on Coastal Plain soil decreases with successive years in the system and that the optimum management practice for conservation of N, energy, time, and labor would be to apply all fertilizer N at planting.

THE USE OF WINTER ANNUAL LEGUMES in conservation-tillage systems can reduce soil erosion, improve soil productivity, increase titration of rainfall, conserve soil water, and furnish N to subsequent summer grain crops. Estimates of N contributed to subsequent crops generally range from 56 to 112 kg ha^{-1} (Hargrove, 1986; Neely et al., 1987; Ebelhar et al., 1984, Touchton et al., 1982).

Research with corn grown in conventional-tillage systems has generally shown the benefit of delaying application of the majority of N fertilizer until 4 to 6 wk after planting (Jung et al., 1972; Bigeriego et al., 1979; Welch et al., 1971). Although delayed application of N has also been shown to increase N efficiency of corn in no-till systems (Fox et al., 1986; Frye et al., 1981), N dynamics in no-till legume systerns complicate timing of fertilizer N applications.

The delay in growth due to low soil temperatures associated with no-till systems in the Corn Belt (Mock and Erbach, 1977; Gupta et al., 1988; Imholte and Carter, 1987) is not appreciable in the South. Thus, demand for N by corn in no-till systems in the South occurs earlier in relation to planting date. This fact is exacerbated by the relatively slow release of N from winter legumes in conservation-tillage systems. Wilson and Hargrove (1986), using a mesh-bag technique in Georgia, reported that 63% of N remained in crimson clover residue under no-tillage 4 wk after placing bags in the field, as opposed to 40% remaining in residue under conventional tillage. Groffman et al. (1987), in a comparison of conventional and no-tillage systems in Georgia, reported that N from crimson clover became available to sorghum [*Sorghum bicolor* (L.) Moench] more gradually than applied fertilizer N, and that tillage affected timing of N availability more than total amount of N available. Huntington et al. (1985), in Kentucky, reported that the majority of N mineralized from decomposing residues of hairy vetch (*Vicia villosa* Roth) in a no-till system became available to corn after silking. Wagger (1989a), however, concluded that crimson clover and hairy vetch provided N in a sufficiently timely manner so as not to limit corn grain yield in North Carolina. Varco et al. (1989), in Kentucky, reported a greater potential for N uptake from hairy vetch during corn grain fill, dependent on precipitation, with no-tillage than conventional tillage, although total N uptake, especially up to corn silking, was greater under conventional tillage.

Despite the evidence that N dynamics under conservation tillage, especially with legume cover crops, is complicated and different than that under conventional tillage, current recommendations for timing of N application in these systems are based on conventional tillage systems that do not use legume cover crops. Synchronization of residue N mineralization, fertilizer-N application time, and subsequent crop demand for N could improve N use efficiency of summer crops planted in winter legume conservation-tillage systems. This study was initiated to determine (i) the N contribution from crimson clover to corn grown in a conservation-tillage system; (ii) the N uptake profile

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Abbreviations: GDU, growing degree units, Corn-legume System-Nitrogen Applications.

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Table 1. Dry matter yield, tissue N concentration, and N content of cover crops at burndown, 7 to 10 d prior to planting corn.

Cover Crop		Dry Matter (Mg ha^{-1}) 1986	1987	1988	Mean	Tissue N (g kg^{-1}) 1986	1987	1988	Mean	N Content (kg ha^{-1}) 1986	1987	1988	Mean
Clover	Forage	3.76	5.79	5.39	4.98	25.8	27.4	24.5	25.9	96	159	132	129
	Roots	0.61	1.02	1.95	1.19	23.5	21.3	18.2	21.0	14	22	36	24
	Total	4.37	6.81	7.34	6.17	—	—	—	—	111	181	168	153
Rye†	Forage	1.88	3.85	1.65	2.46	17.2	13.1	16.7	15.7	32	50	28	37
	Roots	0.43	0.67	0.67	0.59	6.4	14.0	6.0	8.8	3	9	4	5
	Total	2.31	4.52	2.25	3.05	—	—	—	—	35	59	32	42

† Samples taken from area bordering experimental area. For comparative purposes only.

of corn grown in this type system; and (iii) the optimum N rate and time of application for corn grown in this system on a Coastal Plain soil.

MATERIALS AND METHODS

This field study was conducted for 3 yr (1986-1988) on a Norfolk sandy loam (tine, loamy, siliceous, thermic Typic Kandiudults) located at the E. V. Smith Research Center of the Alabama Agricultural Experiment Station in east-central Alabama. Initial soil organic matter content (0-to 20-cm depth) averaged 12.5 g kg^{-1}. Soil pH averaged 6.6 and cation exchange capacity averaged 3.6 cmol$_c$kg^{-1}. Initial Mehlich I extractable P, K, Ca, and Mg (Hue and Evans, 1979) averaged 132 (very high), 80 (medium), 860, and 110 kg ha^{-1}, respectively. An application of 80 kg K ha^{-1} was made to the site on 5 Mar. 1986 and on 15 Sept. 1987 29 kg P ha^{-1} and 56 kg K ha^{-1} were applied to the site. The site has a well developed tillage pan 20 to 30 cm deep and previous research has shown the necessity for in-row subsoiling when growing corn on this site (Reeves and Touchton, 1986).

