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REDUCTION OF NITRATE LEACHING IN AGRICULTURAL SOILS VIA COVER CROPS

by

M. G. Wagger

Department of Soil Science

and

College of Agriculture and Life Sciences
North Carolina State University
Raleigh, North Carolina 27695

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ABSTRACT

The inherent inefficiency of fertilizer N utilization by corn can lead to a relatively large pool of residual soil N subject to leaching and possible contamination of groundwater supplies, particularly on sandy soils in the North Carolina Coastal Plain. The objectives of this research were to:(I) determine the extent of NO_3 leaching with respect to fertilization scheme and (ii) evaluate the potential of several cover crops (crimson clover, rye, spring oat, wheat, and native weeds) to recover residual fertilizer N from a corn production system. Soil inorganic N concentrations following corn harvest in September were two-to threefold greater at most depths when the previous corn N rate was 300 vs 150 kg ha^{-1}. Moreover, the largest differences in residual soil N levels between N rates occurred in the 45- to 75-cm depth range. Rye was the most effective cover crop in reducing profile soil inorganic N concentrations, followed by oat> wheat= crimson clover= native weeds. The greatest soil inorganic N concentrations just prior to corn planting the following spring occurred in the 75- to 90-cm soil layer, ranging from 1 mg kg^{-1} under rye to 9 mg kg^{-1} under native weeds. Estimates of N released from decomposing cover crops during the corn growing season were 59 kg ha^{-1} for crimson clover, 32 kg ha^{-1} for rye, 25 kg ha^{-1} for spring oat, and 17 kg ha^{-1} for wheat. In another experiment using ^{15}N methodology, cover crop recovery of fall applied ^{15}N fertilizer immediately prior to corn planting was 10% for native weeds, 5% for crimson clover, and 35% for rye. The corresponding residue ^{15}N released by corn maturity was in the order of crimson clover (23%) > native weeds (14%) > rye (7%).

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SUMMARY AND CONCLUSIONS

Field experiments on a Coastal Plain soil (Norfolk loamy sand) served as a basis for characterizing NO_3 leaching potential and the subsequent potential of winter annual cover crops (crimson clover, rye, spring oat, wheat, and native weeds) to recover and recycle residual fertilizer N. Two approaches were used to evaluate these N dynamics. The first method established two levels of residual soil N via fertilizer N applied to the previous corn crop, while the second method employed ^{15}N- enriched potassium nitrate applied to microplots immediately prior to planting rye and crimson clover cover crops in early fall.

Considerably higher concentrations of residual soil inorganic N occurred following corn fertilized with 300 vs 150 kg N ha^{-1}. Because the greatest concentrations (33 mg kg^{-1}) at the high fertilizer N rate were found in the 45- to 75-cm depth interval, it is likely that further downward movement during winter months would remove this inorganic N from the effective crop rooting zone. In this regard, a winter annual cover crop of rye was quite effective in accumulating residual fertilizer N and thereby minimizing further N losses from the plant-soil system. Spring oat showed some moderate potential for accumulating soil N and reducing NO_3 leaching while wheat, crimson clover, and native weeds were relatively ineffective in this role.

Estimates of the subsequent cover crop N pool potentially available to corn by 16 weeks was in the order of crimson clover > rye > spring oat > wheat. Based on a recommended fertilizer N rate of 150 kg ha^{-1} for corn grown in the North Carolina Coastal Plain, the percentage of this N requirement met by cover crop N release ranged from 12% with wheat to 40% with crimson clover.

In general, results from the ^{15}N experiment confirmed findings from the unlabeled N experiment. Rye recovery of fall-applied ^{15}N-enriched fertilizer was 35% by the following April compared to 10% by native weeds and only 5% by crimson clover. As a percentage of the total residue ^{15}N, nearly 23% of the crimson clover N was released by corn maturity compared to 14% of the native weed N and 7% of the rye N. Low total N accumulation by rye and crimson clover, however, severely limited actual N contributions to corn growth and yield.

RECOMMENDATIONS

Specific recommendations based on one site-year of data in the Coastal Plain are difficult to make. Given the dynamic role climate plays in field research, multiple year studies are required to properly assess treatment effects. Nevertheless, there are some clear patterns that emerged in these experiments. Results of studies using two approaches to assess NO_3 leaching potential and the subsequent cover crop recovery of residual fertilizer N in soil indicated the ability of rye over that of spring oat, wheat, crimson clover, and native weeds to fill this niche. In situations (environmental stress or pest-related pressures) where low yields of a high-N requirement crop such as corn result in relatively high levels of residual soil inorganic N, rye should be the cover crop of choice for remedial action. With respect to cover crop release of N, crimson clover would serve better in this capacity compared to the grasses evaluated. Therefore, in order to optimize the inherent capabilities of grasses and legumes, a grass-legume biculture may be more appropriate in cover-crop based production systems. Further investigation is warranted on the role of bicultures in soil water and nutrient dynamics.

Finally, if cover crops are to be widely used as a soil management tool, the potential scope of application should be expanded. This expansion might include the evaluation of rye cultivars with respect to nutrient recovery and the use of cover crops to recycle nutrients contained in animal wastes.

INTRODUCTION

Groundwater contamination by agricultural chemicals is one of the major problems facing agriculture in the 1990's. Nitrate is of particular concern because relatively low concentrations (10 ppm NO_3-N) impair water for human consumption and because many shallow groundwater supplies now exceed recommended NO_3-N drinking water standards (Hallberg, 1986; Keeney, 1986). Increases in groundwater NO_3 levels have been associated with major increases in N fertilization, primarily with respect to corn (Zea mays L.) (Hallberg, 1987).

Long-term experiments in the Corn Belt have shown that fertilizer N removal by corn grain rarely exceeds 40% at economically optimum corn yields (Blackmer, 1986; Oberle and Keeney, 1990 a,b). In cases where residual N from previous crop fertilization remains in the soil, the potential for NO_3 leaching also exists. Analysis of long-term climatic data for North Carolina shows that rainfall exceeds evapotranspiration during the winter and early spring months (van Bavel and Verlinden, 1956). With an annual crop such as corn, the land is often bare during this period when the greatest potential for significant leaching exists.

