Plant and Soil **243:** 187–195, 2002.

Oat plant effects on net nitrogen mineralization

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Received 23 March 2001. Accepted in revised form 5 April 2002

Key words: cover crops, denitrification, N balance, oat plants

Abstract

Living plants have been reported to stimulate, inhibit, or have no effect on net nitrogen mineralization in soil. A series of experiments were conducted to evaluate the influence of living oat plants *Avena sativa* on net N mineralization. Oat plants were grown in plastic cylinders containing soil, and net N mineralization was assessed by determining the N balance in these microcosms. Measured N inputs included N contained in the oat seeds and N_2 fixation. N losses by NH_3 volatilization and denitrification were also measured. We observed that in some soils net N mineralization was stimulated by as much as 81%, but in other soils there was no effect of living oat plants on net N mineralization. N mineralization responses are related to past cropping histories of the soils.

Introduction

It is generally recognized that improved synchrony between N supply and N demand will increase N use efficiency and decrease offsite N transport from agricultural systems. Mineralization of soil organic matter can be a major source of inorganic N in agricultural soils. It has been estimated that from 1 to 3% of the organic N pool is mineralized annually and that this can represent from 8 to 120 kg N ha^{-1} (Bundy and Meisinger, 1994). Thus, a greater understanding of the factors that influence N mineralization may aid efforts to improve N use efficiency.

Growing plants may have an impact on the mineralization of organic material in soil. In recent investigations of oat and rye root decomposition Malapassi et al., (2000), reported an apparent stimulation of net N mineralization by growing oat and rye plants. This result is similar to other reports of a stimulatory plant effect on net N mineralization (Haider et al., 1989; Wheatley et al., 1990). Reasons for this phenomenon include increased microbial activity due to root C inputs (Clarholm, 1985; Ingham, 1985) or decreased microbial immobilization resulting from more effective competition for N by plants (Griffiths and Robinson, 1992).

However, living plants have not always been observed to stimulate net N mineralization. Other studies have reported no effect of living plants on net N mineralization or an increase in N-immobilization (Breland and Bakken, 1991). Bremer and Kuikman (1997) recently reported that plant effects on net N mineralization may depend on soil N status. Under conditions of low N availability, growing wheat plants did not influence net N mineralization, but at high N additions net N mineralization was reduced. The reduced net N mineralization at high N additions was attributed to increased N immobilization. This latter report was interesting in that analysis of the unlabeled N pools indicated a stimulatory effect of plants on net N mineralization. However, ^{15}N results provided the opposite result, namely, that in conditions of adequate N availability, net N mineralization is decreased in the presence of living plants. Differences in denitrification N loss between the planted and unplanted treatments were speculated as the reason for the discrepancy between the unlabeled N and ^{15}N results (Bremer and Kuikman, 1997).

Clearly, the complexities inherent in plant-soil systems preclude the development of generalizations concerning the effects of living plants on N mineralization

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at this time. Our study was undertaken as part of a larger study investigating soil N dynamics under winter cover crops. We conducted a series of laboratory experiments to determine the effects of living oat (*Avena sativa* L. 'Ogle') plants on net N mineralization.

Materials and methods

In all the experiments of this study the same general protocol was used. Incubations were carried out in polycarbonate cylinders (30 cm×4 cm i.d.) filled with 150 g air dried soil (bulk density 1.0) and adjusted to a water content of 35% (approx. 60% water filled pore space). Oats were planted in the cylinders (1 seed/cylinder), the cylinders were capped with open cell foam plugs and then placed in a growth chamber. The growth chamber had a constant temperature of 20 °C with a 12 h light, 12 h dark regime. Cylinders without oat plants were also incubated in the growth chamber. At weekly intervals throughout the incubations, cylinders were weighed and soil water content was adjusted to initial levels with distilled H_2O. Net N mineralization, defined as the increase in the soil mineral N pool plus the N taken up by the plants+N lost through denitrification, was determined by N balance calculations. In progressing from experiments 1 to 4, a greater number of measurements were performed to better define N cycling as affected by plants. Details of each experiment are provided below.