The experimental area was disked, field cultivated, and seeded with 'Tibbee' crimson clover in mid-October of 1985, 1986, and 1987. At mid to full bloom each year, clover was killed with an application of 0.94 kg a.i. ha^{-1} paraquat dichloride (1,1' -dimethyl-4,4' - bipyridiniun dichloride). Kill dates were 11 Apr. 1986, 25 Apr. 1987, and 19 Apr. 1988. A four-row in-row subsoiler equipped with fluted coulters and rolling cultivator baskets was used to subsoil 38 cm deep within the row on 76-cm centers. This operation resulted in a tilled strip approximately 30 cm wide. Tbe remaining interrow area was covered by the clover residue. A John Deere Flex-71 planter was used to seed Pioneer brand hybrid 3320 corn within the tilled strip at a rate of 69 000 seeds ha^{-1}. Planting dates were 18 Apr. 1986, 5 May 1987, and 29 Apr. 1988. The corn was thinned to 56 800 plants ha^{-1} 3 wk after emergence. Starter fertilizer consisting of 20 kg K ha^{-1}, 12 kg Mg ha^{-1}, 25 kg S ha^{-1}, 10 kg P ha^{-1}, 4.5 kg Zn ha^{-1}, and 2 kg B ha^{-1} was banded over the row at planting. Weeds were controlled with an early post-emergency spray of 0.9 kg a.i. ha^{-1} of atrazine [6-chloro-N-ethyl-hP-(l-methylethyl)-1,3,S-triazine-2,4-diamine] plus 1.7 kg a.i. ha^{-1} of alachlor [2-chloro-N-(2,6-die thylphenyl)-N-(methoxymethyl)acetamide].

Plots consisted of 4 rows, 76 cm wide, 10.7 m long. The experimental design was a randomized complete block with four replications. Treatments were a factorial arrangement of N rates and N application times. Nitrogen as NH_4NO_3 was broadcast at rates of 34, 67, or 134 kg ha^{-1}. Application times were at planting, or 3, 6, or 9 wk after planting. A zero-N control and split applications (1/3 at planting and 2/3 6 wk later) of the 67 and 134 kg ha^{-1} N rates were also included. Space limitations prevented inclusion of a non-legume cover crop treatment in the study, however, an area bordering the experimental plots was planted to cereal rye each fall, killed at the same time as the clover, and corn was planted into the area but did not receive any N fertilizer. Samples were taken from this area at all scheduled sampling times, but were not included in statistical analyses of data as the area was not included within the experimental design area.

Table 2. Effect of N rate and application time on corn grain yield; ANOVA and single degree of freedom contrast summaries.

Source†	df	1986	1987	1988
		P>F		
N rate	2	0.06	0.001	0.11
Time	3	0.28	0.0001	0.03
N rate × Time	6	0.88	0.38	0.75

Contrast	1986 Yield Mg ha^{-1}	1986 P>F	1987 Yield Mg ha^{-1}	1987 P>F	1988 Yield Mg ha^{-1}	1988 P>F
N at planting	5.32		6.83		8.31	
vs.		0.34		0.61		0.08
N split (67 kg ha^{-2})	6.16		7.11		7.42	
N at planting	6.50		7.50		7.69	
vs.		0.03		0.33		0.53
N split (134 kg ha^{-1})	8.34		7.00		7.38	
0 - N	4.80		4.27		6.66	
vs.		0.02		0.0001		0.04
all other treatments	6.24		6.43		7.43	

† 0-N clover control excluded from factorial ANOVA. Yield for rye border check averaged 0.125, 0.125, and 1.38 Mg ha^{-1} in 1986, 1987, and 1988, respectively.

The test was not managed as irrigated corn, however, supplemental irrigation was applied to the test area, including the rye border area, during periods of drought stress in order to prevent loss of data. Irrigations were made at from 7 to 14 d intervals since the last irrigation or rainfall when plants shaved extreme drought stress. If rainfall did not occur within 2 d of treatment N applications, then 20 mm of irrigation water was applied to move N into the soil.

Root and forage samples for dry matter and N determination were collected from the four replications of clover and the nonreplicated rye comparison area at cover crop burndown (7 d before planting in 1986 and 10 d before planting in 1987 and 1988). Sample area was 0.25 m^2, and roots were excavated and screened from the sample areas of a depth of 30 cm. Corn whole plant samples were taken for determination of dry weight and N concentration at 3 wk intervals throughout the season until physiological maturity (black layer). Eight plants per plot were taken at 3 wk when the plots were thinned to 56 800 plants ha^{-1}. Four plants per plot were taken at the 6, 9, 12, and 15 wk sampling dates. At these dates, alternate plants from within the middle two rows were chosen so as to reduce any effect of plant removal on collective plant responses. Although cumulative sampling reduced final plant population by 17%, the final stand at grain harvest was 46 900 plants ha^{-1}, well within the recommended plant population for corn not managed as an irrigated crop. Stand counts were made at the same time for calculation of N uptake. Nitmgen concentrations in plant tissue were measured with a LECO CHN-600 carbon-hydrogen-nitrogen analyzer (LECO Corporation, St. Joseph. MI). The middle two rows of each plot were hand harvested for grain and weights were adjusted to 155 g kg^{-1} moisture.

Combined analysis of variance (ANOVA) with year in the model showed significant year-by-response-variable interactions; data were therefore analyzed separately by year. Single degree of freedom contrasts were performed to separate the effects of split N treatments and the O-N control. The 34, 67, and 134 kg N ha^{-1} treatments were also analyzed as a factorial arrangement with fertilizer application time (at planting, or 3, 6, or 9 wk after planting). Mean separation was made with a protected LSD at the 0.10 level of significance. Dummy variable multiple regression procedures (Draper and Smith, 1981) with stepwise elimination of nonsignificant variables, including block and N application time, were used to analyze N rate effect on yield.

RESULTS AND DISCUSSION

Cover Crop

Dry matter, tissue N concentration, and N content of cover crops at burndown are listed in Table 1. Nitrogen content of clover ranged from 111 to 181 kg ha^{-1}. By comparison, N content of the rye border area ranged from 32 to 59 kg ha^{-1}. The fraction of total N accumulated in the roots of cover crops ranged from 12.1 to 21.4% for clover and 8.6 to 15.3% for rye. Mitchell and Teel (1977) reported similar distribution of N in roots and aerial portions of grass and legume cover crop mixes.

