Biol Fertil Soils (2003) 38:144–153
DOI 10.1007/s00374-003-0645-y

ORIGINAL PAPER

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Recovery of fertilizer nitrogen from continuous corn soils under contrasting tillage management

Received: 4 December 2002 / Accepted: 9 May 2003 / Published online: 28 June 2003

Abstract Tillage systems influence soil properties and may influence the availability of applied and mineralized soil N. This laboratory study (20°C) compared N cycling in two soils, a Wooster (fine, loamy Typic Fragiudalf) and a Hoytville (fine, illitic Mollic Epiaqualf) under continuous corn (*Zea mays*) production since at least 1963 with no-tillage (NT), minimum (CT) and plow tillage (PT) management. Fertilizer was added at the rate of 100 mg ^{15}N kg^{-1-1} soil as 99.9% ^{15}N as NH_4Cl or $Ca(NO_3)_2$ and the soils were incubated in leaching columns for 1 week at 34 kPa before being leached periodically with 0.05 M $CaCl_2$ for 26 weeks. As expected, the majority of the $^{15}NO_3^-$ additions were removed from both soils with the first leaching. The majority of applied $^{15}NH_4^+$ additions were recovered as $^{15}NO_3^-$ by week 5, with the NT soils demonstrating faster nitrification rates compared with soils under other tillage practices. For the remaining 22 weeks, only low levels of $^{15}NO_3^-$ were leached from the soils regardless of tillage management. In the coarser textured Wooster soils (150 g clay kg^{-1}), mineralization of native soil N in the fertilized soils was related to the total N content ($r^2 \geq 0.99$) and amino acid N ($r^2 \geq 0.99$), but N mineralization in the finer textured Hoytville (400 g clay kg^{-1}) was constant across tillage treatments and not significantly related to soil total N or amino acid N content. The release of native soil N was enhanced by NH_4^+ or NO_3^- addition compared to the values released by the unfertilized control and exceeded possible pool substitution. The results question the use of incubation N mineralization tests conducted with unfertilized soils as a means for predicting soil N availability for crop N needs.

Keywords Added N interaction · N immobilization · N mineralization · Tillage systems

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Introduction

Research has shown that the rate of N mineralization for crop use is affected by many soil properties including physical, biochemical, chemical and microbiological features (Campbell and Paul 1978; Carter and Rennie 1982; Varvel 1994; Omay et al. 1997). Several specific soil factors such as temperature, moisture and pH have been identified as affecting soil N mineralization in literature discussions of interactions of N fertilizers and N availability. Soil texture has also been found to affect soil N mineralization as soils with higher clay levels resulted in lower N mineralization rates (Pare and Gregorich 1999) due to physical protection by clay layers (Verberne et al. 1990). The quality of crop residues (C/N ratio) added or remaining in the soil can stimulate or decrease N availability depending on whether the crop residue results in immobilization of available N or mineralization of native soil N (Westerman and Kurtz 1973; Woods et al. 1987; Pare and Gregorich 1999).

Tillage is clearly an important regulator or driving variable for element cycling, especially N, in agrosystems through influences on soil properties (Buchanan and King 1993). Long-term no-tillage (NT) management results in physical soil properties that are generally different from comparison plow tillage (PT; Dick et al. 1991; Choudhary et al. 1997). No-tillage also has a large impact on the biological properties influencing the timing and amount of N cycling (Dick 1984; Martens 2001). On a national basis, no-tillage practices have increased surface (0–15 cm) soil organic matter content with the increase dependent on previous soil management, cropping sequences and fertility levels (Lal et al. 1997; Martens 2001). Nutrient release from soil organic matter (SOM) in agrosystems occurs through complex, biologically mediated processes, but tillage can increase the nutrient transfer due to increased organic mineralization following tillage-induced soil aeration and aggregate degradation (House et al. 1984).

Soil microbial biomass levels and activity are considered to be the transformation agent of SOM and a

reservoir of plant nutrients, especially N (Jenkinson and Ladd 1981). Soil microbial activity can initially increase following tillage due to release of soil nutrients, but long-term tillage management has been found to decrease microbial activity (Martens 2001). In contrast, NT management can increase microbial biomass by decreasing soil disturbance and by increasing soil C content, plus NT provides better regulation of soil moisture due to residue mulching (Franzluebbers et al. 1994). Tillage also profoundly affects the immobilization-mineralization processes and net N availability due to differences between residue placement on the soil surface in NT or incorporation by tillage (Martens 2001). Although in the first few years of conversion from tillage to NT management, immobilization processes can reduce soluble N concentrations, long-term NT has been found to increase N cycling due to a larger pool of organic N (Black 1973; Rice et al. 1986) and an increase in the active organic N pools (McCarty et al. 1998). Research has shown that soils with different crop residue additions and different soil texture have different N mineralization rates, but little data has been presented to evaluate the interaction of contrasting tillage management and form of N fertilizer interactions on total seasonal N availability.

In addition, a mechanism described as the priming effect or the added N interaction (ANI) has been found to increase microbial activity with addition of microbial nutrients (N) or C sources to the soil (Hart et al. 1986; Woods et al. 1987; Azam et al. 1994; De Nobili et al. 2001). Woods et al. (1987) provided conclusive evidence that N fertilizers can increase microbial activities, but not necessarily microbial numbers, especially in soil where low mineral N concentrations limit microbial activity. The noted trend for reduced mineral N concentrations in NT suggests that ANI due to increased net N mineralization as described by Jenkinson et al. (1985) could potentially be different under different tillage management.