Experiment 1

Six replicates of each treatment (with and without oat plants) were prepared. Three cylinders of each treatment were sacrificed after 21 and 42 d, and N partitioning in the plant and soil pools was determined. Shoots were removed from the cylinders, dried, weighed, and ground for total N analysis. Following removal of the shoot, the entire soil mass (+roots) was extruded into a jar containing 600 ml of 2 *M* KCl. The slurry was gently agitated and roots were removed from the slurry by hand. The roots were then dried, weighed, and ground for total N analysis. Soil mineral N (NO_3^-+NO_2^-+NH_4^+) was determined on the KCl extracts by colorimetric methods using a Lachat autoanalyzer (Lachat Instruments, Mequon, WI.) following the procedure described by Keeney and Nelson (1982). Total C and N of the plant shoot and root material was measured by dry combustion on a Carlo-Erba NA 1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ). The soil used in this experiment was a Tama silt loam (fine-silty, mixed, mesic Typic Argiudolls; Oelmann, 1981) collected from no-tillage plots under a corn/soybean rotation near Marshalltown, IA.

Experiment 2

The soil for this experiment was a Canisteo loam (fine-loamy, mixed (calcareous), mesic Typic Endoaquolls; Andrews and Dideriksen, 1981) collected from the Iowa State University Agronomy and Agricultural Engineering Research Center located about 11 km west of Ames, Iowa. This soil was collected from a corn/soybean field in the fall after soybean harvest. The soil was air dried, sieved, placed in cylinders, and incubations with and without plants were established as described in Experiment 1. Five replicates of each treatment (with and without oat plants) were sacrificed at 28 and 42 d. Soil mineral N, root N and shoot N were determined as described for Experiment 1. In addition N loss by denitrification was quantified on the day before cylinders were sacrificed using the acetylene inhibition technique as described by Parkin and Robinson (1989). Additional sets of cylinders were prepared to measure denitrification-N loss at days 1, 7 and 14. Nitrogen gains by soil N_2 fixation were determined using the acetylene reduction technique (Weaver and Danso, 1994) on the same cylinders used to measure denitrification. Nitrogen losses by ammonia volatilization were determined on a separate set of cylinders (10 cylinders with oat plants and 10 cylinders without plants). In these determinations, a glass fiber filter paper saturated with 5 *M* H_2SO_4 was suspended in the headspace of each cylinder. Filters were removed at weekly intervals and analyzed for NH_4^+, colorimetrically.

Experiment 3

The soil for this experiment was a Canisteo loam soil as in Experiment 2, however, the soil was collected at a different time and from a different location at the Iowa State University Agronomy and Agricultural Engineering Research Center. This soil was collected in the late spring from plots which had been previously planted to soybeans and followed by a rye (*Serale cereale* L.) cover crop. Incubations with and without oat plants were established as described previously, and at 28 and 42 d, 10 replicates of each treatment were sacrificed to determine mineral N content, and N uptake by

oat plants. Denitrification and N_2 fixation was determined in additional sets of cylinders at 1, 7, 14, 28 and 42 d. Because in the previous experiment ammonia volatilization was not a significant N loss mechanism, it was not measured in this experiment.

Experiment 4

Five replicates of each treatment (with and without oat plants) in soils from four plots having differing cropping histories were set up as described above and sacrificed at 6 weeks. This experiment was designed to evaluate the influence of cropping history on plant-N mineralization interactions. The Canisteo loam soil for this experiment was collected in the fall from plots with oat and rye cover crops following soybeans, as well as from control plots without a history of grass cover crops. Soil mineral N, root N and shoot N were determined as described for Experiment 1. Denitrification, NH_3 volatilization, and N_2 fixation were not determined as it was determined in previous experiments that these processes were not significantly influenced by the presence of living oat plants. Soil organic matter fractions were isolated according to methods described by Cambardella and Elliott (1992). Twelve 20-g sub-samples were dispersed overnight with 0.5% w/v sodium hexamethphosphate on a reciprocating shaker. The dispersed solutions were poured through a 53 μm sieve and the soil slurry passing through the sieve (mineral-associated organic matter) was dried overnight at 60 °C. Mineral-associated organic C and N and total organic C and N in a non-dispersed soil sample were measured using dry combustion methods in a Carlo-Erba NA 1500 CHN elemental analyzer (Haakes Buchler Instruments, Paterson, NJ) after removal of carbonates with 1 M H_2SO_4. Particulate organic matter C or N was quantified as the difference between total soil organic C or N in a non-dispersed soil sample and mineral-associated C or N. Microbial respiration was determined by placing 5 g air dry soil into 60 mL amber glass vials. Water was added to bring soils to 30% gravimetric water content, and vials were sealed with caps containing butyl rubber septa. Vials were incubated in the laboratory at 23°C (±1 °C). At daily intervals for the first 7 d, the air in the vials was purged with humidified, CO_2-free air, and the purged air was directed through an infrared gas analyzer to determine CO_2 concentration. After 7 d, sampling was performed at 2 d intervals up to 24 d. Respiration potential is expressed as cumulative CO_2-C produced g^{-1} soil over the 24 d incubation period.