Grain Yield

As expected, reduced corn grain yields were obtained with the O-N control in all three years (Table 2). In the first year of the system (1986) there was an extreme drought (Fig. 1). Although the test was irrigated, the frequency and amount was not sufficient to completely offset the effects of the extreme lack of rainfall. There was a nonsignificant trend for split application of 67 kg N ha-' to increase yield compared to N applied at planting (Table 2). The difference was significant at the 134 kg ha-' N rate. In 1987 and 1988, however, split ap plication did not result in yield increases. Split applications of fertilizer N is the standard recommendation for corn grown on the coarse-textured soils of the Southern Coastal Plain (Gilliam and Boswell, 1984). Our data, however, suggest that split applications are not necessary for corn grown in a winter legume conservation system on these soils.

In 1986, excluding the split application treatments, time of N application did not affect grain yield (Table 2 and Fig. 2). In 1987, delaying N application until 6 wk after planting tended to reduce grain yield (Fig. 2). In both 1987 and 1988, delaying application until 9 wk after planting resulted in large yield reductions.

In 1986 grain yield increased linearly with applied N regardless of N application time (Fig. 2). Predicted maximum yield for N applied at planting was obtained with 116 kg ha^{-1} in 1987 and 93 kg ha^{-1} in 1988. Maximum economic yield, however, would be achieved at lower N rates. For example, average 1991 fertilizer and corn prices for Alabama farmers (N priced at \$0.62 kg^{-1} [Goodman et al., 1991] and corn valued at \$104.11 Mg^{-1} [Alabama Farm Facts, 1991]), results in a N/corn price ratio of 5.96. Taking the first derivative of the regressions for N applied at planting and setting them equal to the N/corn price ratio (Nelson et al., 1985) results in maximum economic yield being obtained with 104 kg ha-' in 1987 and 73 kg ha^{-1} in 1988. There were no N rate by N application time interaction effects on grain yield in any year (Table 2).

Dry Matter Accumulation

Despite limited irrigation, the extreme drought in 1986 probably influenced dry matter accumulation. Neither N rate nor timing of N application, including split application treatments, affected corn dry matter accumulation (Table 3 and Fig. 3 and 4). At maturity, the only treatment differences were between the O-N control vs. all other treatments (Table 3). Total dry matter 15 wk after planting averaged 13.50 Mg ha^{-1} for the O-N control vs. 16.00 Mg ha^{-1} for all other treatments with fertilizer N

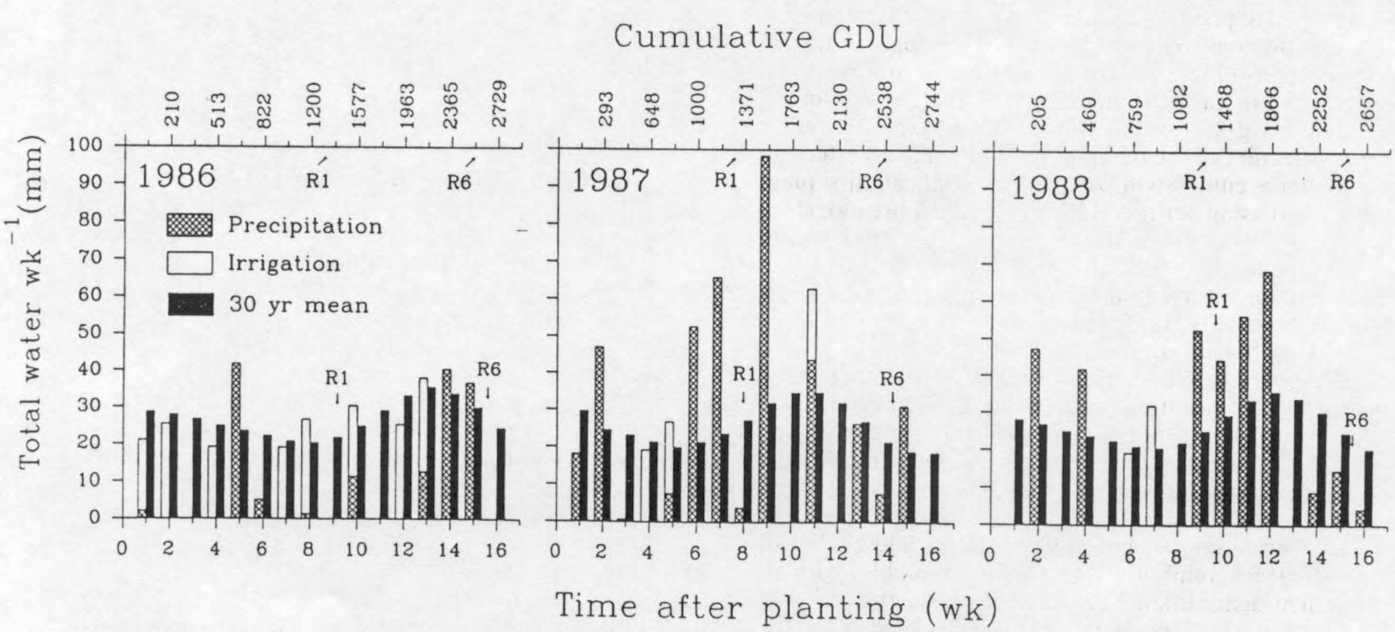

Fig. 1. Rainfall, irrigation, and growing degree units (GDU) for corn grown in 1986 to 1988 in a conservation-tillage system following a crimson clover cover crop. R1 denotes silking and R6 is physiological maturity (black layer formation).