Winter annual cover crops have been recognized as an integral component of southern agricultural systems for many years because of their role in soil erosion control and enhancement of soil productivity. With the refinement of conservation tillage technology, new strategies have evolved with regard to cover crop management. The role of nonleguminous cover crops in efficient use of water and N was recently reviewed by Wagger and Mengel (1988). Indirect evidence for cover crops utilizing residual N can be found in studies reported 2by Langdale et al. (1979), Pelchat (1986), and Utomo (1986). In these experiments, N content of winter wheat (Triticum aestivum L.) or rye (Secale cereale L.) cover crops ranged from 12 to 66 kg N ha^{-1}. Pelchat (1986) found that increasing N applications to the previous corn crop from 0 to 180 kg N ha^{-1} resulted in an increase of 16 kg ha^{-1} in N uptake by the subsequent cover crop. Information is limited, however, on the role of cover crops as sinks for residual N. Moreover, a better understanding of the management of cover crops in this role is needed to ensure that the residual N trapped is effectively recycled to subsequent summer crops.

Winter cover crop effects on NO_3 leaching were evaluated more directly in drainage lysimeters by Karraker et al. (1950). They found only small leaching losses under bluegrass (Poa pratensis L.) sod and rye cover crops. Large losses of NO_3 occurred under a lespedeza (Lespedeza spp.) sod, but not when a winter rye cover crop was grown. They concluded that most of the NO_3 came from decomposing, senescent lespedeza residues. In Sweden, Bertilsson (1988) concluded that a rape (Brassica napus L.) cover crop could greatly reduce NO_3 losses, even when farm yard manure was applied in the autumn. These studies point to a potential benefit of cover crops with respect to reduction in NO_3 leaching. However, definitive data on the differences among cover crops for their residual NO_3 use-efficiency are not available.

With the aforementioned factors in mind, the objectives of this research were to: (1) determine the extent of NO_3 leaching with respect to fertilization scheme and (2) evaluate the potential of several cover crops to capture residual fertilizer N from a corn production system.

MATERIALS AND METHODS

Two methods were employed to accomplish each objective, each providing unique information. The research was conducted on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) at the Lower Coastal Plain Research Station in Kinston. This and similar Coastal Plain soils are quite susceptible to leaching losses of fertilizer N in crop production systems. Selected soil physical and chemical characteristics of the surface 0.15 m prior to the initiation of the experiment were as follows: 86% sand, 8% silt, 6% clay, 2.3 $cmol_c$ kg^{-1} CEC, and pH 5.8.

<u>Objective 1</u>: Leaching of Fertilizer N

<u>Unlabeled N Experiment</u>

With the first method, a gradient of residual fertilizer N was established by applying 150 or 300 kg N ha^{-1}, as ammonium nitrate, to corn during the 1992 growing season. These rates represent 100 and 200%, respectively, of the recommended amount for corn grown in the Coastal Plain. All plots received a broadcast application of 50 kg N ha^{-1} as ammonium nitrate at corn planting and either 100 or 250 kg N ha^{-1} surface banded 10 cm to the side of each row approximately 6 weeks after planting. Following corn harvest in September 1992, 5-cm diameter soil cores (3 per plot) were taken to a depth of 90 cm in 15-cm increments. Soil samples were air dried, extracted with 2M KCl (10 g soil in 100 mL) for 1 hr, and analyzed for NH_4 and NO_3 on a Lachat auto-analyzer.

<u>Labeled N Experiment</u>

A second approach employed ^{15}N methodology under field conditions. Prior to planting rye and crimson clover cover crops in early October, the experimental area was chisel plowed and disked. The experiment was established in an area that had a previous crop of corn fertilized with 150 kg N ha^{-1}. A fallow (no cover crop) treatment and the two monocultures comprised the 3 treatments in a randomized complete block design experiment with three replications.

Field microplots consisting of galvanized steel flashing were used to prevent the lateral movement of water and fertilizer ^{15}N. The microplots measured 2 by 3 m, with flashing installed approximately 10 mm into the soil and extending 10 mm above the soil surface. Microplots were divided into 4 quadrants to facilitate fertilizer application. Potassium nitrate labeled with 10 atom % ^{15}N was uniformly added as a solution to the soil surface at 50 kg N ha^{-1} (ca. 30 g ^{15}N per microplot) on 13 October 1992. In order to simulate a profile distribution of residual fertilizer N that might occur after a corn growing season, the fertilizer solution was moved into the soil over a 10-day period by approximately 8.0 cm of natural rainfall and applied water. Four soil cores (1.59-cm diameter) were obtained per microplot (1 core per quadrant) and composited in 15-cm increments to a depth of 90 cm following the last application of water in mid-October. Holes were filled with soil from the adjacent untreated area to minimize any alteration in soil water dynamics.

Soil samples were air-dried, ground with a mortar and pestle, and analyzed for total inorganic N as previously described. Once the inorganic N concentration was determined, an extract volume containing 40 to 100 μg N was incubated in 120-mL specimen cups with 0.4 g MgO and 0.2 g Devarda's alloy for 6 days (Sorensen and Jensen, 1991). Glass fiber disks (ca. 7 mm diameter) were acidified with 20 μL $KHSO_4$ and sealed in a Teflon packet to trap gaseous ammonia. Following the 6-day incubation period, glass fiber disks were removed from the Teflon packet and desiccated over concentrated H_2SO_4 for 48 h. All ^{15}N analyses were conducted on a Europa Scientific Tracer Mass Stable Isotope Detector.

Objective 2: Utilization of Residual N

For each approach outlined under Objective 1, winter annual cover crops were evaluated for their ability to recover residual fertilizer N that might otherwise be lost to leaching during the winter months.

Unlabeled N Experiment

The experimental area was chisel plowed and disked prior to planting cover crops in early October. Crimson clover (*Trifolium incarnation* L.), rye, wheat, and spring oat (*Avena sativa* L.) were drilled in plots measuring 5.8 by 15.2 m. Seeding rates were 28 kg ha^{-1} for crimson clover and 56 kg ha^{-1} for the grasses. A fallow (no cover crop) and 4 cover crops comprised the 5 main plot treatments and two levels of residual soil N represented the split-plot factor in a randomized complete block design with 4 replications. Winter annual weeds in the fallow treatment were allowed to grow during the cover crop phase of the study and consisted primarily of henbit (*Lamium amptexicaule* L.) and chickweed (*Stellaria media* L.).

Aboveground cover crop DM was determined in December, early March, and mid April by harvesting a 0.5-m^2 quadrat from each plot on all sampling dates. After the first sampling date, care was taken to provide adequate distance between newly, and previously harvested areas. Plant samples were dried at 65°C, weighed, ground, and analyzed for total N and C on a Perkin Elmer 2400 CHN Elemental Analyzer. Soil sampling was conducted to a depth of 90 cm in 15-cm increments at each plant sampling date. Soil samples were analyzed for total inorganic N in the same manner as previously described.