In all experiments, statistical significance was assessed using Student's *t*-test.

Results

Experiment 1

Growing oat plants had a significant effect on changes in soil mineral N pools (Table 1). The initial mineral N concentration (NH_4^++NO_2^-+NO_3^-) of the soil used in Experiment 1 was 1037 μg N cylinder^{-1} (6.9 μg N g soil^{-1}). Over the first 21 d, the average mineral N concentration in cylinders without plants had increased by 1943 μg N cylinder^{-1} to 2976 μg N cylinder^{-1}, but in the treatment with growing oat plants soil mineral N pools decreased slightly to 966 μg N cylinder^{-1}. By day 42, the mineral N content of the cylinders without plants had not changed, but the mineral N pool in the cylinders with oat plants had decreased from 966 μg N cylinder^{-1} to 76.6 μg N cylinder^{-1}.

The difference in soil mineral N concentrations between the two treatments (with and without plants) was more than accounted for by accumulation of N in oat plant tissue (Table 1). At day 21, the average oat shoot biomass was 50.4 mg cylinder^{-1} (dry weight) and root biomass was 11.4 mg cylinder^{-1}. Using the measured N content of the shoot and root material (5.10% and 1.29%, respectively), it was calculated that the average N contents of the oat shoot and roots were 2550 and 148 μg N plant^{-1}. By day 42, plant biomass had increased to 130 and 28.9 mg dry material in the shoot and roots, respectively. At this time, the shoot N content decreased to 3.9% N, but the root N content remained at 1.29% N (data not shown), and the resulting N contained in the shoots at day 42 averaged 4010 μg N plant^{-1}, and the roots contained 367 μg N plant^{-1}. It should be noted that in the with-plant treatment, each replicate cylinder contained only a single oat plant and that this plant density is similar to average plant densities observed in the field. The average plant shoot mass of 130 mg dry shoot biomass cylinder^{-1} (measured at day 42) is equivalent to 1031 kg shoot biomass ha^{-1} when converted to an areal basis. This value is in the range of oat cover crop biomass levels (420–1070 kg dry shoot biomass ha^{-1}) reported by Johnson et al. (1998). The average root biomass we observed (28.9 mg root material cylinder^{-1} at day 42) is also comparable to root dens-

Table 1. Effect of growing oat plant on the distribution of nitrogen in different pools (Experiment 1, Tama Soil)

Harvest Time/ Treatment	μg N cylinder^{-1}	mg dry matter cylinder^{-1}		μg N cylinder^{-1}		
	Soil Mineral N[1]	Shoot Biomass	Root Biomass	Root N	Shoot N	Cumulative Dentrification[2]
Day 21						
No Plant	2976 a (14.0)	–	–	–	–	95.1 a (135)
With Plant	966 b (799)	50.4 (19.7)	11.4 (5.3)	148 (72)	2550 (936)	24.1 a (4.7)
Day 42						
No Plant	2963 a (14.6)	–	–	–	–	190 a (270)
With Plant	76.6 b (13.5)	130 (0)	28.9 (6.8)	367 (63)	4010 (357)	48.2 a (9.5)

[1]Starting soil mineral N concentration at day 0 was 1037 μg N/cylinder.
[2]Denitrification estimated from measurements made at day 21 and day 42.
At each time point values followed by different letters are statistically significant ($P<0.05$). Values in parentheses are standard deviations (n=3).

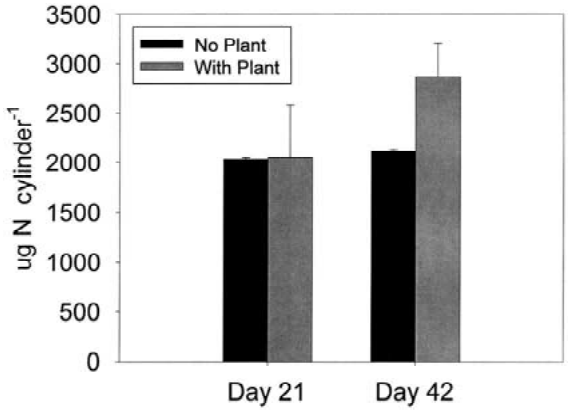

Figure 1. Net N mineralized in soil with and without growing oat plants (Experiment 1). Initial soil inorganic N levels and N contained in oat seeds have been subtracted. Error bars indicate one standard deviation of three replicates.

ities observed in the field (Kaspar, unpublished data). Thus, we do not think that our results are influenced by abnormally high root biomass.