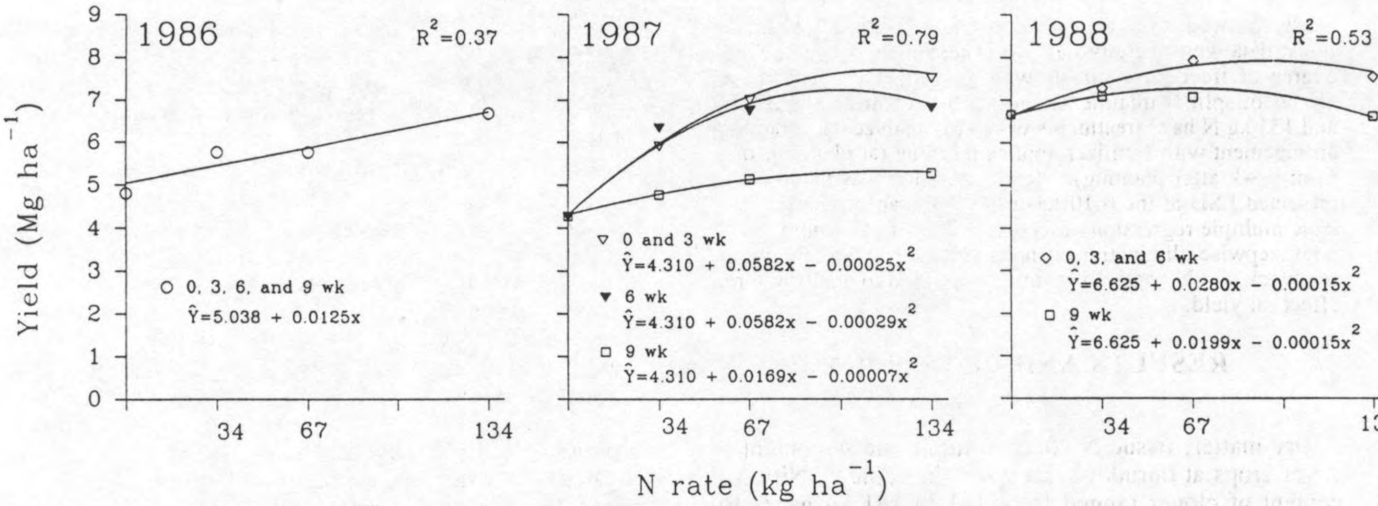

Fig. 2. Influence of rate of applied N on corn grain yield in a conservation-tillage system following a crimson clover cover crop. Base equation is for N applied at planting (0 wk); other lines (1987 and 1988) are significant linear and/or quadratic deviations in slope from base regression due to N application time.

applied. Total corn dry matter from the rye border area averaged only 7.01 Mg ha^{-1}.

In 1987, corn was planted late and rainfall distribution during tasseling and silking was favorable (Fig. 1). Corn accumulated growing degrees units (GDU, base 10°C) more rapidly than in 1986 or 1988 (Fig. 1), compressing the growing season. Both rate and time of application significantly affected dry matter production, but there were no interaction effects of these two treatment variables on dry matter (Table 3). Dry matter at 9, 12 and 15 wk after planting from O-N control plots averaged 11%, 20%, and 29% less, respectively, than treatments that received fertilizer N. Total dry matter 15 wk after planting averaged 10.45 Mg ha^{-1} for O-N vs. 14.65 Mg ha^{-1} for treatments receiving fertilizer N. By comparison, corn dry matter from the rye border area averaged 3.70 Mg ha^{-1}.

Beginning 6 wk after planting in 1987, 134 kg N ha^{-1} applied at planting significantly increased dry matter production compared to 134 kg N ha^{-1} applied in split applications (Table 3). Total dry matter at maturity averaged 18.73 Mg ha^{-1} for this rate of N applied at planting vs. 14.35 Mg ha^{-1} when applied in split applications. Split application of the 67 kg N ha^{-1} rate had no effect on dry matter accumulation compared to application at planting.

Increasing fertilizer N rate in 1987 (treatments other than split applications) increased dry matter accumulation beginning 9 wk after planting (Table 3 and Fig. 3). At maturity, dry matter averaged 10.45, 12.74, 14.52, and 16.45 Mg ha^{-1}, respectively, for O-N, 34, 67, and 134 kg N ha^{-1} applications.

Applying N later than 3 wk after planting generally reduced dry matter production in 1987 (Table 3 and Fig. 4). Total dry matter 15 wk after planting averaged 15.31 Mg ha^{-1} when N was applied at planting, 15.20 Mg ha^{-1} when N was applied 3 wk after planting, 13.80 Mg ha^{-1} when N was applied 6 wk after planting, and 13.96 Mg ha^{-1} when N was applied 9 wk after planting ($P < 0.18$).

In 1988, rainfall was generally favorable, with an excellent distribution from tasseling through most of grain fill (Fig. 1). Dry matter production was generally not affected by N rate (Table 3 and Fig, 3) or N application time (Table 3 and Fig. 4), including no consistent effect over sampling dates from split applications. In the third year of corn after clover, total dry matter produced without any fertilizer N still tended to be less than when fertilizer was applied (13.72 Mg ha^{-1} vs. 15.84 Mg ha^{-1}, $P < 0.29$) but the difference was not as great as in 1987.

Nitrogen Uptake

In 1986, total N uptake at maturity averaged 164 kg ha^{-1} for all treatments with N applied vs. 128 kg ha^{-1} when N fertilizer was not applied (Table 4). Nitrogen uptake by corn in the rye border area averaged 76 kg ha^{-1}.

For the first year of corn following clover, split applications of 67 kg N ha^{-1} had no effect on N uptake, however, the split application of 134 kg N ha^{-1} increased N uptake. At maturity, N uptake averaged 168 vs. 208 kg ha^{-1} when 134 kg N ha^{-1} was applied at planting vs. in split applications ($P < 0.11$).

At maturity, the 134 kg ha^{-1} N rate resulted in greater N uptake than the 34, or 67 kg ha^{-1} N rates, while N uptake by corn fertilized with 34 or 67 kg N ha^{-1} was similar (Table 4 and Fig. 5). Apparent fertilizer N recovery (N content from fertilized plots - N content from O-N control plots) averaged 54 kg ha^{-1} for the 134 kg N ha^{-1} applied.

Excluding split applications, time of N application had little effect on N uptake in 1986 (Table 4 and Fig. 6). There was, however, a slight difference in the uptake patterns between N applied 9 wk after planting compared to N applied at planting or 3, or 6 wk after planting (Fig. 6). Nitrogen applied at 9 wk was rapidly taken up by the corn during this growing season. There were no interaction effects of N rate and application time on N uptake in 1986.