Thus long-term tillage management is an unexplored variable in the complicated process of fertilizer and native soil N availability. The objectives of the experiment presented here were to determine the interaction of increased soil organic C content resulting from continuous application of different tillage management systems [i.e., NT, chisel tillage (CT), and PT] on (1) available N from fertilizer and native soil N, (2) the subsequent mineralization of immobilized fertilizer N and (3) mineralization of native soil N in two soil types (i.e., silt loam and clay loam soils) under continuous corn production.

Materials and methods

Soils

Two soils from the long-term tillage trials at Wooster and Hoytville (Ohio, United States), started by van Doren et al. (1976), have been cultivated to continuous corn with PT (plow followed by additional tillage), chisel (CT, one seasonal pass) and NT since 1962 and 1963, respectively. The soils were sampled in June and July 1998 from the 0- to 5-cm depth of the profile and the field moist soils passed through a 2-mm screen to remove large pieces of plant residue and stored at 4°C until use. Moisture content of the soil at experiment start, pH (1:2.5 soil/0.01 M $CaCl_2$), organic C and total N by dry combustion and amino acid composition and N content by the method of Martens and Frankenberger (1992) were determined.

Experimental procedure

In 50-ml conical centrifuge tubes (3.5×14 cm) with a hole placed in the bottom, 20 g (dry weight basis) field moist soil were packed between plugs of glass wool at the respective bulk density (Table 1) measured at sampling. The replicate samples were treated with deionized water (controls) or deionized water containing 2 mg ^{15}N (99.9%) as NH_4Cl or $Ca(NO_3)_2$ to reach −34 kPa moisture potential and incubated at 20°C for 1 week. At intervals (week 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 22, 23, 26) during the 26-week study, the samples were removed from the incubator and leached with 25 ml 0.05 M $CaCl_2$. At completion of the leaching, the samples were placed back into the incubator. The leached solution was collected in weighed 50-ml beaker and evaporated at 40°C on a hot plate until dry. The leachates were quickly cooled in a desiccator, weighed and a small amount of water was used to transfer the sample to a weighed sterilized Nalgene polypropylene 1.2-ml vial. The leachate was dried in an oven set at 60°C overnight, the dry weight recorded for determination of total N content and atom %^{15}N values and the sample stored at −20°C.

Chemical analysis

Total leached N and C and atom %^{15}N of the leachate were determined by adding a small amount of deionized water to the sample vial and a micropipette was used to dispense an aliquot to a tin capsule. The capsule was weighed, dried and prepared for analysis by direct combustion isotope ratio mass spectrometry

Table 1 Properties of the Wooster and Hoytville soils (0–5 cm)[a]

Soil	Classification	pH	Organic C g kg^{-1}	Total N	Amino acid-N	Bulk density g cc^{-3}	Moisture g kg^{-1}	Sand	Clay
Wooster SL	Typic Fragiudalf							250	150
No-tillage		6.03	28.0 A[b]	2.30 A	1.31 A	1.12 A	214 A		
Chisel		5.63	14.6 B	1.12 B	0.97 B	1.19 A	163 B		
Plow		6.13	9.98 C	0.81 B	0.56 C	1.25 A	134 B		
Hoytville SCL	Mollic Epiagualf							210	400
No-tillage		6.76	40.9 A	3.72 A	2.26 A	1.38 A	199 A		
Chisel		7.05	23.2 B	2.11 B	0.98 B	1.34 A	135 B		
Plow		6.17	19.3 B	1.85 B	0.70 B	1.32 A	135 B		

[a] See Materials and methods for a description of analyses (*SL* silty loam, *SCL* silty clay loam)
[b] *Letter following the column value* indicates significant mean differences at P >0.05

using a Europa Scientific Integra 20/20 isotope ratio mass spectrophotometer (Europa Scientific, Crewe, England).

Calculations

The calculations for recovery of ^{15}N-labeled fertilizer in the leachate and remaining in soil at the end of week 26 are given by the ratio of atom $\%^{15}N$ in the soil pool to the atom $\%^{15}N$ in the fertilizer (Hauck and Bremner 1976). The recovery of fertilizer (RF) was calculated by the isotope method where:

$$RF = TNleached(A_f - A_{uf})/F(A_u - Au_f)$$

where TN is the total N leached or immobilized (mg tube^{-1}); F is the ^{15}N fertilizer rate (2.0 mg tube^{-1}); and A_u, A_{uf} and A_f are the atom $\%^{15}N$ excess of fertilizer N, atom $\%^{15}N$ excess of the control (no ^{15}N added), and atom $\%^{15}N$ excess of fertilized soil, respectively.

The data were statistically analyzed using the General Linear Model (GLM) procedure of SAS (SAS 1990), and the means were separated by the least significant difference (LSD) at $P \leq 0.05$.

Results and discussion

The soils were chosen because of the documented history of continuous corn production for more than 35 years that has resulted in a range of soil properties with the only variable being different tillage management (van Doren et al. 1976; Dick 1983; Dick et al. 1991). Use of the continuous corn soils also eliminated from the experiment the effect of different crop residues on the potential mineralizable N pool (Deng and Tabatabai 2000). The leaching procedure was adopted on the assumption that the amount of residual $CaCl_2$ in the extracted soil had no significant effect on the mineralization of soil organic N during the subsequent incubation. Westerman and Tucker (1974) found no significant change in the release of NH_4^+ during a 49-day incubation of soils treated with equivalent levels of $CaCl_2$. Table 1 shows that the contrasting tillage managements with continuous corn production significantly influenced the soil organic C content, total N content, amino acid N content and moisture content in the 0- to 5-cm depth, especially when the NT practice was compared with the PT and CT management.