Denitrification N loss was determined when cylinders were sacrificed at day 21 and day 42. These values were used to estimate cumulative denitrification-N loss over the course of the incubation (Table 1). The mass of N lost through denitrification was low relative to increases the soil mineral N pools and N uptake by the plants. There seemed to be a trend of higher denitrification N loss in the treatment without oat plants; however, these apparent differences were not significant.

Data of Table 1 were used to compute net N mineralization rates (Figure 1). Net N mineralization for the no-plant treatment was computed by subtracting the initial soil mineral N content from the final mineral N content and adding denitrification N losses. Net N mineralization in the with-plant treatment was computed the same way except the N contained in the plant was also added. In this computation the N contained in the oat seed was subtracted (approximately 600 μg^{-1} seed), as presumably this N was incorporated into the plant and, therefore included in our measurements of plant N content. At 21 d, there was no difference in net N mineralization between the two treatments (P=0.965); however at 42 d net N mineralization was significantly greater (P=0.019) in the cylinders with growing oat plants. The additional net N mineralization in the presence of growing oat plants averaged 750 μg N cylinder^{-1} (5.0 μg N g soil^{-1}). These estimates of net N mineralization indicate that growing oat plants had a stimulatory effect on net N mineralization. While these results account for denitrification-N losses, N loss through ammonia volatilization as well as N gains through N_2 fixation were not measured.

Experiment 2

This experiment was carried out to repeat the first results and, additionally, to document N losses due to ammonia volatilization and N gains to the system by soil N_2 fixation. In the no-plant treatment soil mineral N levels increased from 902 μg N/cylinder at time 0 to 1156 ug N cylinder^{-1} at day 28 and 2069 μg N cylinder^{-1} at day 42 (Table 2). In the cylinders containing oat plants, soil mineral N decreased to 324 μg N^{-1} cylinder at day 28 and 229 μg N cylinder^{-1} at day 42. In the with-plant treatment, oat biomass increased throughout the incubation and by day 43 average N up-

Table 2. Effect of growing oat plants on the distribution of nitrogen in different pools (Experiment 2)

Harvest Time/ Treatment	μg N cylinder	mg dry matter cylinder^{-1}		μg N cylinder^{-1}				
	Soil Mineral N[1]	Shoot Biomass[2]	Root Biomass	Root N	Shoot N	Ammonia Volatilized	Nitrogen Fixation	Cumulative Dentrification
Day 28								
No Plant	1156a (535)	–	–	–	–	3.71a (0.52)	ND[3]	1226a (519)
With Plant	327b (47.6)	114 (12.8)	14.8 (4.8)	142 (39)	3428 (380)	3.90a (1.05)	ND	644a (156)
Day 42								
No Plant	2069a (480)	–	–	–	–	6.71a (1.77)	ND	1227a (519)
With Plant	229b (127)	144 (36.4)	15.3 (4.7)	187 (57)	4046 (298)	21.5a (19.4)	ND	652b (156)

[1]Initial mineral N content=902 μg N/cylinder.
[2]Seed N content=616 μg N/seed.
[3]ND=not detectable.
At each time point values followed by different letters are statistically significant ($P<0.05$). Values in parentheses are standard deviations (n=5).

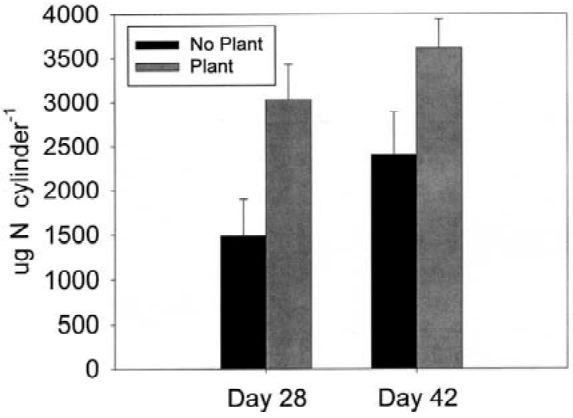

Figure 2. Effect of living oat plants on net N mineralization Experiment 2. Soil was collected in the fall following soybean harvest. Error bars indicate one standard deviation of five replicates.

take in the roots and shoots was 187 μg N cylinder^{-1} and 4046 μg N cylinder^{-1}, respectively. Ammonia volatilization losses were low. Cumulative NH_3 volatilization over the 42 d incubation accounted for only 3.01 μg N cylinder^{-1} in the no-plant treatment and 17.6 μg N cylinder^{-1} in the with-plant treatment.