In 1987, with a compressed growing season and good rainfall distribution (Fig. 1), both fertilizer N rate and application time affected N uptake (Table 4 and Fig. 5 and 6). Compared to plots with N applied, O-N plots lagged in N uptake throughout the growing season (Table 4). By the end of the season, 95 kg N ha^{-1} was taken

Table 3. Effect of N rate and application time on corn dry matter accumulation; ANOVA and single degree of freedom contrast summaries.

Source†	df	Weeks after planting 3	6	9	12	15
		$P > F$				
1986						
N rate	2	0.81	0.48	0.11	0.99	0.33
Time	3	0.34	0.12	0.41	0.55	0.99
N rate × time	6	0.44	0.13	0.31	0.69	0.95
1987						
N rate	2	0.84	0.22	0.05	0.01	0.0001
Time	3	0.005	0.0001	0.002	0.007	0.18
N rate × time	6	0.30	0.57	0.77	0.27	0.14
1988						
N rate	2	0.51	0.05	0.30	0.41	0.19
Time	3	0.19	0.29	0.11	0.13	0.37
N rate × time	6	0.56	0.14	0.32	0.65	0.85

Contrast	Weeks after planting 3: dry matter Mg ha^{-1}	$P > F$	6: dry matter Mg ha^{-1}	$P > F$	9: dry matter Mg ha^{-1}	$P > F$	12: dry matter Mg ha^{-1}	$P > F$	15: dry matter Mg ha^{-1}	$P > F$
1986										
N at planting	0.023		0.46		5.40		11.19		15.25	
vs.		0.41		0.52		0.10		0.31		0.60
N split (67 kg ha^{-1})	0.020		0.42		6.36		12.53		16.28	
N at planting	0.020		0.35		5.68		10.73		16.56	
vs.		0.51		0.0003		0.55		0.66		0.52
N split (134 kg ha^{-1})	0.023		0.59		6.21		11.30		17.85	
0 - N	0.016		0.39		5.39		10.91		13.50	
vs.		0.07		0.19		0.79		0.80		0.09
all other treatments	0.019		0.45		5.50		10.67		16.00	
1987										
N at planting	0.172		2.04		7.24		11.69		14.41	
vs.		0.21		0.98		0.62		0.19		0.31
N split (67 kg ha^{-1})	0.145		2.04		7.59		13.42		15.96	
N at planting	0.123		2.52		8.48		13.75		18.73	
vs.		0.47		0.01		0.03		0.44		0.006
N split (134 kg ha^{-1})	0.108		1.97		6.86		12.73		14.35	
0 - N	0.107		1.84		6.14		10.00		10.45	
vs.		0.35		0.55		0.13		0.01		0.0005
all other treatments	0.122		1.93		7.21		12.44		14.65	
1988										
N at planting	0.291		0.87		5.51		10.30		17.35	
vs.		0.07		0.31		0.10		0.35		0.37
N split (67 kg ha^{-1})	0.189		1.03		4.71		8.81		15.40	
N at planting	0.243		1.47		4.89		12.12		17.24	
vs.		0.60		0.44		0.46		0.06		0.66
N split (134 kg ha^{-1})	0.213		1.34		5.22		9.15		16.27	
0 - N	0.235		0.76		5.29		10.15		13.72	
vs.		0.42		0.003		0.25		0.40		0.29
all other treatments	0.202		1.04		4.56		9.18		15.84	

† 0-N clover control excluded from factorial ANOVA.

up by corn in plots with no supplemental N fertilizer compared to 165 kg ha^{-1} in plots with fertilizer N applied. Only 28 kg N ha^{-1} was taken up by corn grown in the rye border area.

There was a nonsignificant trend for greater N uptake in 1987 with split applications of 67 kg N ha^{-1} compared to the total being applied at planting (Table 4). However, with 134 kg N ha^{-1} the effect was reversed. At this rate, N uptake throughout the entire season was greater in plots with N applied at planting compared to split applications. Fifteen weeks after planting, total N uptake averaged 220 kg ha^{-1} vs. 164 kg ha^{-1} for N applied at planting vs. split applied.

Increasing N rates resulted in well defined differences in N uptake patterns in 1987 (Fig. 5). At all rates, the increased N uptake, due to incremental increases in N fertilizer, nearly equalled or exceeded the increment of fertilizer N applied. The apparent high efficiency of fertilizer N application in 1987 probably was a result of the relatively good rainfall distribution. This not only increased corn response to N, but likely optimized the N release from clover residue. Wagger (1986b) reported that despite similar N contents in crimson clover residue at the start of two seasons, cumulative N release from residue was 36% greater in a year of adequate rainfall compared to a year of poor rainfall distribution.

During the compressed growing season of 1987, applying N 3 wk after planting resulted in a somewhat more

