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Fate of Legume and Fertilizer Nitrogen-15 in a Long-Term Cropping Systems Experiment

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ABSTRACT

Relying more on biological N_2 fixation has been suggested as a way to meet one of the major challenges of agricultural sustainability. A ^{15}N study was conducted to compare the fate of applied legume and fertilizer N in a long-term cropping systems experiment. Nitrogen-15–labeled red clover (*Trifolium pratense* L.) and $(NH_4)_2SO_4$ were applied to microplots within the low-input and conventional cropping systems of the Farming Systems Trial at the Rodale Institute Research Center in Pennsylvania. The ^{15}N was applied to soil and traced into corn (*Zea mays* L.) in 1987 and 1988. Residual ^{15}N was also traced into second-year spring barley (*Hordeum vulgare* L.). Legume and fertilizer ^{15}N remaining in soil was measured and loss of N was calculated by difference. More fertilizer than legume N was recovered by crops (40 vs. 17% of input), more legume than fertilizer N was retained in soil (47 vs. 17% of input), and similar amounts of N from both sources were lost from the cropping systems (39% of input) over the 2-yr period. More fertilizer than legume N was lost during the year of application (38 vs. 18% of input), but more legume than fertilizer N was lost the year after application (17 vs. 4% of input). Residual fertilizer and legume ^{15}N was distributed similarly among soil fractions. Soil microbial biomass was larger in the legume-based system. A larger, but not necessarily more active, soil microbial biomass was probably responsible for the greater soil N supplying capacity in the legume-based compared with fertilizer-based system.

MANAGING NITROGEN INPUTS in crop production systems to achieve economic and environmental sustainability is a major challenge facing agriculture. Relying less on commercial fertilizer N and more on biological N_2 fixation by legumes has been suggested as a way to meet this challenge (Keeney, 1982; National Academy of Sciences, 1989). Nitrogen-15 methodology is recognized as a valuable tool for determining the fate and behavior of N applied in the environment (Hauck, 1971, 1982; L'Annunziata and Legg, 1984). Field experiments using ^{15}N have studied the recovery of fertilizer N by crops and have documented that use efficiency varies due to a number of factors, including timing and method of N application, tillage method, and climate. A well-managed, first-year, single-harvested crop recovers between 50 and 70% of applied fertilizer N (Allison, 1966; Stanford, 1973). In addition, 10 to 40% of applied fertilizer N may remain in soil, 5 to 10% may be lost by leaching, and 10 to 30% may be lost to the atmosphere in gaseous forms (Kundler, 1970; Westerman et al., 1972).

Studies evaluating the fate of ^{15}N from legume residues decomposing under field conditions concluded that: (i) <30% of legume N was recovered by a subsequent nonlegume crop; (ii) large amounts of legume N were retained in soil, mostly in organic forms; (iii) total recovery of legume N in crops and soils after 1 yr averaged 70 to 90%; and (iv) <5% of legume N from the original application was recovered by a second nonlegume crop (Ladd et al., 1983; Muller and Sundman, 1988; Harris and Hesterman, 1990; Ta and Faris, 1990).

Direct comparisons of commercial fertilizers vs. legumes as an N source for crops using ^{15}N in field experiments are rare. Westcott and Mikkelsen (1987) compared vetch (*Vicia benghalensis* L.) and $(NH_4)_2SO_4$ as N sources for flooded rice (*Oryza sativa* L.) using ^{15}N. They found that rice recovered twice as much fertilizer N as vetch N when applied at either 60 kg ha^{-1} (18 vs. 9% recovery) or at 120 kg ha^{-1} (52 vs. 26% recovery). Janzen et al. (1990) compared the annual legumes Tangier flatpea (*Lathyrus tingitanus* L.) and lentil (*Lens culinaris* Medikus) to $(NH_4)_2SO_4$ as an N source for wheat at three locations in Canada. Wheat recovered an average of 14% of applied legume N and 36% of fertilizer N. More legume N than fertilizer N was retained in soil. Ladd and Amato (1986) compared a medic (*Medicago littoralis* Rohde ex Lois.) with three different fertilizers as an N source for wheat in Australia. They reported greater recovery of fertilizer N than legume N by wheat (46 vs. 17%) and greater retention of legume N than fertilizer N in soil (62 vs. 29%).

Values for total ^{15}N recovery (crops plus soil) indicate that similar amounts of legume and fertilizer N are lost to the environment. This contradicts the belief by some that legume N is less susceptible than fertilizer N to losses from the soil–plant system (USDA, 1980; Papendick et al., 1987; Bezdicek and Granastein, 1989). Since loss of N from either source represents both an economic loss and potential for environmental pollution, better estimates of N loss from legume and fertilizer-based cropping systems are needed.