Cumulative denitrification was determined by integrating measurements made at days 1, 7, 14, 28 and 42. Cumulative denitrification-N loss was not significantly different in the two treatments at day 28, but by day 42, denitrification N loss was approximately 500 μg N cylinder^{-1} higher in the without plant treatment. N_2 fixation by free living N_2 fixing bacteria was not detected in these incubations (detection limit=1.5 μg N cylinder^{-1}).

The data of Table 2 were used to compute net N mineralization (Figure 2). As in Experiment 1, net N mineralization was calculated by subtracting the initial mineral N pool from the mineral N pools at days 28 and 42, and in the case of the with-plant treatment, adding the N incorporated into the oat tissue. Also, denitrification-N losses and NH_3 volatilization losses were added. Net N mineralization was significantly higher in the with-plant treatment at both time points. At 28 d, net N mineralization averaged 1484 μg N cylinder^{-1} in the no-plant treatment, which was significantly higher ($P<0.001$) in the with-plant treatment (3028 μg N cylinder^{-1}). At 42 d, net N mineralization increased in both treatments, and the with-plant treatment was significantly ($P<0.001$) higher by 1216 μg N cylinder^{-1}.

Experiment 3

This experiment was designed to document the results of the first and second experiment. The influence of growing oat plants on partitioning of N into various pools at 28 and 42 days for Experiment 3 is presented in Table 3. By day 28, the soil mineral N pool increased from a starting value of 1785 μg N cylinder^{-1} on day 0 to 4230 μg N cylinder^{-1} in the no-plant cylinders. At this time, soil mineral N in the with-plant treatment was 1790 μg N cylinder^{-1}. At the end of the incubation on day 42, mineral N in the no-plant cylinders increased to 4840 μg N cylinder^{-1} and the with-plant soil mineral N pool decreased to 1460 μg N cylinder^{-1}. Oat biomass (roots+shoots) reached an average level of 80.5 mg cylinder^{-1} on day 28 and

Table 3. Effect of growing oat plants on the distribution of nitrogen in different pools (Experiment 3)

Harvest Time/ Treatment	μg N cylinder	mg dry matter cylinder^{-1}		μg N cylinder^{-1}			
	Soil Mineral N[1]	Shoot Biomass[2]	Root Biomass	Root N	Shoot N	Nitrogen Fixation	Cumulative Dentrification
Day 28							
No Plant	4230a (335)	–	–	–	–	ND[3]	484a (592)
With Plant	1790b (756)	55.9 (15.2)	24.6 (17.5)	258 (158)	2380 (815)	ND	417a (261)
Day 42							
No Plant	4840a (401)	–	–	–	–	ND	484a (592)
With Plant	1460b (1587)	99.9 (36.4)	25.4 (13.2)	268 (77.2)	3580 (1240)	ND	418a (261)

[1]Initial mineral N content=1785 μg N/cylinder.
[2]Seed N content=616 μg N/seed.
[3]ND=not detectable.
At each time point values followed by different letters are statistically significant ($P<0.05$). Values in parentheses are standard deviations (n=5).

125.3 mg cylinder^{-1} on day 42. On day 28, N contained in oat shoots and roots accounted for 2380 and 285 μg N cylinder^{-1}, respectively. By day 42, root N (268 μg N cylinder^{-1}) was not significantly different than on day 28, but N in the oat shoots averaged 3580 μg N cylinder^{-1}. Ammonia volatilization losses were not measured. Nitrogen fixation was measured at day 1, 7, 14, 28 and 42, but was not detected at any of these times. Cumulative denitrification-N loss was not significantly different in the two treatments at either day 28 or day 42 ($P>0.10$), and accounted for 484 μg N cylinder^{-1} in the no-plant treatment and 418 μg N cylinder^{-1} in the with-plant treatment (Table 3).