The first question of this study was: "would the difference in organic C content because of long-term tillage management, especially in the NT soils, change the availability of fertilizer applied N?" Research has noted that crop N deficiencies may occur in systems converted to NT due to several mechanisms such as lower net mineralization and nitrification and greater N immobilization that may limit fertilizer and soil N availability (Doran 1980a, 1980b). The cumulative recovery of added ^{15}N fertilizer from the Wooster and Hoytville soils ranged from 62% for NH_4^+ to almost 90% for the NO_3^- addition (Fig. 1). The average recovery (leached + remaining) following the 26-week experiment was not significantly different for the two soils tested (Table 2). The results shown in Fig. 1 and Table 2 suggest that different long-

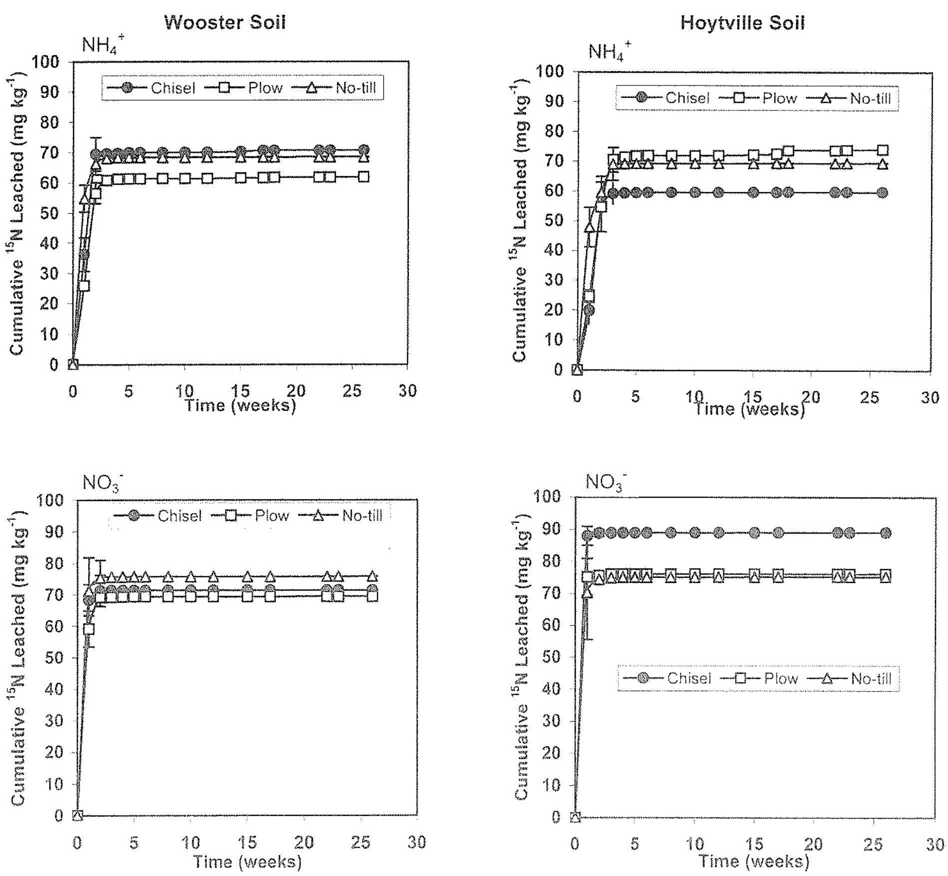

Fig. 1 Cumulative ^{15}N leached from $^{15}NH_4^+$ and $^{15}NO_3^-$ addition to the Wooster and Hoytville soils from different long-term tillage management systems

Table 2 Amount of ^{15}N labeled fertilizer (mean ± standard deviation) in the Wooster and Hoytville soil incubated for 26 weeks (*NT* no tillage, *CT* minimum tillage, *PT* plow tillage)[a]

Soil	N form	Recovered as leachate	Recovered in soil	Not recovered
		mg kg^{-1}		
Wooster				
NT	NH_4^+	69.8±2.2	6.72±0.4	23.8
NT	NO_3^-	76.0±1.3	0.41±0.2	23.5
CT	NH_4^+	70.8±4.2	6.04±0.3	23.4
CT	NO_3^-	71.0±1.5	0.76±0.6	27.9
PT	NH_4^+	62.0±2.0	5.23±0.5	32.5
PT	NO_3^-	69.9±1.3	0.88±0.6	29.7
Wooster mean		68.9±4.5 A	3.32±3.0 A	26.8±3.8 A
Hoytville				
NT	NH_4^+	69.9±1.3	10.3±1.0	19.1
NT	NO_3^-	75.2±0.8	0.82±0.6	23.5
CT	NH_4^+	61.9±2.4	10.2±1.3	27.0
CT	NO_3^-	89.0±0.5	0.00	11.0
PT	NH_4^+	71.5±1.3	8.01±0.4	20.1
PT	NO_3^-	76.1±0.8	0.37±0.1	23.6
Hoytville mean		73.9±8.9 A	4.96±5.1 A	20.7±5.5 C
Mean	NH_4^+	67.7±4.5 A	8.04±2.5 B	24.3±4.9 B
Mean	NO_3^-	76.2±6.8 B	0.66±0.5 C	23.2±6.5 B
Tillage mean	NT	72.7±3.3 A	4.55±4.8 A	22.5±2.3 B
	CT	73.2±11 A	4.23±4.8 A	22.3±7.8 B
	PT	69.8±5.9 A	3.65±3.6 A	26.5±5.6 A

[a] *Letter following the value* indicates significant mean differences at$P$ >0.05

term tillage management had little influence on total recovery of fertilizer N during a growing season as measured in this experiment. The data in Fig. 1 also shows that the nitrification of fertilizer $^{15}NH_4^+$ in the PT and CT managed soils required at least 4 weeks while nitrification in the NT soil was nearly complete after 2 weeks because of potentially higher soil nitrifying populations found in soils under NT management (Rice and Smith 1983). The soils and tillage practices showed similar nonrecovered N percentages with 24.3±4.9% not recovered for NH_4^+ and 23.2±6.5% not recovered for NO_3^- additions. Denitrification may be the loss mechanism for the N not recovered because of the periodic leaching that resulted in low soil moisture tensions.