Despite reports of greater recovery of N by wheat from fertilizer than from legume sources (Ladd and Amato, 1986; Ta and Faris, 1990), little difference in wheat yields or total N uptake was observed. Lower use efficiency of legume N by wheat was thus associated with greater uptake of soil N. Bolton et al. (1985) suggested that greater soil N supplying capacities in legume-based systems can compensate for low crop use efficiency of legume N. This may be due to a larger and more active microbial population in the legume-based system. Legume N inputs may also contribute more than fertilizer N to long-term soil fertility through buildup of organic N reserves (Ladd et al., 1981; Frye et al., 1985; Harris and Hesterman, 1990; Janzen et al., 1990).

The goal of the research reported herein was to compare the fate of legume and fertilizer N in a long-term experiment with cropping systems common to the northeastern and north-central regions of the USA. Specific objectives were to (i) to follow the fate of ^{15}N-enriched red clover and $(NH_4)_2SO_4$ applied to established legume- and fertilizer-based cropping systems, and to calculate N loss

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Abbreviations: CEC, cation exchange capacity; CONV, conventional N input; LIP-A, low input–animal; LIP-CG, low input–cash grain.

during two growing seasons, (ii) measure and compare the recovery and distribution of legume and fertilizer N in three soil fractions (inorganic, microbial biomass, and nonbiomass organic), and (iii) measure and compare the size and activity of the microbial biomass in soils from the legume- and fertilizer-based systems.

MATERIALS AND METHODS

The long-term experiment used for this ^{15}N study was the farming systems trial located at the Rodale Institute Research Center in Kutztown, east-central Pennsylvania. This experiment was established in 1981 to investigate yield-limiting factors when converting from conventional to low-input farming methods. A description and results of this study have been reported by Liebhardt et al. (1989) for the first 5 yr, and by Peters et al. (1992) for the second 5 yr. In this experiment, two low-input cropping systems, one with an animal component and the other a cash grain rotation, are being compared with a conventional corn–soybean rotation. The main N source for each cropping system is animal manure for the low input–animal (LIP-A), legume green manure for the low input–cash grain (LIP-CG), and inorganic fertilizer for the conventional (CONV). The N is applied before each corn crop in all systems. Herbicides and insecticides are used in the conventional system but not in the low-input systems. Each cropping system was originally initiated at three different phases of its rotation, or *entry points*, in order to assess the effect of the starting crop on the conversion process. The experimental design is a split-plot, randomized complete block with eight replications. Cropping systems are the main plots and rotation entry points are the subplots. Each subplot measures 6.1 by 91.5 m. The soil is a Comly silt loam (fine-loamy, mixed, mesic Typic Fragiudalf). The climate is humid continental with annual precipitation of 1080 mm and an annual mean temperature of 12.4°C.

Two entry points for the LIP-CG and CONV systems were used in this study. The cropping sequence for treatments used, up to and including the crop grown the year of ^{15}N application, are shown in Table 1. Initial soil properties for the experimental area were measured in 1987. Average pH was 6.8, organic matter was 24 g kg^{-1}, Bray P1 was 338 kg ha^{-1}, and K, Ca, Mg, and CEC were 0.32, 6.4, 1.9 and 9.9 cmol(+) kg^{-1}, respectively.

Application of Nitrogen-15

On 6 May 1987, ^{15}N-enriched red clover shoots (5.5% atom excess, C:N = 15:1) and $(NH_4)_2SO_4$ (10% atom excess) were applied to microplots in Entry Point 1 subplots of the LIP-CG and CONV cropping systems, respectively. Legume N was applied at a rate equivalent to 165 kg ha^{-1} and fertilizer N was applied at a rate of 124 kg N ha^{-1}.

Microplots consisted of undisturbed soil columns (61 cm diam. by 45 cm deep) enclosed by open-ended sheet metal cylinders that extended 5 cm above the soil surface. The cylinders were installed in four of the eight replications of the long-term experiment using a gas-powered post-hole digger (Harris and Hesterman, 1990). Soil in the microplots receiving ^{15}N-enriched red clover was excavated to 15 cm, existing clover roots were removed from the soil by hand, and labeled red clover was mixed into the soil and returned to the microplot. The labeled legume material was produced in a sand-filled bench in the greenhouse and fertilized weekly with a nutrient solution containing $(^{15}NH_4)_2SO_4$ (10% atom excess). Shoot material was clipped, cut to 7-cm lengths with scissors, mixed thoroughly, and then dried at 60°C for 4 d before application to microplots. Soil in microplots of the CONV system was also excavated to a 15-cm depth, mixed, then returned to simulate spring plowing. Enriched $(NH_4)_2SO_4$ was then applied in granular form directly to the microplots and incorporated into the top 5 cm of soil using a small hand cultivator.