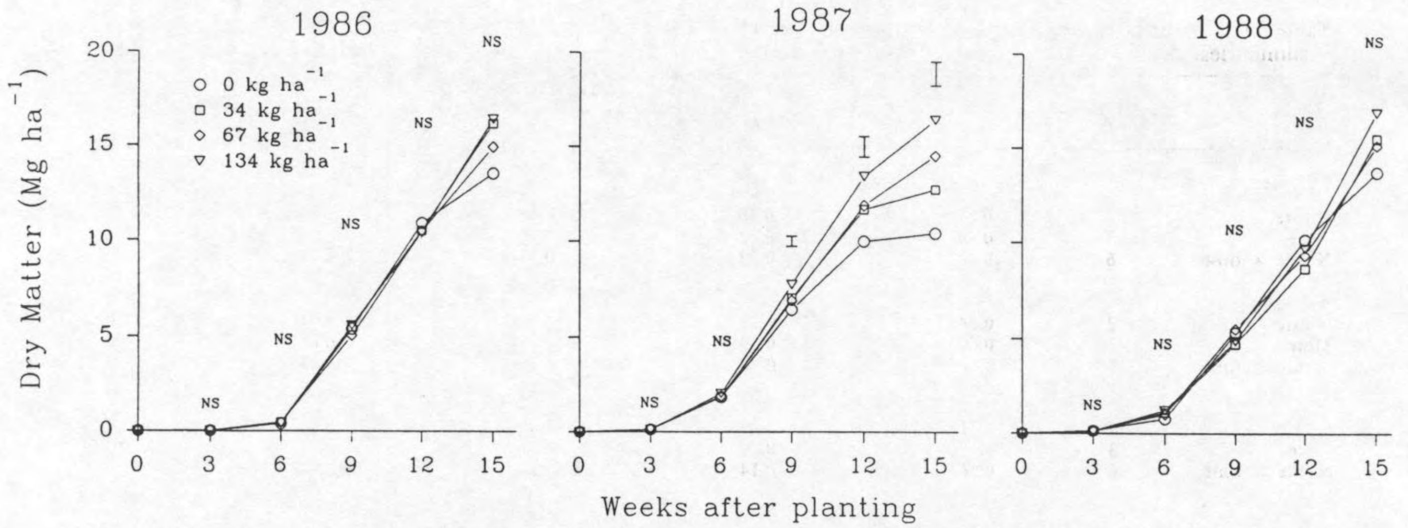

Fig. 3. Influence of applied N rate, averaged over application time, on dry matter accumulation of corn grown in 1986 to 1988 in a conservation-tillage system following a crimson clover cover crop. Vertical bars represent $LSD_{0.10}$ for values other than O-N control; NS = not significant.

rapid N uptake pattern compared to N applied at planting (Fig. 6). Delaying application until 9 wk after planting resulted in similar total N uptake by the end of the season, although it resulted in depressed grain yields (Fig. 3). Significant N rate-by-application-time interactions occurred at 6 and 15 wk after planting (Table 4). At 6 wk after planting, the interaction was due to an average 25 kg N ha^{-1} greater uptake from the 134 kg N ha^{-1} fertilizer application compared to the 34 and 67 kg N ha^{-1} applications, which averaged 58 kg N ha^{-1} plant uptake ($LSD_{0.10}$ = 9.9 kg N ha^{-1}). Total N uptake 15 wk after planting in 1987 as affected by the interaction of N rate and application time is shown in Table 5. When the 134 kg N ha^{-1} rate was applied at planting or 3 wk later, N uptake was maximized. Plant uptake of N with the 134 kg N ha^{-1} rate decreased while uptake with the 67 kg N ha^{-1} rate increased when applied at 6 or 9 wk after planting. We can offer no explanation for this apparent anomaly.

By the third year following clover (1988), total corn N uptake was less, but not significantly so, for O-N plots compared to plots fertilized with N (Table 4). This trend, however, was not apparent until 15 wk after planting. Nitrogen uptake in the rye border area averaged only 39 kg ha^{-1}. The total N uptake in O-N plots in 1988 (150 kg ha^{-1}) was 17% greater than in 1986, and 58% greater than in 1987. Apparent N contribution from clover (N uptake from O-N clover plots - N uptake from rye border area) was 52, 67, and 111 kg ha^{-1} in 1986, 1987, and 1988, respectively. The greater N uptake, and the lower fertilized N requirements needed to produce maximum yield with successive years, discussed previously, suggest that available soil N under crimson clover increased with successive years in this conservation-tillage system.

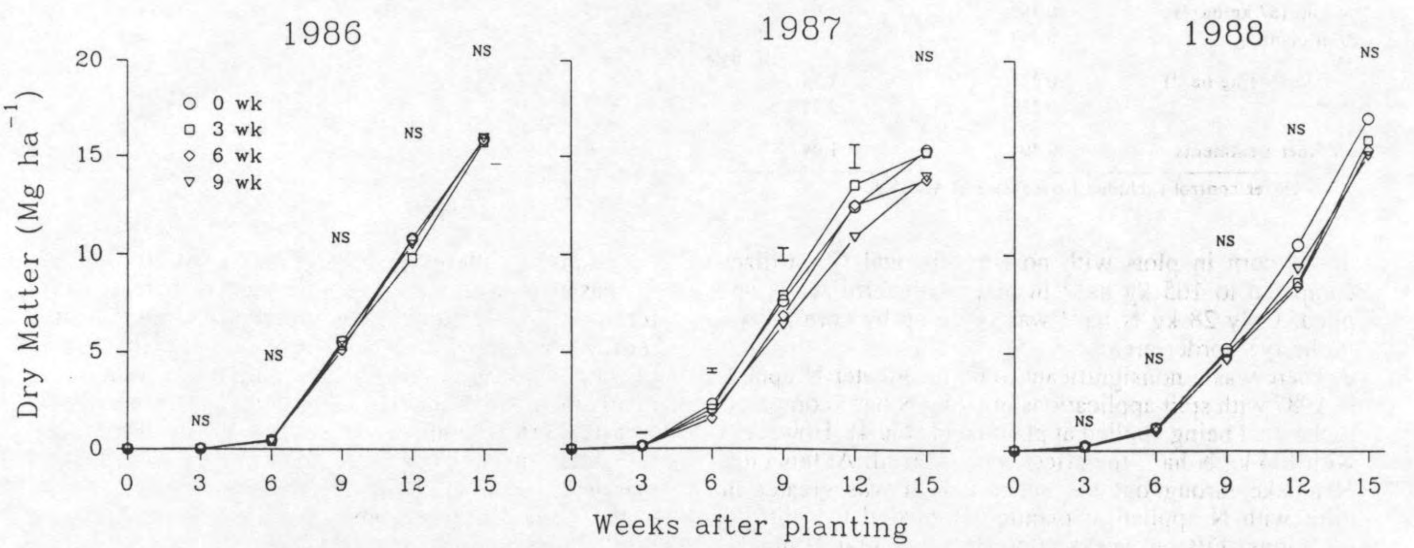

Fig. 4. Influence of N application time, averaged over rate, on dry matter accumulation of corn grown in 1986 to 1988 in a conservation-tillage system following a crimson clover cover crop. Vertical bars represent $LSD_{0.10}$ for values other than O-N control; NS = not significant.