A second question was: "would the differences in organic C content due to tillage management impact fertilizer ^{15}N immobilized and subsequent release of immobilized ^{15}N?" Research has noted that early season immobilization of fertilizer N can be a major sink for fertilizer and mineralized N, especially in NT systems (Martens 2001). Table 2 reports the ^{15}N balance for the soils at the end of the 26-week experiment and shows little or no immobilization of $^{15}NO_3^-$. However, from 8% to 10% of the $^{15}NH_4^+$ additions were recovered in the soil fraction in the finer textured Hoytville soil even after 26 weeks of periodic leaching. The very low amount of NO_3^- immobilized may be due to the role of NH_4^+ in the NO_3^- immobilization process. Rice and Teidje (1989) reported that low levels (0.1 μg NH_4^+-N g^{-1} soil) of NH_4^+ inhibited microbial NO_3^- assimilation in soils and pure culture studies. The inhibitory properties of NH_4^+ on NO_3^- was confirmed by Recous et al. (1992) who found that microorganisms preferentially assimilated NH_4^+ three to four times faster than NO_3^- during the first 4 weeks after N application. Due to the higher levels of C present in the NT soils, a greater percentage of the NH_4^+-N additions had been expected to be immobilized by the NT soils compared with the contrasting PT management, but the differences measured here were not statistically different for the different tillage managements after 26 weeks (Table 2).

The data in Fig. 1 also show that little fertilizer $^{15}NH_4^+$ was released with continued incubation of the soils following the first weeks of the experiment, suggesting ^{15}N that remained in the soils was in a form not easily leached during the study. Broadbent (1986) found that microbial immobilized N was present as amino acid N, which was resistant to rapid biological mineralization. Kelley and Stevenson (1995) also reported that seasonally immobilized fertilizer N was no more available to microorganisms and plants than native humus N. The limited availability of microbially immobilized N is in contrast to N availability if the N was nonbiologically immobilized as NH_4^+ fixed to soil clays or organic matter. Green et al. (1994) found that nonbiologically fixed $^{15}NH_4^+$ was rapidly released and nitrified when anaerobic conditions used to support fixation were changed to aerobic conditions that favored nitrification.

A third question of this study was: "would the difference in organic C content because of long-term tillage management, especially in the NT soils, change the availability of native soil N?" Long-term NT has been shown to cycle more N in soils due to a larger supply of organic N (Black 1973; Rice et al. 1986; Maskina et al. 1993) and an increase in the active organic N pools (McCarty et al. 1998). To evaluate the contribution of the fertilizer and the mineralized native soil N to the total N pool, the $^{15}N/^{14}N$ ratio and the $^{14}N/^{15}N$ ratio of the leached N were calculated for the $^{15}NH_4^+$ additions to the two soils and are shown in Fig. 2. The PT treatment