In order to better understand the recycling of N trapped by cover crops, and thereby potentially reduce the N required by the subsequent summer crop, cover crop decomposition was monitored with nylon mesh bags containing plant residue from the respective cover crops following corn fertilized with 150 kg N ha^{-1} only. Aboveground whole plant material was collected immediately prior to chemical desiccation in mid April, air-dried on greenhouse benches, and 18.0 g placed in 1-mm mesh nylon bags (15.2 by 30.5 cm). This addition corresponded to a residue loading rate of 3.7 Mg dry matter ha^{-1}. Growth stage at harvest was heading for rye, boot for oat and wheat, and mid-bloom for crimson clover. The samples were carefully handled to minimize detachment or breakage of various plant parts. Prior to mesh bag placement in the field, corn was planted via no-tillage in chemically desiccated cover crops. Bags were placed on the soil surface in the corn interrow on 4 May 1993 and retrieved at 1,2,4,6,8, and 16 weeks after field placement. Bag contents were dried at 65°C, weighed, ground, and analyzed for total C and N. Soil contamination was accounted for by ashing a 1-g subsample at 550°C and all plant constituents are reported on an ash-free basis.

Nonlinear regression equations for percent original N remaining at each mesh bag retrieval date were determined by fitting the data to one and two pool models, previously described by Ranells and Wagger (1992), using the Marquardt option of the NLIN procedure developed by SAS (SAS, 1985). A single pool model assumes that all of the plant N will mineralize at the same rate. The two pool model attempts to segregate plant N into two groups of mineralizable N; one that quickly mineralizes and a second, more passive pool that releases N more slowly. The general form of the equations were as follows;

Eq. [1] $PNR = P + (100-P)e^{-kt}$

Eq. [2] $PNR = 100Pe^{-k1t} + 100(1-P)e^{-k2t}$

where: PNR = Percent nitrogen remaining at time 't'

P = N pool(s)

K, k1, k2 = rate constant of N release

An appropriate model was chosen for each cover crop treatment based on successful regression and root mean square error values.

Labeled N Experiment

Cover crop utilization of residual fertilizer N in the ^{15}N experiment followed an approach similar to that previously described; however, a more detailed N balance should be obtained with this method. After profile distribution of ^{15}N-enriched fertilizer occurred, the cover crops and native weeds in the fallow microplots were allowed to grow until corn planting the following April. Plant and soil samples were taken during the cover crop season in December, early March, and mid April. In order to estimate cover crop dry matter and N accumulation for the December and March sampling dates, a 534-cm^2 area was harvested in each microplot quadrant and then composited into one sample. Care was taken to provide adequate distance between the December and March harvested areas. All plant material was dried at 65°C, weighed, ground, and analyzed for total C, N, and ^{15}N. For the April sampling date, aboveground biomass was completely harvested in each microplot and allowed to air dry on greenhouse benches before it was weighed and subsampled for moisture, total N, and ^{15}N determinations. Soil sampling was conducted to a depth of 90 cm in 15-cm increments at each plant sampling date, with samples processed and analyzed as previously described.

Air-dried cover crop material from the April harvest was placed in newly established microplots where the same unlabeled cover crops were harvested and removed. Corn ('Dekalb-Pfizer 689') was hand planted on 27 April 1993. All microplots received a broadcast application of 33 kg N ha^{-1} as ammonium nitrate at planting and 67 kg N ha^{-1} as ammonium nitrate surface banded 10 cm to the side of each row approximately 6 weeks after planting. This was done so that corn recovery of cover crop ^{15}N would not be constrained by low available soil N. Previous research in North Carolina has shown that fertilizer N at 90 kg ha^{-1} was sufficient to optimize corn yields when preceded by crimson clover or hairy vetch cover crops (Wagger, 1989b). Lime, P, and K were applied broadcast according to soil test recommendations for corn. Residual weed control was provided with 2.24 kg a.i. ha^{-1} alachlor [2-chloro-N-(2', 6'-diethylphenyl-N-(methoxymethyl)-acetamide] and 2.24 kg a.i. ha^{-1} atrazine [6-chloro-N-ethyl-N'-methylethyl)-1,3,5-triazine-2, 4-diamine]. Post-emergent weed control was provided by a broadcast,directed application of 1.08 kg a.i. ha^{-1} linuron [N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea] 6 weeks after planting. At maturity, corn was hand harvested from each microplot, weighed, and subsampled for moisture, total N, and ^{15}N determinations. Soil sampling was conducted after corn harvest and analyzed for inorganic N and ^{15}N as previously described. Data was analyzed by treatment using SAS GLM procedures (SAS, 1985).

RESULTS AND DISCUSSION

Unlabeled N Experiment

Residual Soil N and Cover Crop Performance

It was anticipated that the 150 and 300 kg N ha^{-1} rates applied to the previous corn crop would provide a soil inorganic N gradient from which to evaluate the ability of various cover crops to capture residual fertilizer N. The initial soil sampling following corn harvest in September 1992 revealed significant ($p=0.10$) differences in the distribution of inorganic N between N rates applied to the previous corn crop (Fig. 1a). There was a modest increase with depth in soil inorganic N levels under corn fertilized with 150 kg N ha^{-1}, ranging from a low of 5 to 8 mg kg^{-1} in the upper 30 cm to 18 mg kg^{-1} between 60 to 90 cm. In contrast, residual soil inorganic levels following corn fertilized with 300 kg N ha^{-1} ranged from 11 to 33 mg kg^{-1}, being significantly higher by approximately two-to threefold at most depths compared to the low N rate treatment. Moreover, the largest differences between N rates occurred in the 45- to 75-cm depth range. Without some form of intervention, these elevated soil inorganic N concentrations (ca. 33 mg kg^{-1}) this deep in the soil profile would likely be lost from the plant-soil system before planting of next year's row crop. In this study, precipitation from cover crop seeding in October to termination of cover crop growth and corn planting the following April was 50 cm.

The hypothesis was that the above-mentioned gradient in residual soil inorganic N would subsequently be influenced by cover crop species due to differences in rooting characteristics, growth rates, and N requirements. Cover crops were seeded in early October 1992 and by December only rye had shown a dry matter (DM) response (Fig. 2) due to residual soil inorganic N levels. In general, DM accumulation values were in the order of rye > oat > wheat > fallow = crimson clover. The corresponding cover crop N accumulation values reflected a similar pattern, with the N content in rye following the high N rate nearly double (39 vs. 21 kg N ha^{-1}) that of rye after corn fertilized with 150 kg N ha^{-1} (Fig. 3). There was no difference in N accumulation among the other cover crop treatments due to prior N rate, with mean values across N rates ranging from 4 kg N ha^{-1} in crimson clover to 17 kg N ha^{-1} in spring oat.