Plant and Soil Analyses, Year 1

Six corn seeds were planted in each microplot on 6 May 1987 after ^{15}N application. Soon after emergence, plants were thinned to three per microplot and the thinned plants were left on the surface of the microplot. Microplots were kept weed free by hand-weeding and returning any weeds to the soil surface. The remaining three corn plants were harvested on 5 Oct. 1987. Corn grain, stover, and roots were separated, weighed, ground, and analyzed for total N and ^{15}N on a Europa Scientific Tracermass mass spectrometer after conversion of the sample N to N_2 by Dumas combustion in a Roboprep CN analyzer (Europa Scientific Ltd., Crewe, England; Harris and Paul, 1989). Roots were handpicked from the top 15-cm soil layer and washed with tap water before drying. After corn harvest, entire soil layers from 0- to 15-cm, 15- to 30-cm, and 30- to 45-cm were excavated, weighed and then mixed thoroughly before sampling. A subsample from each layer was dried and analyzed for total N, inorganic N, and ^{15}N in each fraction. Soil total N and ^{15}N were measured by the same method used for corn samples. Soil inorganic N (NO_3^- + NH_4^+) in filtered KCl extracts (100 mL 2 *M* KCl:20 g air-dry soil, shaken 1 h) was measured colorimetrically on a Lachat flow-injector analyzer using Lachat QuikChem Method no. 12-107-04-1-A. Inorganic ^{15}N in KCl extracts was released as NH_3 following reduction of NO_3–N with Devarda's alloy and addition of MgO. The released NH_3 was trapped on acidified filter disks (Whatman no. 3, 6 mm diam.) as NH_4–N (Brooks et al., 1989). The $^{15}NH_4$–N was analyzed on the Europa Scientific Tracermass after combustion of the filter disks in the Roboprep analyzer.

Microbial biomass C and N in field-moist samples collected from the 0- to 15-cm soil layer of each microplot after corn or barley harvest were determined using the chloroform fumigation incubation method (Jenkinson and Powlson, 1976). Soil samples were stored for 2 wk prior to microbial biomass analyses. Soils were not reinoculated after fumigation. Parameters used in calculating biomass C and N were: biomass C = C_f/K_c,

Table 1. Cropping systems and rotation entry points for the low input–cash grain (LIP-CG) and conventional (CONV) cropping systems of the long-term Rodale experiment.

Cropping system	Rotation entry point	Crop							
		1981	1982	1983	1984	1985	1986	1987	1988
LIP-CG	1	Oat Red clover	Corn	Oat Red clover	Corn	Soybean	Oat Red clover	Corn	–
	2	Soybean	Oat Red clover	Corn	Wheat Hairy vetch	Corn	Barley Soybean Wheat	Wheat Red clover	Corn
CONV	1	Corn	Corn	Soybean	Corn	Soybean	Corn	Corn	–
	2	Soybean	Corn	Corn	Soybean	Corn	Soybean	Corn	Corn

where C_f = CO_2-C evolved during 10 d from the fumigated sample, and K_c = 0.41; and biomass N = N_f/K_n, where N_f = NH_4-N released during a 10-d incubation and K_n = $(-0.014 \times C_f/N_f) + 0.39$ (Voroney and Paul, 1984). Carbon respired from unfumigated control soils during the 10- to 20-d period was used as a measure of microbial activity and to calculate specific respiratory activity (CO_2-C respired divided by microbial biomass C; Schnurer et al., 1985). Similarly, N mineralization during the 0- to 20-d period in unfumigated control soils was used as a measure of N availability and to calculate a specific mineralization activity (N mineralized divided by microbial biomass N). Soil excavated from the microplots after corn harvest was returned by layer after sampling. Labeled corn stover and roots were not returned to the microplots. This methodology is similar to that reported in Harris and Hesterman (1990). In that study, it was observed that excavating and returning soil to microplots by layer did not affect recovery of alfalfa ^{15}N by a second-year barley crop.