Unlike Experiments 1 and 2, net N mineralization in this experiment was not stimulated by living oat plants (Figure 3). Net N mineralization on day 28 was actually significantly greater (P=0.025) in cylinders without plants, but cumulative net N mineralization on day 42 was not significantly different (P=0.34) between the with- and without-plant treatments. Since the experimental protocol was the same in all the experiments, we suspect that the initial soil material used in these experiments may have influenced the results. The soil used in Experiment 3 was the same as in Experiment 2, but was collected at a different time and location. The soil of Experiment 2 was from a corn/soybean field collected in the fall following soybean harvest; however, the soil for Experiment 3, was collected in the late spring from experimental plots with rye cover crops. Thus, it was hypothesized that cropping history and/or time of year may may influence the response of net N mineralization to the presence of plants.

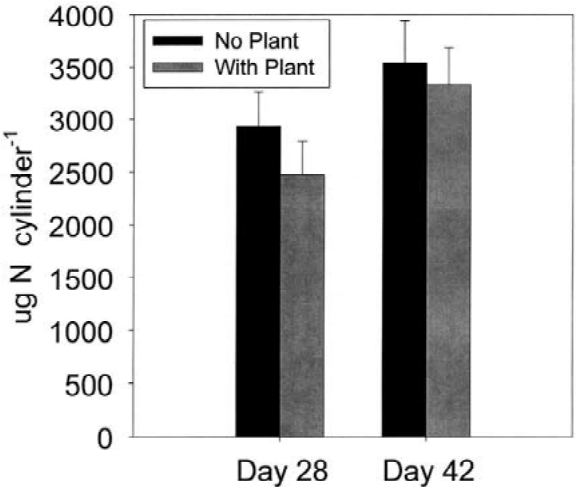

Figure 3. Effect of growing oat plants on net N mineralization in Experiment 3. Soil was collected in the spring from plots with a rye cover crop. Error bars indicate one standard deviation of five replicates.

Experiment 4

This experiment tested the hypothesis that the net N mineralization response to growing oat plants is influenced by the cropping history. Soil was collected before corn planting in the spring from experimental field plots with the following cropping histories: (1) a soybean crop the previous year, (2) a soybean crop followed by an oat winter cover crop, and (3) a soybean crop followed by a rye winter cover crop. Net N mineralization was significantly affected by the past cropping history (Figure 4). This cropping history effect occurred in both the presence and absence of living oat

Table 4. Chemical, and biological properties of soils used in Experiment 4

Cropping History	pH	Organic C (%)	Organic N (%)	Respiration Potential[1] μg C g soil^{-1}	Soluble Carbon μg C g soil^{-1}	POM C μg C g soil^{-1}	POM N μg N g soil^{-1}
Corn/Soybean	6.25	2.02a	0.163a	410a	135a	6200a	433a
Corn/Soybean/Oat	6.23	2.48b	0.197b	367a	139a	6916a	411a
Corn/Soybean/Rye	6.47	2.65b	0.216b	542b	143a	7082a	492a
Probability		<0.001	<0.001	<0.05	>0.20	>0.05	>0.05

[1]Respiration potential is expressed as cumulative CO_2-C produced over a 24 d period.

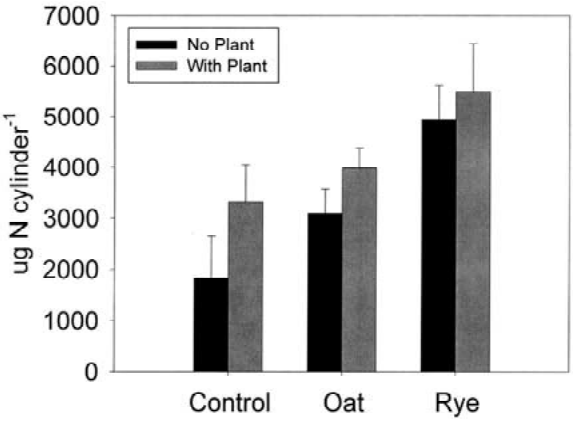

Figure 4. Effect of oat plants on net N mineralization in soil with different cropping histories. Control soil had soybeans the previous year. Oat and Rye soils had soybeans the previous year followed by oat and rye winter cover crops, respectively. Shown is net N mineralization after 42 days. Error bars indicate one standard deviation of five replicates.