Table 4. Effect of N rate and application time on corn N uptake; ANOVA and single degree of freedom contrast summaries.

Source†	df	Weeks after planting 3	6	9	12	15
		P > *F*				
1986						
N rate	2	0.76	0.60	0.06	0.27	0.03
Time	3	0.004	0.55	0.64	0.13	0.51
N rate × time	6	0.79	0.46	0.12	0.61	0.96
1987						
N rate	2	0.88	0.0006	0.0001	0.0001	0.0001
Time	3	0.0001	0.0001	0.0001	0.08	0.93
N rate × time	6	0.57	0.03	0.21	0.40	0.09
1988						
N rate	2	0.62	0.006	0.01	0.12	0.004
Time	3	0.0007	0.002	0.0002	0.20	0.36
N rate × time	6	0.27	0.08	0.23	0.60	0.74

Contrast	Weeks after planting 3: N kg ha^{-1}	3: *P* > *F*	6: N kg ha^{-1}	6: *P* > *F*	9: N kg ha^{-1}	9: *P* > *F*	12: N kg ha^{-1}	12: *P* > *F*	15: N kg ha^{-1}	15: *P* > *F*
1986										
N at planting	1.0		16		104		143		142	
vs.		0.14		0.17		0.10		0.27		0.53
N split (67 kg ha^{-1})	0.8		13		131		167		157	
N at planting	1.0		12		111		133		168	
vs.		0.99		0.01		0.11		0.10		0.11
N split (134 kg ha^{-1})	0.9		20		137		168		208	
0 - N	0.6		13		89		131		128	
vs.		0.10		0.34		0.21		0.55		0.05
all other treatments	0.8		14		104		133		164	
1987										
N at planting	7.5		56		108		131		146	
vs.		0.05		0.31		0.12		0.09		0.19
N split (67 kg ha^{-1})	5.6		50		134		164		171	
N at planting	5.9		83		147		184		220	
vs.		0.24		0.0001		0.08		0.18		0.005
N split (134 kg ha^{-1})	4.8		53		118		159		164	
0 - N	3.8		40		78		106		95	
vs.		0.20		0.008		0.005		0.0007		0.0001
all other treatments	4.4		51		114		157		165	
1988										
N at planting	5.8		26		106		145		195	
vs.		0.06		0.49		0.02		0.57		0.43
N split (67 kg ha^{-1})	4.3		30		83		132		173	
N at planting	5.9		47		101		190		217	
vs.		0.10		0.18		0.68		0.06		0.74
N split (134 kg ha^{-1})	4.6		40		104		143		208	
0 - N	4.9		21		86		133		150	
vs.		0.19		0.003		0.73		0.78		0.15
all other treatments	4.3		32		89		139		186	

† 0–N clover control excluded from factorial ANOVA.

Total soil N was not determined on individual plots, however, composite samples taken from O-N plots (20-cm depth) showed that total N increased from 0.24 g kg^{-1} in 1986 to 0.32 g kg^{-1} in 1988. Frye et al. (1985) reported that corn grain yields under no-till with a hairy vetch cover crop increased over time; they concluded that the increased soil productivity was due mainly to increased N supply as organic N increased in the soil. McVay et al. (1989) in no-tillage experiments on both a Coastal Plain and Limestone Valley soil, found that after 3 yr, total N was greater following crimson clover that either wheat or fallow.

There were no consistent differences over sampling dates due to split application with either the 67 kg N ha^{-1} or 134 kg ha^{-1} N fertilizer rate in 1988 (Table 4). By the end of the season, N uptake averaged 195 vs. 173 kg ha^{-1} with 67 kg N ha^{-1} applied at planting vs applied in split applications. With 134 kg N ha^{-1} applied, N uptake averaged 217 vs. 208 kg ha^{-1} when applied at planting vs. in split applications.

The 134 kg N ha^{-1} fertilizer rate increased N uptake compared to the 34, or 67 kg ha^{-1} N rates in 1988 (Fig. 5). There was little difference in the uptake pattern of N as affected by rates of applied N of 67 kg ha^{-1} or less.

As in 1987, delaying N application beyond 3 wk after planting in 1988 affected the N uptake profile (Fig. 6). the only N rate-by-application-time interaction for plant N untake occurred at 6 wk after planting (Table 4). This resulted because the 134 kg N ha^{-1} rate increased N uptake to 46 kg N ha^{-1} when applied at planting or 3