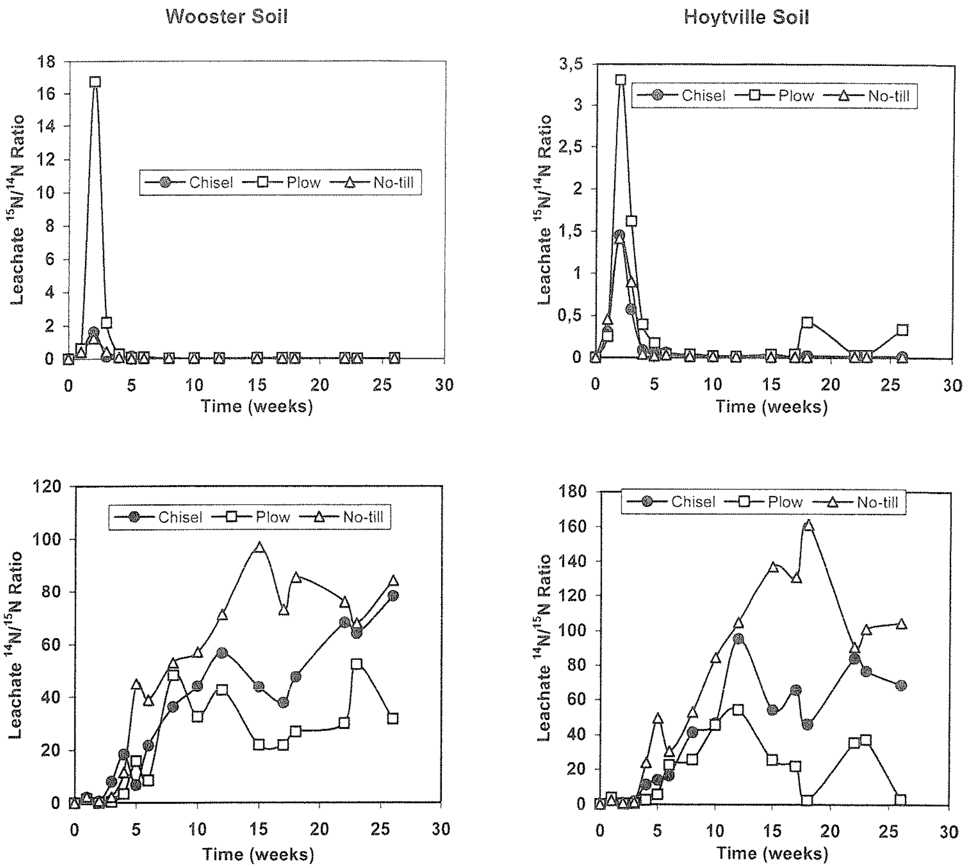

Fig. 2 Leached $^{15}N/^{14}N$ and leached $^{14}N/^{15}N$ ratios in the $^{15}NH_4^+$ treated Wooster or Hoytville soils from different tillage management systems

resulted in a greater $^{15}N/^{14}N$ ratio in the Wooster and Hoytville soils (more than 16 and 3, respectively) compared with the NT and CT treatment (1.5, respectively) during the first three leachings (Fig. 2), although the $^{15}NH_4^+$ availability (measured as $^{15}NO_3^-$ leached) was similar for each soil and tillage management system (i.e., 5 weeks). The results suggest that fertilizer additions to intensively tilled soils as compared with less tillage (i.e., CT and NT) would result in a greater relative contribution of the fertilizer N to early plant nutrition as compared with soil N contributions. The $^{15}NO_3^-$ availability for the different management practices was even shorter and in the second week of leaching the $^{15}N/^{14}N$ ratio fell to near zero (data not presented). The NT and CT treatments for the Wooster and Hoytville soils resulted in a maximum $^{15}N/^{14}N$ ratio of about 1.5 at week 2. The lower $^{15}N/^{14}N$ values for NT and CT treatments may result from increased N mineralized in the NT and CT soils because of increased total N cycling (McCarty et al. 1998).

The contribution of soil N mineralization to the total soil N pool (native + fertilizer N) can also be measured by evaluating the $^{14}N/^{15}N$ ratios, which show that after the first 4 weeks, the proportion of N from the soil pool increased for all soil treatments and especially for the NT soils (Fig. 2). The variations in the $^{14}N/^{15}N$ ratios after week 6 reported in Fig. 2 were the result of the division of two small numbers and slight changes in either of the numbers resulted in large changes in the ratio. The average $^{14}N/^{15}N$ ratios calculated for the 26-week Wooster and Hoytville NT, CT and PT incubations were 51.1 (W) vs 71.7 (H), 35.6 (W) vs 41.7 (H) and 22.5 (W) vs 19.5 (H), respectively, suggesting that (a) the contribution from the fertilizer N to the leached N pool was limited after the first month of the experiment regardless of soil type or tillage management system (Fig. 2) and (b) greater N mineralization was occurring in the NT system compared to the CT and PT (Fig. 2).

Nitrate addition appeared to have stimulated a greater release of N from native pools during the first few weeks as compared to NH_4^+ additions. The greater N release by NO_3^- additions was evident even in the Wooster PT soil that had the lowest total N content of the soils tested. The stimulation of soil organic matter mineralization by NO_3^- additions noted in the soils tested may be due to the reported preference of soil microorganisms for NH_4^+ over NO_3^- (Jackson et al. 1989; Rice and Tiedje 1989; Recous et al. 1992). Thus, an extremely low NH_4^+ concentration in the presence of a large NO_3^- concentration may promote mineralization of organic matter to obtain the energy to utilize the NO_3^- additions.

Schepers and Moiser (1991) stated that a general estimate of N mineralization could be based on soil organic matter content by assuming 2% of the total organic N mineralized annually. In this study, an average 5.5±1.5% of native total N content was leached from the Wooster treatments after 26 weeks compared with

Table 3 Cumulative leached C (as DOC) and N (as NO_3^-) and mean percentage of organic C and total N leached from Wooster and Hoytville soil incubated for 26 weeks[a]

Soil	N form	Leached C	Leached N
		mg kg^{-1}	
Wooster			
NT	NH_4^+	183 (0.7)	91.2 (4.0)
NT	NO_3^-	190 (0.7)	121 (5.3)
CT	NH_4^+	185 (1.3)	75.6 (6.8)
CT	NO_3^-	210 (1.4)	79.1 (7.1)
PT	NH_4^+	140 (1.4)	29.3 (3.6)
PT	NO_3^-	95.2 (1.0)	47.2 (5.9)
Hoytville			
NT	NH_4^+	358 (1.0)	43.4 (1.2)
NT	NO_3^-	456 (1.3)	64.5 (1.7)
CT	NH_4^+	245 (1.1)	9.58 (0.5)
CT	NO_3^-	252 (1.1)	58.3 (2.8)
PT	NH_4^+	171 (0.9)	55.2 (2.9)
PT	NO_3^-	155 (0.8)	75.3 (4.1)
Mean percentage	NH_4^+	1.07%±0.26 A	3.10%+2.26 A
	NO_3^-	1.05%±0.27 A	4.48%±2.01 A

[a] *Values in parentheses* indicate the percentage of total organic C and total N content leached from the different treatments. The cumulative values were obtained from the summation of total C and N content leached at each of the leaching times