Even though cover crop N accumulation differed between species by December, there was little difference in soil inorganic levels due to cover crop. Consequently, soil inorganic N results for this date are presented as mean values across cover crops for the 150 and 300 kg ha^{-1} N rates (Fig. 1b). From

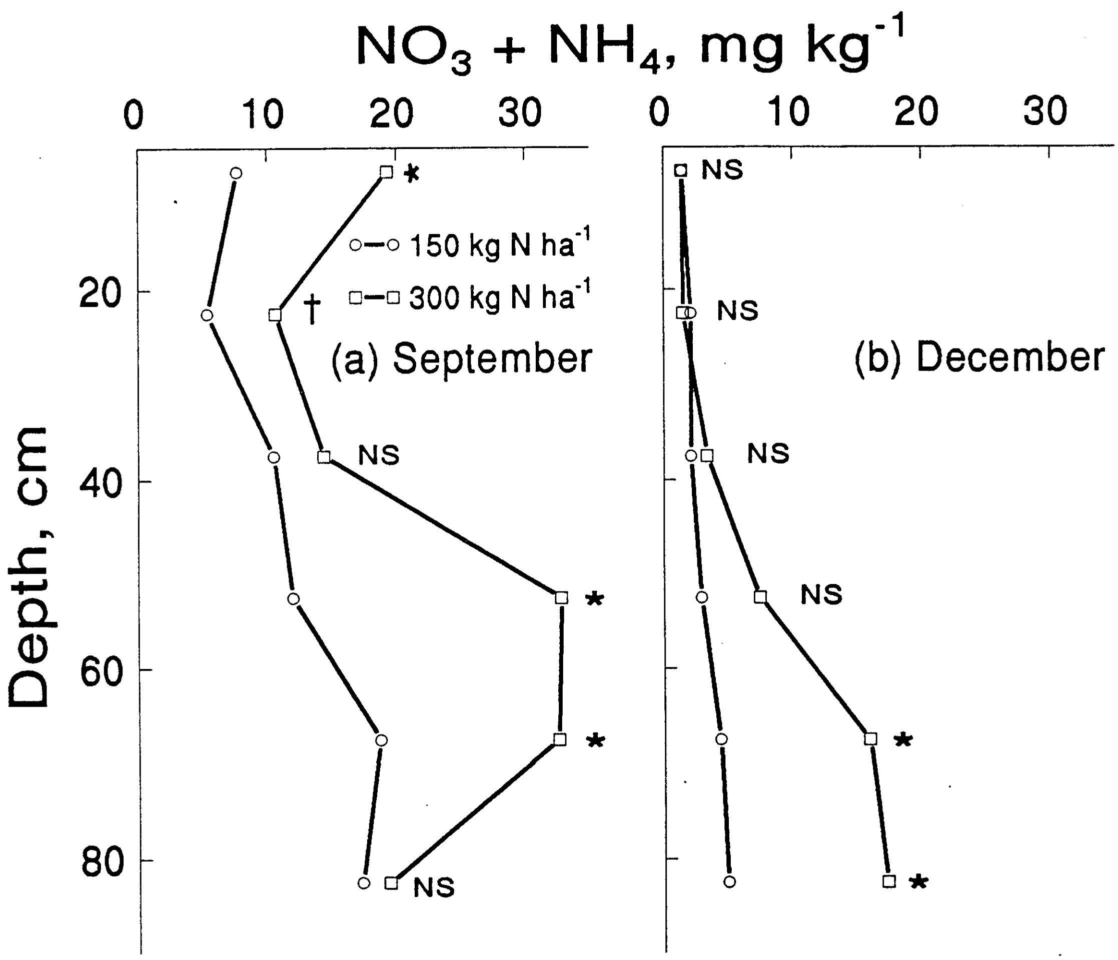

Fig. 1. Distribution of soil inorganic N in September (a) and December (b) 1992 as affected by previous corn N fertilization rate. Data points for the December sampling date represent mean values across all cover crop treatments. The symbols † and * indicate F test significant at 0.10 and 0.05 probability levels, respectively, while NS=nonsignificant.