plants. In the cylinders without living oat plants, net N mineralization was significantly ($P<0.019$) affected by soil history, with the no cover crop soil (control) exhibiting the lowest net N mineralization (1830 μg N cylinder^{-1}) and the soil from the rye cover crop plot having the highest net N mineralization (4940 μg N cylinder^{-1}). The presence of living oat plants eliminated the differences in net N mineralization of the no cover crop and oat cover crop soils (3320 μg N cylinder^{-1} and 3990 μg N cylinder^{-1}, respectively) but net N mineralization in the rye cover crop soil with living oat plants (5480 μg N cylinder^{-1}) was significantly higher ($P<0.003$). For the no cover crop soil and the oat cover crop soil, the presence of living oat plants significantly stimulated net N mineralization over the no-plant treatments ($P<0.005$). This is the same result observed for Experiments 1 and 2 where soil collected from soybean fields without winter cover crops. In contrast, net N mineralization in the rye cover crop soil (Figure 4) was not significantly influenced by the presence of living oat plants ($P>0.326$). This result is the same as observed in Experiment 3 where the soil was collected from plots with a past rye cover crop. These results show that past cropping history not only influences net N mineralization, but also the magnitude of the stimulatory effect of living oat plants on net N mineralization. Differences in oat plant growth in each of the soils is likely not a factor in explaining these differences. There was a trend of increased plant biomass and oat plant-N in the oat and rye cover crop soil, however, this trend was not significant. Thus, it appears that the differential stimulation of net N mineralization by plants in the soils with different cropping histories may be due to an inherent property(s) of the soils.

Additional measurements on the soils of this experiment indicted differences in the organic pools (Table 4). Total organic C and N were significantly higher in the oat and rye cover crop soils than in the non-cover crop soil. There was a trend of higher particulate organic matter (POM) C and N in the oat and rye cover crop soils, these differences were not significant. However, respiration potential was significantly higher in the rye cover crop soil. These trends of increased organic matter and activity in the soils with a past history of cover crops are reflected by the increased net N mineralization observed in these soils (Figure 4).

Discussion

There are conflicting reports in the literature concerning the influence of plants on N mineralization. In studies where plants have had a positive effect, possible reasons for this stimulation include increased microbial activity due to root exudation, increased microbial activity due to wetting and drying cycles induced by the plant, and decreased immobilization due to competition for N by the plant (Dormaar, 1990). Grif-

fiths and Robinson (1992) proposed a model whereby carbon released by plant roots stimulated microbial activity, resulting in stimulated soil organic matter degradation and N immobilization. This N was then released when bacteria were consumed by nematodes, resulting in plant stimulated net N mineralization. This concept was an extension of previous work by Clarholm (1985) and Ingham et al. (1985). Clarholm (1985) demonstrated that root C inputs or exogenous C additions (glucose) resulted in a stimulation of soil organic matter mineralization and N immobilization by bacteria. Subsequent grazing of bacteria by protozoa resulted in increased net N mineralization.

There have also been studies where there have been no stimulation of net N mineralization by growing plants, or a decrease in net N mineralization. Bremer and Kuikman (1997) observed that plant effects on net N mineralization were sensitive to the inorganic N status of the soil. These investigators observed that in the presence of high NH_4 levels combined with added straw residue, net N mineralization was lower in soil planted to wheat than in fallow pots. This decrease in net N mineralization was reported to be due to increased microbial immobilization.

It is possible that all of these mechanisms are valid. Manifestation of a plant effect is dependant upon relative rates of decomposition of organic material, immobilization into microbial biomass, turnover of microbial biomass N, plant N-uptake rates as well as differences in volatile N loss between planted and unplanted soil. Thus, expression of a plant effect may be highly sensitive to the soil conditions. Under conditions where plant N-uptake effectively competes with microbial immobilization for available N, or if immobilization rates are low, apparent net N mineralization may seem to be stimulated by the presence of the plants. It is difficult to determine which, if any, of these scenarios is occurring in a given system. However, a primary factor influencing each of these scenarios is the quality of the labile organic pools undergoing mineralization and, in turn, supporting microbial growth and activity.

Kuzyakov et al. (2000) recently reviewed factors influencing priming effects, and concluded that factors such as added labile C increase microbial activity and subsequently accelerates soil organic matter turnover, which generally results in increased net N mineralization. We suspect that differences in the amounts of labile C in the soils of our study due to differences in cropping history may have been responsible for the varied responses of net N mineralization to growing plants. In Experiment 4 of our study, the rye cover crop soil had the highest net N mineralization, but showed the lowest response of net N mineralization to growing plants. The respiration potential of the rye cover crop soil was significantly greater than either the oat or rye cover crop soils, indicating a higher labile C pool. This higher labile C pools may have served to mask any stimulatory effects of rhizodeposition of C by growing oat plants. In contrast, the oat cover crop soil and the no-cover crop soil had lower net N mineralization, but showed greater responses to growing oat plants.