2.2±1.2% of the native total N content leached from the Hoytville soil, with an average of 3.9% for the two soils (Table 3). In addition, the analysis found that the percentage of mineralized organic C leached from each soil treatment was similar and averaged 1.0% (0.7–1.4%) of the organic C content present at the beginning of the study (Table 3). Leached C/native N ratios were very low (<0.2) for the first 6 weeks before returning to values of 10–15 for the remaining 20 weeks (data not presented). The measured C/N ratios of 10–15 for the leached C and N are in the range of soil organic matter C/N ratios that have been noted in the literature. The low values for the leached C/native N ratios during the first 6 weeks may be due to the enhanced microbial activity measured by extra C mineralized as noted for soils exposed to microbial molecular signals such as free glucose and amino acids (De Nobili et al. 2001). The results suggest that N additions to the soils tested enhanced organic matter mineralization early in the incubation similar to that reported by Woods et al. (1987). Woods et al. (1987) provided conclusive evidence that N fertilizers can increase microbial activities especially in soil where low mineral N concentrations limit microbial activity, which would result in a real added N interaction (ANI) due to increased net N mineralization (Jenkinson et al. 1985).

The use of labeled ^{15}N fertilizer is a powerful tool to determine the impacts of fertilizer additions on the native soil N cycle. Previous research has suggested that fertilizer additions can stimulate soil microorganisms and result in increased mineralization of soil organic matter N (Woods et al. 1987; Azam et al. 1994). Azam et al. (1994) reported that inorganic N additions as $(^{15}NH_4)_2SO_4$ applied to six Illinois soils increased the availability of soil N during a 14-day experiment and concluded that the measured ANI was real (exceeded potential pool substitution). To determine if the N leached in this experiment resulted from an apparent ANI (pool substitution with soil available N) or real ANI (increased net soil organic N mineralization), ANI was calculated from the total N leached (addition of values in Figs. 1 and 3) by the equation $[((^{14}N\ \text{recovered}_{ti} - {}^{14}N\ \text{initially present}_{to}) + {}^{15}N\ \text{recovered}_{ti}) - {}^{15}N\ \text{added}_{to}]$ where $_{ti}$ and $_{to}$ are the time of the weekly leaching and time 0, respectively. The equation calculates the ANI on the assumption that all of the ^{15}N initially was present in the same pool of soil available N. The addition of NH_4^+ to both the Wooster and Hoytville soils resulted in negative N release for five of the six treatments (apparent ANI) during the first week of the experiment (Table 4). Ledgard et al. (1998) reported gross soil N mineralization rates could be as much as 3 to 12 times greater than net soil N mineralization rates and low net mineralization could provide an explanation for the low rates of N leached

Table 4 Cumulative total native soil N leached for various times from the Wooster and Hoytville soils incubated for 26 weeks[a]

Soil	N form	Weeks							
		1	2	3	6	8	10	17	26
		mg kg^{-1}							
Wooster NT	NH_4^+	121.4	167.9	181.0	193.9	195.3	197.1	203.4	211.1
Wooster NT	NO_3^-	208.0	249.3	263.1	279.9	282.6	285.3	292.0	300.3
Wooster CT	NH_4^+	−20.23	100.4	103.6	115.3	116.9	119.8	151.0	161.3
Wooster CT	NO_3^-	117.3	145.9	149.0	155.2	157.1	159.7	170.0	175.6
Wooster PT	NH_4^+	−104.3	−31.33	−17.32	−10.04	−8.423	−6.736	8.139	19.16
Wooster PT	NO_3^-	0.1157	45.85	49.21	60.66	60.89	61.00	67.92	72.64
Hoytville NT	NH_4^+	−8.400	28.69	66.52	79.09	81.01	87.45	100.5	114.5
Hoytville NT	NO_3^-	72.27	100.8	112.7	125.6	128.3	137.8	156.5	167.3
Hoytville CT	NH_4^+	−143.1	−33.92	−9.980	0.158	2.477	4.600	12.23	26.70
Hoytville CT	NO_3^-	125.2	138.02	141.5	149.6	151.9	154.5	171.07	184.1
Hoytville PT	NH_4^+	−54.61	18.32	66.52	82.67	84.46	86.30	114.00	133.1
Hoytville PT	NO_3^-	124.7	131.7	148.3	155.9	157.4	161.3	168.2	180.2

[a] Cumulative total native N leached was calculated as $[((^{14}N\ \text{recovered}_{ti} - {}^{14}N\ \text{initially present}_{to}) + {}^{15}N\ \text{recovered}_{ti}) - {}^{15}N\ \text{added}_{to}]$ where $_{ti}$ and $_{to}$ are the time of the weekly leaching and time 0, respectively