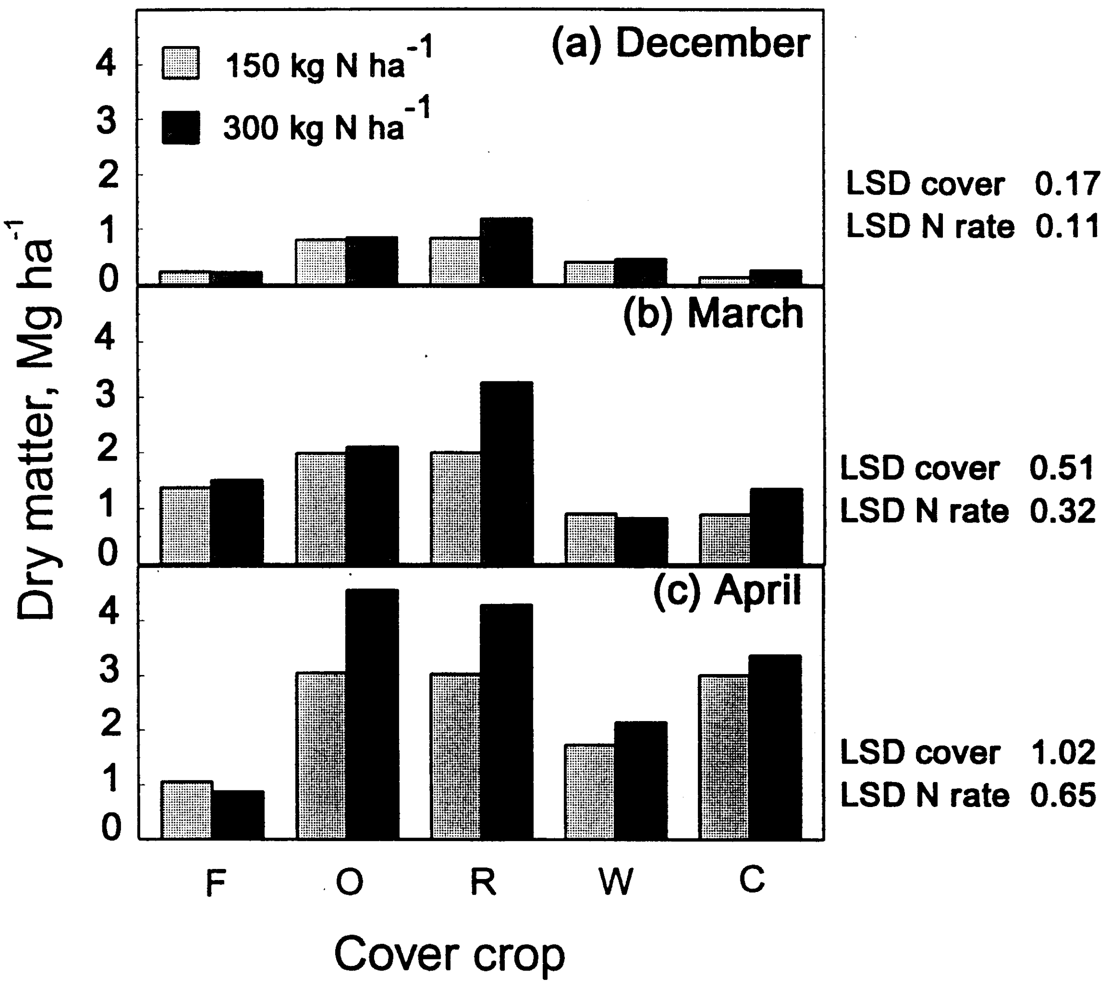

Fig. 2. Dry matter accumulation patterns by fallow (F), oat (O), rye (R), wheat (W), and crimson clover (C) cover crops following the previous corn crop fertilized with 150 or 300 kg N ha^{-1}. LSD values are significant at the 0.05 level of probability.

September to December there was a marked decline in soil inorganic N concentrations under both N rates; however, differences were still evident between N rates. Soil inorganic levels in the upper 45 cm were low (1 to 3 mg kg^{-1}) and similar between N rates. These same relatively low concentrations persisted through the remainder of the profile under the low N rate but increased below 45 cm under the high N rate. It is also of note that the center of highest inorganic N concentration (ca. 17 mg kg^{-1}) had shifted from 60 to 75 cm in September to 75 to 90 cm in December.

Cover crop DM accumulation increased appreciably from December to March as spring regrowth proceeded (Fig. 2a and b). Averaged across N rates, rye accumulated the highest DM (2.64 Mg ha^{-1}) and wheat accumulated the least (0.87 Mg ha^{-1}). Also noteworthy is the result that mean DM in the fallow treatments, which was composed of winter annual weeds, exceeded DM values for both wheat and crimson clover. With regard to prior N rate, and similar to December results, only rye showed a marked DM increase (3.27 vs 2.01 Mg ha^{-1}) when following the 300 vs 150 kg ha^{-1} N rate. Cover crop N accumulation paralleled the DM results, with mean rye N content (40 kg ha^{-1}) approximately two to three fold greater than the other cover crop treatments and rye N accumulation increasing 55% under high residual soil N (Fig. 3). Spring oat at the high residual soil N level accumulated the same amount of N as rye at the low residual N level. Nitrogen accumulation by wheat, crimson clover, and fallow treatments were similar and unaffected by prior N rate.

There were no significant differences due to cover crop in the distribution of soil inorganic N with the prior fertilizer N rate of 150 kg ha^{-1} by March 1993, consequently, data are presented for the prior 300 kg N ha^{-1} rate only (Fig. 4). A distinct pattern was evident in soil inorganic levels, with significant ($p=0.10$) treatment differences confined to the lower two soil depths and concentrations in the order of rye < spring oat < wheat, crimson clover, and fallow. Soil inorganic N concentrations under rye were generally < 1 mg kg^{-1} throughout the profile compared to a mean of 13 mg kg^{-1} under wheat, crimson clover, and fallow plots at the 75- to 90-cm depth. These results, and the concomitant N accumulation values, reflect the ability of rye to effectively utilize residual soil N.

Just prior to cover crop desiccation and corn planting in April 1993, DM accumulation by rye, spring oat, and crimson clover was similar and greater than wheat and fallow treatments (Fig. 2). These DM values were in the range commonly reported in other studies for the region. Only rye and spring oat responded to residual soil N level, increasing an average of 45% (1.37 Mg ha^{-1}) from low to high residual soil N plots. The corresponding N accumulation values, averaged over residual soil N level, were in the order of