Clearly, much needs to be done to precisely determine the effects of plants on soil C and N dynamics. Understanding the dynamics of organic matter decomposition is important not only for preserving soil productivity, but also for enhancing soil's ability to serve as a sink for atmospheric CO_2. It remains to be determined if the observed increase in net N mineralization simply represents a shift in the balance between microbial immobilization and plant incorporation or if plants accelerate the decomposition of soil organic matter. If the latter is true, it is unknown how different pools of organic matter are influenced by the presence of growing plants. Investigations of the temporal dynamics of soil C pools in soils with different cropping histories are clearly warranted. Finally, the knowledge of the extent and magnitude of increased net N mineralization exerted by different plant species may have value in devising strategies to control soil organic matter dynamics.

Acknowledgements

The authors thank J.J. Meisinger for critical review of this manuscript, and O. Smith, J. Ohmacht, and N. Nubel for technical assistance in sampling and analyses.

References

Andrews W F and Dideriksen R O 1981 Soil survey of Boone County, Iowa. USDA-SCS. U.S. Gov. Printing Office, Washington, DC.

Breland T A and Bakken L R 1991 Microbial growth and nitrogen immobilization in the root zone of barley (*Hordeum vulgare* L.), Italian ryegrass (*Lolium multiforum* Lam.), and white clover (*Trifolium repens* L.). Biol. Fertil. Soils 12, 154–160.

Bremer E and Kuikman P 1997 Influence of competition for nitrogen in soil on net mineralization of nitrogen. Plant Soil 190, 119–126.

Bundy L G and Meisinger J J 1994 Nitrogen availability indices. *In* Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. Eds. R W Weaver, S Angle, P Bottomley, D Bezdicek, S Smith, A Tabatabai and A Wollum. pp 951–984. Soil Sci. Soc. Am., Madison, WI.

Cambardella C A and Elliott E T 1992 Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56, 777–783.

Charholm M 1985 Interactions of bacteria, protozoa and plants leading to the mineralization of soil nitrogen. Soil Biol. Biochem. 17, 181–187.

Dormaar J F 1990 Effect of active roots on the decomposition of soil organic materials. Biol. Fertil. Soils 10, 121–126.

Griffiths B and Robinson D 1992 Root-induced nitrogen mineralization: a nitrogen balance model. Plant Soil 139, 253–263.

Haider K, Heinemeyer O and Mosier A R 1989 Effects of growing plants on humus and plant residue decomposition in soil: uptake of decomposition products by plants. Sci. Total Environ. 81/82, 661–670.

Ingham R E, Trofymow J A, Engham E R and Coleman D C 1985 Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. Ecol. Monogr. 55, 119–140.

Johnson T J, Kaspar T C, Kohler K A, Corak S J and Logsdon S D 1998 Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Cons. 53, 276–279.

Keeney D R and Nelson D W 1982 Nitrogen–Inorganic Forms. *In* Methods of Soil Analysis. Part 2, 2nd edition. Eds. A L Page, R H Miller and D R Keeney. pp 643–698. Agron. Soc. Am. and Soil Sci. Soc. Am., Madison, WI.

Kuzyakov Y, Friedel J K and Stahr K 2000 Review of mechanisms and quantification of priming effects. Soil Biol. Biochem. 32, 1485–1498.

Malpassi R N, Kaspar T C, Parkin T B, Cambardella C A and Nubel N A 2000 Oat and rye root decomposition effects on nitrogen mineralization. Soil Sci. Soc. Am. J. 64, 208–215.

Oelmann D B 1981 Soil survey of Marshall County, Iowa. USDA-SCS. U.S. Gov. Printing Office, Washington, DC.

Parkin T B and Robinson J A 1989 Stochastic models of soil denitrification. Appl. Environ. Microbiol. 55, 72–77.

Weaver R W and Danso S K A 1994 Dinitrogen Fixation. *In* Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. Eds. R W Weaver, S Angle, P Bottomley, D Bezdicek, S Smith, A Tabatabai and A Wollum. pp 1019–1046. Soil Sci. Soc. Am., Madison, WI.

Wheatley R, Ritz K and Griffiths B 1990 Microbial biomass and mineral N transformations in soil planted with barley, ryegrass, pea or turnip. Plant Soil 127, 157–167.

Section editor: S. Recous