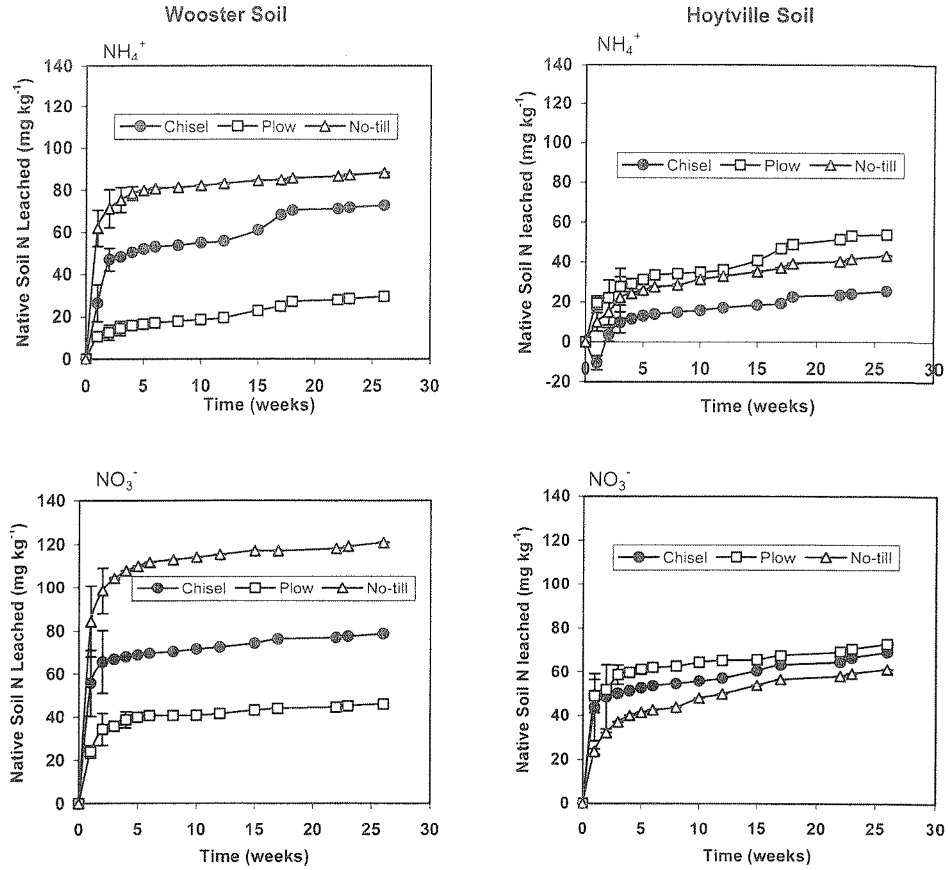

Fig. 3 Cumulative mineralized native N leached from $^{15}NH_4^+$ or $^{15}NO_3^-$ treated Wooster or Hoytville soils from different tillage management systems. Values presented were determined by first subtracting the initial mineral N values (i.e., mineral N at time zero)

from the NH_4^+ additions during the early portion of the experiment. In contrast, addition of NO_3^- to the soil treatments resulted in immediate positive values for N release (real ANI) from all treatments (Table 4). The results suggested that the N additions resulted in real ANI and were especially pronounced with the NO_3^- additions to the Hoytville and Wooster soils.

In general, the impact of fertilizer N on soil N pools was noted to last about 2 weeks for NO_3^- addition and 5 weeks for NH_4^+ additions (Fig. 2). The majority of the native soil N mineralized from the treatments during the 26-week experiment was released within the first 5 weeks of incubation, which was also the period of time for $^{15}NH_4^+$ and $^{15}NO_3^-$ availability in the soils (Figs. 1, 2). Under the test conditions, $^{15}NO_3^-$ additions to soils resulted in higher levels of native N mineralized in the soils compared with $^{15}NH_4^+$ additions regardless of tillage management (Fig. 3). The data show that the release of soil N was much greater while fertilizer N was present in the soils tested (Fig. 1; Table 4). In this study, by week 2, an average of 78±9.7% of the total soil N leached from the NO_3^- treatments for the 26-week study was recovered in the leachate (Table 4). It was not until week 6 that the recovery of native soil N from the NH_4^+ additions was comparable (73.8±12.9%). At the point where the recovery of the leached ^{15}N additions from NO_3^- (week 2) and NH_4^+ (week 6) became negligible, the mineralization of soil N from the treatments also decreased dramatically. The data suggest that the proportion of the total available N pool from soil N mineralization can be altered by additions of fertilizer N.

If additions of fertilizer N alters the soil N mineralization rates, this suggests that incubation methodology to determine N mineralization in soils receiving no N may not result in an accurate prediction of N recommendation. Properly used, the value of an incubation N mineralization test to determine the amounts of N a soil could release will provide a tool to predict the additional amount of fertilizer-N required to produce a desired crop yield (Bremner 1965). The potential stimulation of the soil microbial process by N fertilizers (i.e., the ANI effect) skews the mineralization test results and will result in a low prediction of mineral N release for incubation studies where N is not added as a part of the treatment. Indeed, significant relationships between the developed N index and plant N uptake from non-N fertilized controls have been reported with most tests (Keeney 1982), but the predicted N index generally has not been an accurate index of N availability in studies outside of controlled greenhouse experiments (Cabrera and Kissel 1988).

Increased pools of available soil N due to management have been found to increase N cycling (Black 1973; Rice et al. 1986; McCarty et al. 1998). Approximately 95–98% of the soil total N content is an organic form with predominance of amino acid- and amino sugar-N (Stevenson 1986). Nitrogen additions to the Wooster