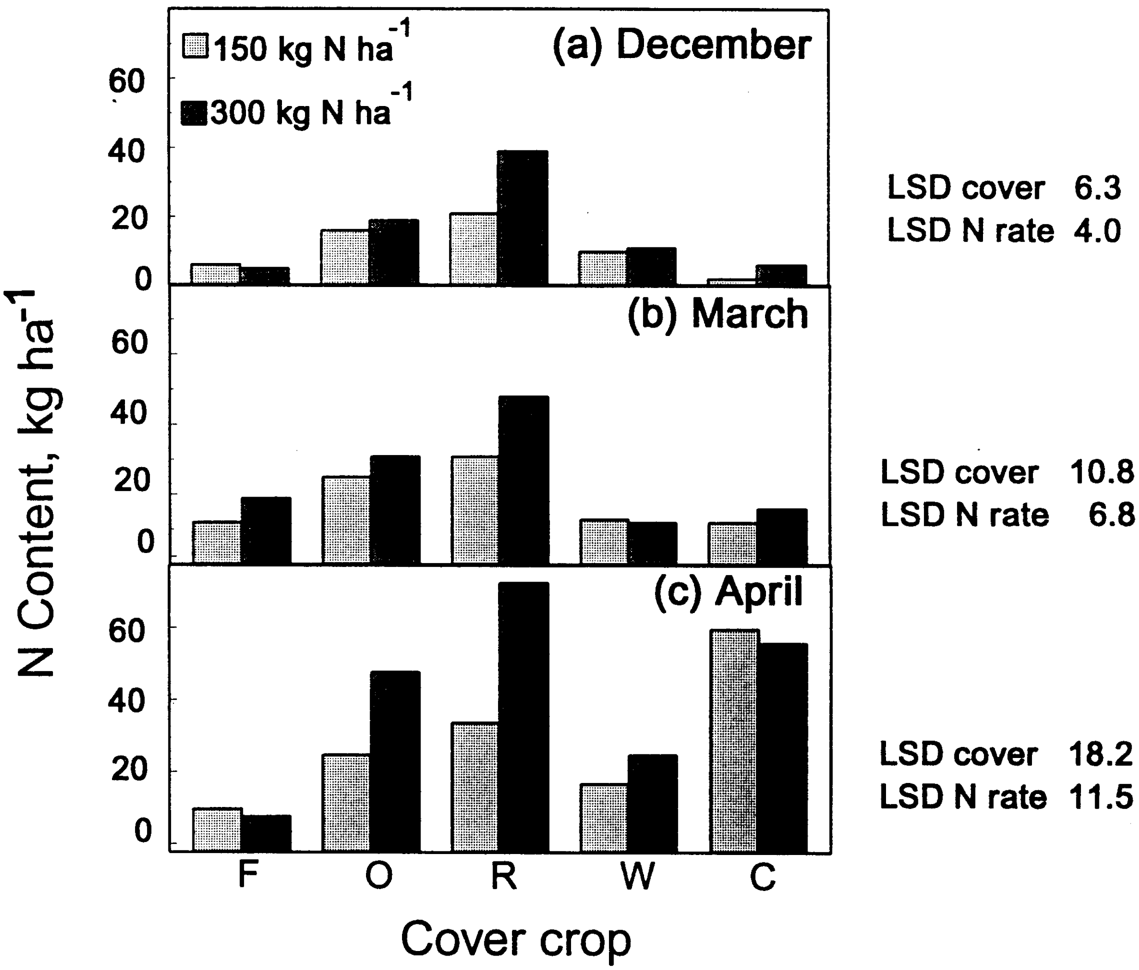

Fig. 3. Nitrogen accumulation patterns by fallow (F), oat (O), rye (R), wheat (W), and crimson clover (C) cover crops following the previous corn crop fertilized with 150 or 300 kg N ha^{-1}. LSD values are significant at the 0.05 level of probability.

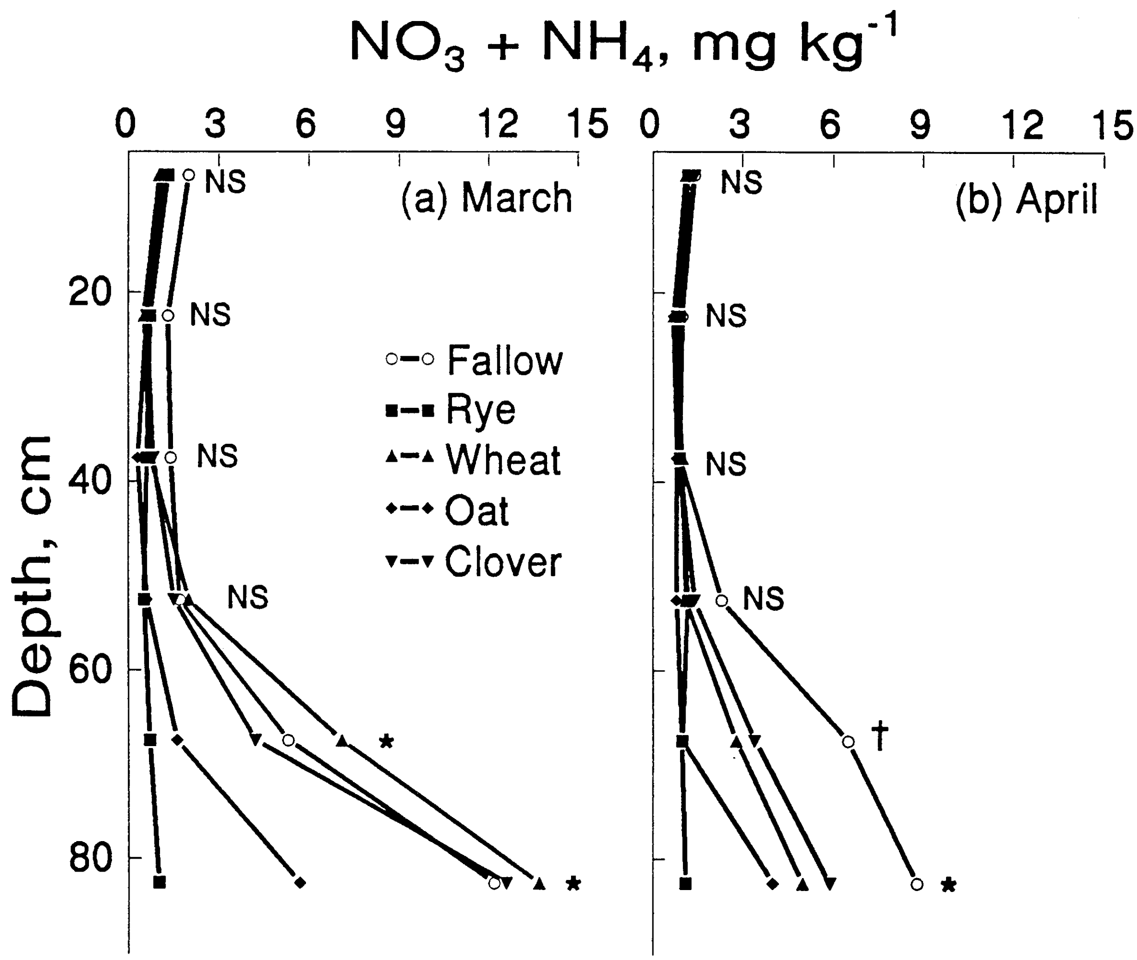

Fig. 4. Distribution of soil inorganic N in March (a) and April (b) 1993 as affected by cover crops following the previous corn crop fertilized with 300 kg N ha^{-1}. The symbols † and * indicate significant treatment differences at 0.10 and 0.05 probability levels, respectively, while NS = nonsignificant.

crimson clover = rye > oat > wheat> fallow (Fig. 3). As with earlier sampling dates, rye N accumulation increased sharply (108%) under high compared to low residual soil N levels. Spring oat also responded to residual soil N level by April, accumulating 27 kg N ha^{-1} at the low residual soil N level compared to 50 kg N ha^{-1} at the high residual N level. Only the fallow treatment, comprised of winter annual weeds whose growth had terminated by the April sampling date, reflected a net decrease in N accumulation. Associated with these relatively low N accumulation values in fallow plots were the greatest soil inorganic N concentrations, most notably in the 60- to 75- (7 mg kg^{-1}) and 75- to 90-cm (9 mg kg^{-1}) depth intervals (Fig. 4). Wheat, crimson clover, and spring oat treatments had inorganic N concentrations intermediate to fallow and rye (1 mg kg^{-1}). While this range in soil inorganic N concentrations was relatively small just prior to planting corn, NO_3 movement below the 90-cm sampling depth appears likely given the differences in cover crop N accumulation.

Cover Crop N Release Rates

Nitrogen release patterns, expressed as a percentage of the initial residue N remaining, are illustrated in Fig. 5. An exponential equation reflected the decline in residue N over time for all curves, with only marginal differences between cover crop residues. These results are somewhat surprising, as previous work has shown distinct differences between cover crop N release rates, particularly between grasses and legumes (Wilson and Hargrove, 1986; Wagger, 1989a). Residue decomposition and N release proceeded at a relatively rapid rate, such that by 4 weeks in the field the N remaining in the respective plant residues ranged from 42 to 50%. By 8 weeks, which corresponded with corn tasseling/silking and a period of high corn N demand, the percentage N remaining ranged from a low of 18% for wheat to 27% for rye. The general order of cover crop N release by 16 weeks was crimson clover > wheat = rye > oat, with a mean residue N remaining value of approximately 8%.