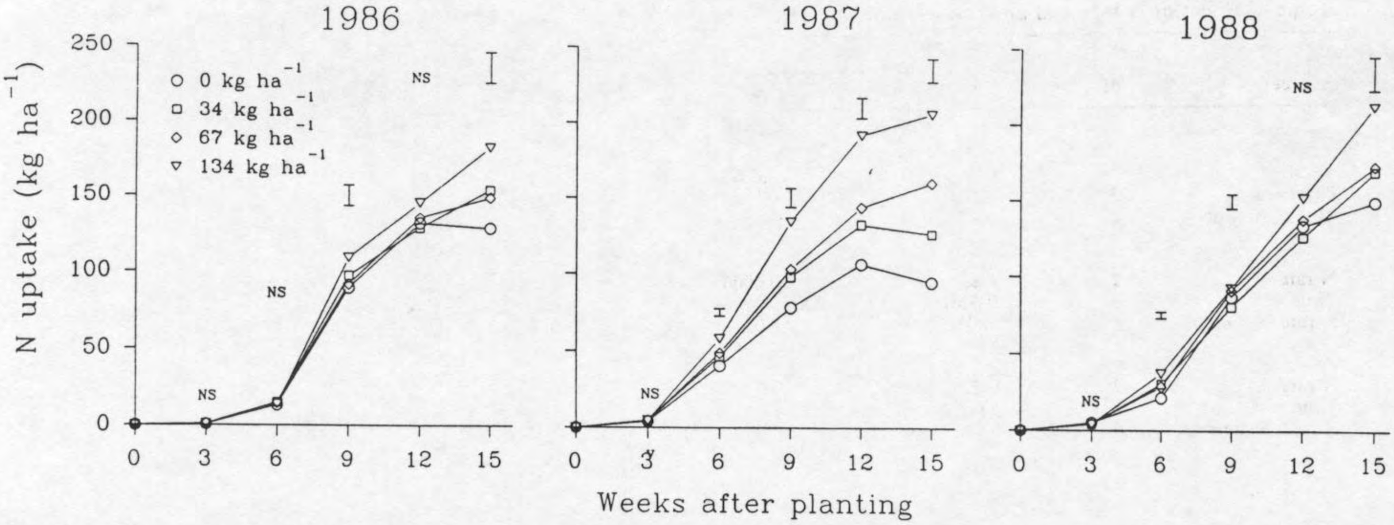

Fig. 5. Influence of applied N rate, averaged over application time, on plant N uptake by corn grown in 1986 to 1988 in a conservation-tillage system following a crimson clover cover crop. Vertical bars represent $LSD_{0.10}$ for values other than O-N control; NS = not significant.

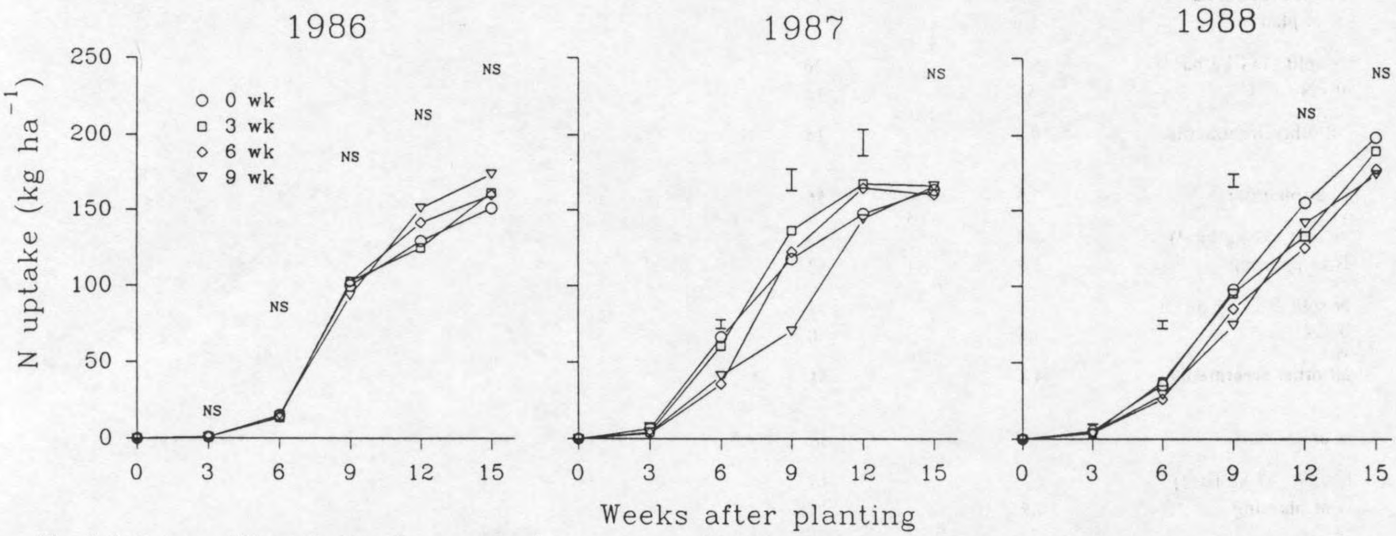

Fig. 6. Influence of N application time, averaged over rate, on plant N uptake by corn grown in 1986 to 1988 in a conservation-tillage system following a crimson clover cover crop. Vertical bars represent $LSD_{0.10}$ for values other than O-N control; NS = not significant.

wk after planting, compared to the 34 and 67 kg N ha^{-1} rates, which averaged 31 kg N ha^{-1} uptake. There was a nonsignificant trend for delayed N application beyond 3 wk to reduce N uptake, however, by the end of the season, total N uptake was not different among the application times (Table 4 and Fig. 6).

CONCLUSIONS

In 2 of 3 yr, dry matter accumulation was not affected by N application time. In 1 yr, when corn was planted late and rainfall distribution was favorable, dry matter production was greater when N was applied at planting compared to split applications or applications later than 3 wk after planting. Application time affected N uptake patterns during the growing season, but generally did not affect total N uptake at the end of the season. With the exception of the first year, split applications of N resulted in equivalent or reduced N uptake compared to application of all N at planting. Also, after the first year, split applications of N were not effective in increasing grain yield compared to applying all N at planting, and applying N later than 6 wk after planting reduced grain

Table 5. Interaction of N rate and application time on corn N uptake at maturity, 15 wk after planting, in 1987.

N rate (kg ha^{-1})	Application Time (wk after planting) 0	3	6	9
	kg N ha^{-1}			
34	124	123	129	129
67	146	149	174	170
134	220	227	177	198
$LSD_{0.10}$ = 31.0	CV = 15.8%			

yield. Our results suggest that applying fertilizer N in split applications is not necessary for corn grown in conservation-tillage systems using winter legumes on Coastal Plain soils. Our results also suggest that fertilizer N requirement soft continuous corn grown in this type of system may decrease with time due to residual effects of legume N. We believe that split applications of fertilizer N did not improve N efficiency or grain yields because late-season N requirements were met through mineralized N from residues of the decomposing legume cover crop. For continuous corn grown in a winter leg ume conservation-tillage system on Coastal Plain soils, the optimum management practice for conservation of N, energy, time, and labor would be to apply fertilizer N at planting.

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