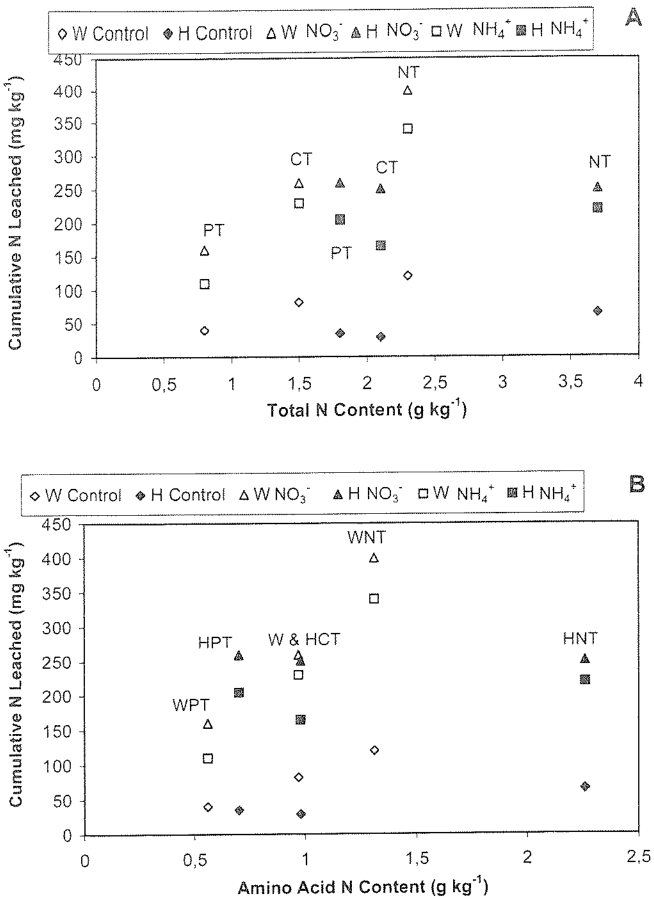

Fig. 4 Relationship between **A** total N content and mineralized native N leached from NH_4^+ and NO_3^- treated Wooster (*W*) or Hoytville (*H*) soils and **B** total amino acid-N content and mineralized native N leached from NH_4^+ and NO_3^- treated W or H soils with different tillage management systems (i.e., NT, CT, or PT). The control values are the incubated W and H soils receiving no N fertilizer addition

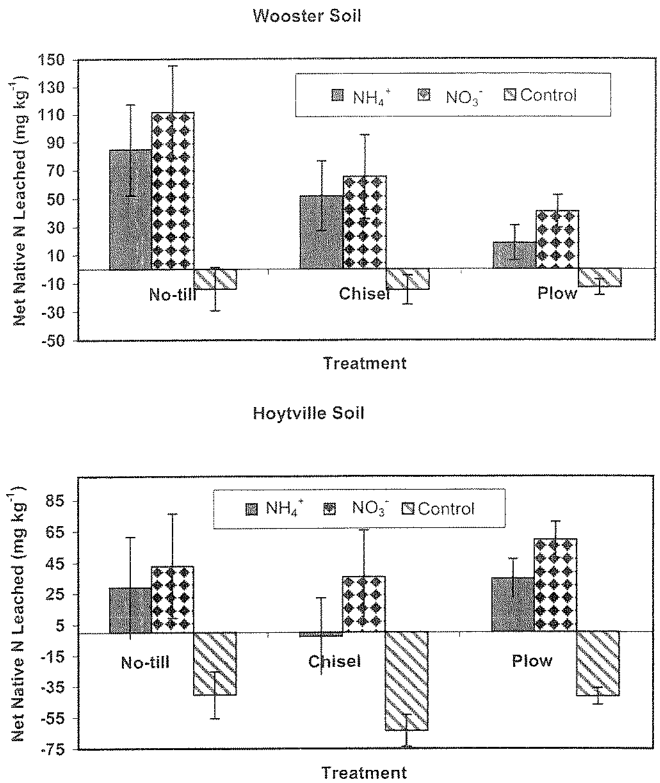

Fig. 5 Net mineralized native N leached during the first 42 days from soils receiving no N addition (control) or treated with NH_4^+ or NO_3^- additions for Wooster and Hoytville tillage treatments

soils (Fig. 3) resulted in significant soil N mineralization differences between the tillage practices that were directly related to the soil total N content (r^2 =0.99; Fig. 4a) supporting the findings of Schepers and Moiser (1991). The data also show that Wooster N mineralization was proportional to the soil amino acid content (Fig. 4b). However, the mineralized soil N differences between Wooster tillage practices were not evident for the finer textured Hoytville soil (Table 3, Figs. 3, 4a, b), even with the noted 2 times differences in total N content between NT and PT treatments (Table 1). The results are consistent with the data of Sorensen (1975), Ladd et al. (1977), van Veen et al. (1985) and Verberne et al. (1990) who reported net mineralization of soil N was more rapid in coarser textured soils compared with a finer texture soil because of the greatly increased surface area of the additional clay minerals in the fine textured soil (Hassink 1994). Ledgard et al. (1998) also reported that higher rates of net N mineralization in certain soils were due to lower soil N immobilization rates and increased net Wooster N mineralization may explain the Wooster/Hoytville N release differences. The increased immobilization of soil N in the control soils (no N added) during the first 42 days was evident as the Hoytville soil immobilized 2 to 3 times more initial soil mineral N than the Wooster soil (Fig. 5).

The critical importance of the early season available N is well documented to obtain optimum yields of corn (Binford et al. 1992), wheat (Johnston and Fowler 1991a, 1991b) and sorghum (Vanderlip 1979) due to the establishment of ear or head size and number of kernels at this point in physiological development. The amount of soil native N leached (42 day native N leached—time 0 initial mineral N content) during the first 42 days of the study following NH_4^+, NO_3^- or no N addition to the Wooster and Hoytville soils is shown in Fig. 5. The results of the Wooster and Hoytville incubations show that N fertilizer additions increased soil N mineralization resulting, in the short-term, in a larger available N pool for plant use (Fig. 5). In comparison, the control soils receiving no N fertilizers did not show positive N mineralization values till after incubation for 10 weeks (data not shown). Nitrogen mineralization in the NT Wooster soils during the 42 days was 2 times the N release in the Wooster PT soils and mineralization was related to soil total N and amino acid-N content. The net N mineralized in the Hoytville soils was not related to total N content or soil amino acid-N content. During the first 42 days, which would correspond to the critical time