Inspection of the initial residue C:N ratios provides some explanation for the relatively small differences in N release rates between the residues. The N concentration or C:N ratio of plant residues has frequently been used as a tool for predicting the rate of decomposition. Oat, rye, and wheat had C:N ratios in a very narrow range of 35 to 37:1 while the C:N ratio of crimson clover was 19:1. Although the C:N ratio of crimson clover was below the theoretical value (25:1) above which net N immobilization occurs (Allison, 1966), and the grasses were above this threshold value, these differences are not overly large. Another contributing factor may have been the cover crop developmental stage at the cessation of growth. Ranells and Wagger (1992) reported that a greater proportion of crimson clover N was released from clover collected at the late vegetative stage compared to harvest dates ranging from early bloom to late seed set. Averaged over 2 years, C:N ratios increased from 14:1 to 18:1 between late vegetative and late bloom while cellulose and lignin concentrations increased an average of 48%. Of the structural carbohydrates, lignin is the most resistant to decomposition by microorganisms and its presence in cell walls can retard the degradation of cellulose (Szegi, 1988; Waksman and Hutchings, 1936).

It is important to obtain some index of N availability based on the initial residue N content. Estimates of N released from each cover crop were calculated from values generated by the decomposition curves and then multiplied by the cover crop N content at the time of desiccation for cover crops following the previous low fertilizer N rate (150 kg ha^{-1}). Using this approach, the potentially available N by 16 weeks was 59 kg N ha^{-1} for crimson clover, 32 kg N ha^{-1} for rye, 25 kg N ha^{-1} for oat, and 17 kg N ha^{-1} for wheat.

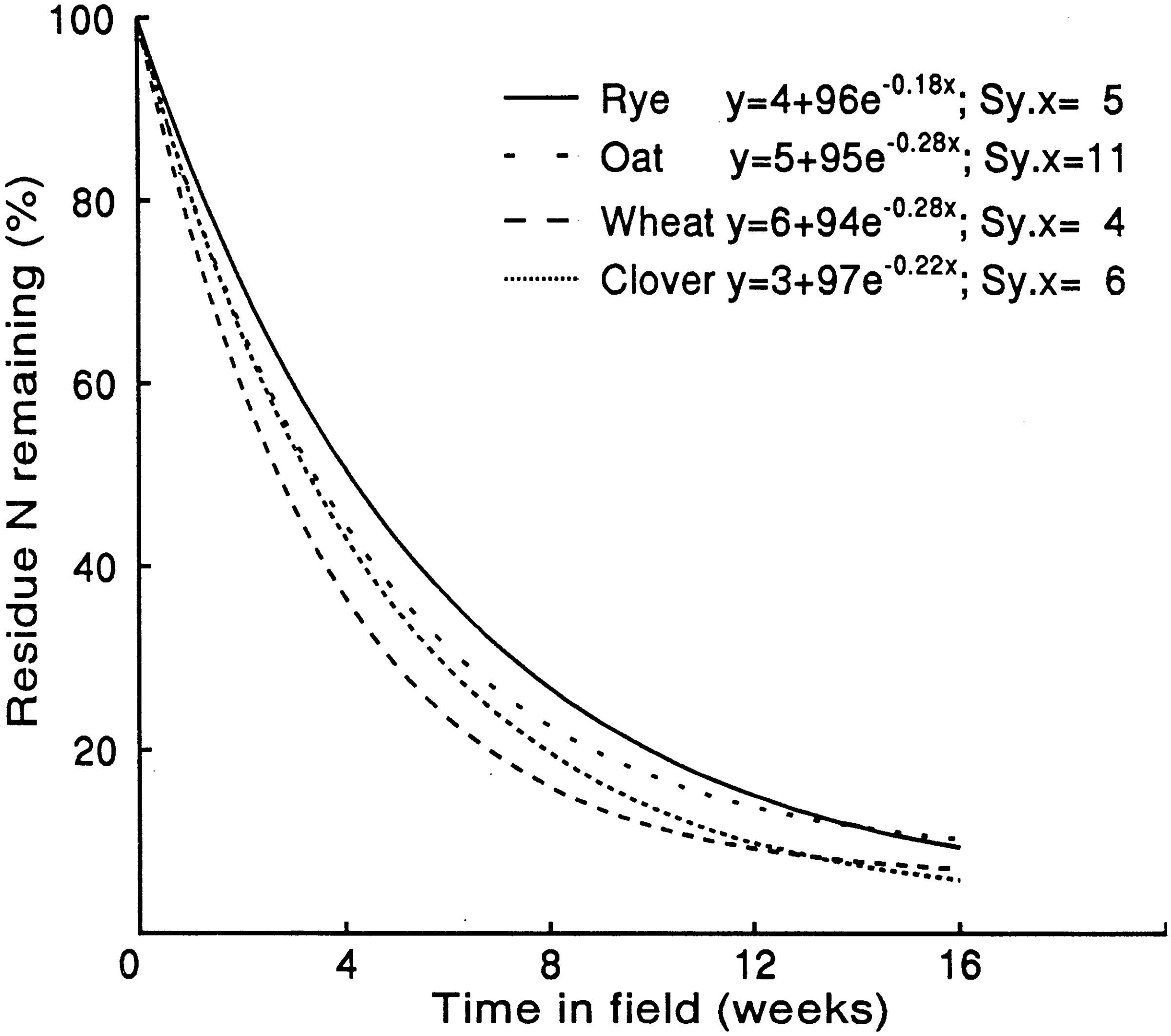

Fig. 5. Percentage of initial cover crop N remaining during the 1993 corn growing season. Sy.x represents the root mean square error.

15N-Labeled Experiment

Cover Crop Recovery of ^{15}N

Following the application of ^{15}N labeled KNO_3 to microplots planted to the respective cover crops, soil sampling was conducted to determine the residual profile NO_3 distribution. Averaged across microplots, approximately 55% of the labeled fertilizer was in the surface 15 cm of soil and 34% in the 15- to 30-cm depth (data not presented). Below 45 cm the distribution of ^{15}N was relatively uniform, including detectable enrichment in the 75- to 90-cm soil layer. The intent was to facilitate a somewhat deeper and more uniform distribution of ^{15}N in the soil profile but apparently 7.5 cm of irrigation water was not sufficient for this task. In this regard, it is also important to characterize the precipitation environment from cover crop planting to termination of growth the following spring. From October 1992 to April 1993 generally below normal precipitation prevailed (Table 1), which would moderate further downward movement of NO_3.

Estimates of fertilizer ^{15}N recovered by cover crops in December and March were based on small area samples in each microplot. By mid December 1992, < 1% of the applied ^{15}N had been recovered in each cover crop treatment (Table 2). The results were unexpected since there were substantial differences in cover crop DM estimates, ranging from approximately 0.75 Mg ha^{-1} for fallow and crimson clover treatments to 1.85 Mg ha^{-1} for rye. However, profile soil inorganic N was considerably lower under rye (16 kg N ha^{-1}) compared to crimson clover (53 kg N ha^{-1}) and fallow (71 kg N ha^{-1}). By early March 1993, estimates of cover crop ^{15}N recovery had increased considerably from December values. Winter annual weeds in fallow microplots had accumulated 10%, crimson clover 5%, and rye 20% of the fertilizer ^{15}N applied the previous fall (Table 2). The associated soil inorganic ^{15}N values in March reflected the continued ability of rye to better utilize residual soil N than crimson clover or winter annual weeds. Profile soil inorganic N in March decreased sharply from December levels, yet there was nearly a fourfold difference between rye (6 kg N ha^{-1}) and crimson clover/fallow (22 kg N ha^{-1}) treatments.

Just prior to termination of cover crop growth in April, recovery of residual ^{15}N in crimson clover and fallow treatments was unchanged from March estimates (Table 2). In contrast, rye ^{15}N recovery increased from 20 to 35%. These results are similar to those from a study conducted on the Maryland Coastal Plain, where average percent recoveries of fall N were 8% for native weed cover, 8% for crimson clover, and 45% for rye (Shipley et al., 1992). Based on the initial fertilizer ^{15}N application of 50 kg ha^{-1}, N recovery was 2.5, 5, and 17.5 kg ha^{-1} for crimson clover, fallow, and rye, respectively. As might be expected, profile soil inorganic N declined to relatively low amounts from March to April but levels were approximately threefold greater under fallow and crimson clover treatments compared to rye.

Table 1. Precipitation during the 1992-1993 cover crop growing season and departures from 30-yr averages (in parentheses).

Month	Precipitation
	cm
October	6.3 (-1.4)
November	4.0 (-3.2)
December	6.6 (-2.3)
January	14.1 (3.3)
February	4.0 (-5.5)
March	6.2 (-3.9)
April	8.5 (-0.4)

Table 2. Cover crop recovery of fertilizer ^{15}N and profile soil inorganic N content at various times during the 1992-1993 cover crop season.

Cover Crop	Cover crop ^{15}N recovery			Profile soil inorganic N		
	Dec†	Mar†	Apr	Dec	Mar	Apr
	— % of total ^{15}N —			— kg ha^{-1} —		
Fallow	< 1	10	10 a‡	71 a	22 a	15 a
Crimson clover	< 1	5	5 a	53 a	22 a	15 a
Rye	< 1	20	35 b	16 b	6 b	5 b

† ^{15}N recovery values are estimates based on small area samples within microplots

‡ Means within each date followed by the same letter are not significantly different at $p > 0.05$.

Corn Recovery of Residue ^{15}N

Total cover crop N at desiccation in April was 19, 21, and 61 kg ha^{-1} for fallow, crimson clover, and rye treatments, respectively (data not presented). These values represent the cover crop N pool potentially available to the subsequent corn crop. Poor stands in crimson clover microplots severely limited its potential N contribution to corn.

Approximately 5 wk after returning ^{15}N labeled cover crop residues to new microplots, estimates of corn recovery of residue N were < 1% for all treatments (Table 3). Corn was at the V3 to V4 developmental stage, a period when plant demand for N is relatively small compared to later stages of development. The inorganic soil ^{15}N pool, which also represents N mineralized during cover crop decomposition, indicates very distinct differences in available residue N. As a percentage of the total residue ^{15}N, about 6% of the rye N, 15% of the native weed N, and 34% of crimson clover N resided in the soil inorganic N pool. The results illustrate the relative differences in grass vs. legume C:N ratios with respect to governing residue decomposition. Three wk later (25 June), corn had recovered nearly 11% of the N in crimson clover compared to 6% in fallow and 2% in rye treatments. The amounts of residue ^{15}N in soil inorganic N pools at this date were low, such that treatment differences were generally of no agronomic consequence.

Corn recovery of residue ^{15}N by physiological maturity in early September followed a pattern similar to the mid-season sampling date (Table 2). In summing up the total residue ^{15}N available during the corn growing season, including an estimate of ^{15}N in corn roots, approximately 23% of the crimson clover N was released compared to 14% of the native weed N and 7% of the rye N. Based on the initial N content of the respective cover crops, these percentages equate to only 3, 5, and 4 kg ha^{-1} of available N from fallow, crimson clover, and rye, respectively. These N contributions would have no impact on corn yield potential.

Finally, these corn recovery values of residue ^{15}N were less than half of the estimated 80 to 90% of initial N that was released from grass and legume residues during the corn growing season in the mesh bag experiment at the same location. It should be noted that N-availability estimates using a mesh bag approach only provide information with respect to a potentially available N pool, and therefore do not afford a direct measurement of residue-N contributions to a cropping system. Nevertheless, results obtained with ^{15}N-labeled residues in this study suggest considerable overestimation of N contributions from cover crop residues based on a mesh bag technique.

Table 3. Distribution of ^{15}N recovered from cover crop residues at various times during the 1993 corn growing season.

Cover Crop	Corn ^{15}N recovery			Profile soil inorganic ^{15}N		
	6 Jun†	25 Jun†	9 Sep	6 Jun	25 Jun	9 Sep
	% of total residue ^{15}N					
Fallow	< 1	6.2	9.7(10.9)‡a§	14.7 a	4.2 a	2.8 a
Crimson clover	< 1	10.6	16.8(18.8) b	33.8 b	< 1 b	4.0 a
Rye	< 1	2.2	6.1 (6.9) a	5.7 c	< 1 b	< 1 a

† ^{15}N recovery values are estimates based on sampling 3 corn plants in each microplot.

‡ The value in parentheses represents an estimate of corn N recovery when the root ^{15}N component is included and is based on roots comprising 15% of the total plant dry weight at physiological maturity.

§ Means within each date followed by the same letter are not significantly different at $p > 0.05$.

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GLOSSARY

Abbreviations (units of measurements)

mg kg^{-1}	milligrams per kilogram
kg ha^{-1}	Kilograms per hectare
Mg ha^{-1}	megagrams per hectare