Plant and Soil Analyses, Year 2

Spring barley was planted in microplots of both the LIP-CG and CONV systems on 29 Mar. 1988 to measure recovery of residual legume and fertilizer ^{15}N by a second nonlegume crop. Seeding rate was 108 kg ha^{-1} and no additional N was applied to either system. Mature barley plants were harvested on 24 July 1988, separated into grain, straw and roots, and analyzed for total N and ^{15}N using the same procedures as for corn. Soil was sampled after barley harvest and analyzed for the same parameters as for the corn sequence.

To account for year-to-year variability, the same experiment described above was repeated starting in May 1988. This provided a second 2-yr cycle with corn in 1988 and spring barley in 1989. All N application, planting, harvesting, sampling and laboratory procedures were identical to those used for the 1987–1988 cycle, with the exception that the ^{15}N red clover plant material and $(NH_4)_2SO_4$ were both applied at a rate of 124 kg N ha^{-1}. Red clover plant material for both 2-yr cycles was produced at the same time (at the beginning of the experiment) and was stored, after drying, in sealed containers. We applied ^{15}N and planted corn on 3 May 1988, harvested corn and sampled soil on 14 Oct. 1988, planted barley on 10 Apr. 1989, and harvested barley and sampled soil on 26 July 1989.

Calculation of Nitrogen-15 and Statistical Analyses

Recovery of ^{15}N from red clover and $(NH_4)_2SO_4$ by first-year corn, second-year barley, and soil after each crop was calculated using the same equations used by Harris and Hesterman (1990). Loss of ^{15}N was estimated at two points during the cropping sequence of each cropping system, after corn harvest and after barley harvest, by subtraction (i.e., applied N not accounted for in crops and soil). All data were analyzed by two-way analysis of variance for a randomized complete block with four replications.

RESULTS AND DISCUSSION

Fate of Legume and Fertilizer Nitrogen-15

Entry Point 1 (1987 Corn–1988 Barley)

Corn recovered 15% of the red clover N applied to the LIP-CG and 49% of the $(NH_4)_2SO_4$-N applied to the CONV system (Table 2). Over three times more legume N than fertilizer N was recovered in soil sampled after corn harvest. Losses of applied N from the legume- and fertilizer-based systems were not significantly different, and based on application rates, were equivalent to 34 and 38 kg N ha^{-1} for red clover and $(NH_4)_2SO_4$, respectively. The second-year spring barley crop recovered small amounts of residual legume and fertilizer ^{15}N in 1988 (Table 2).

More legume N than fertilizer N remained in the soil after barley harvest in 1988 (57 vs. 19% of input); however, the decline in the amount of fertilizer N left in the soil between corn harvest in 1987 and barley harvest in 1988 was equal to the amount of residual fertilizer N taken up by the barley crop. This means there was no additional loss of fertilizer N from the CONV cropping system during this period. In contrast, the decline in the amount of legume N in soil during this same period exceeded the amount taken up by the barley crop. Twelve percent of the legume N originally applied, or the equivalent of 20 kg N ha^{-1}, was lost from the LIP-CG between corn harvest in 1987 and barley harvest in 1988.

Total ^{15}N balances after two growing seasons showed more fertilizer N than legume N recovered by crops (51 vs. 17% of input), more legume N than fertilizer N remaining in soil (57 vs. 19% of input) and similar amounts of N lost from each source.

Entry Point 2 (1988 Corn–1989 Barley)

Corn recovered 16% of the legume N applied to the LIP-CG and 29% of fertilizer N applied to the CONV system in 1988 (Table 2). Sixty percent of the legume N applied,

Table 2. Fate of red clover ^{15}N in the low input–cash grain (LIP-CG) cropping system and fate of ammonium sulfate ^{15}N in the conventional (CONV) cropping system of the long-term Rodale experiment.

Cropping system	Year 1			Year 2			Total (Year 1 + 2)		
	Corn	Soil	Loss	Barley	Soil	Loss	Crops	Soil	Loss
	% of input								
Entry Point 1†									
LIP-CG	14.7	72.1	13.2	2.7	57.1	12.2	17.4	57.1	25.4
CONV	49.3	20.5	30.2	1.3	19.2	0.0	50.6	19.2	30.4
Significance	***	***	NS	NS	***	NS	**	***	NS
CV, %	11	13	41	22	6	6	11	6	9
Entry Point 2‡									
LIP-CG	16.4	60.2	23.4	1.1	37.4	21.7	17.5	37.4	45.1
CONV	29.4	24.7	45.9	0.6	15.1	9.0	30.0	15.1	54.9
Significance	NS	*	**	*	***	NS	NS	***	NS
CV, %	38	7	14	21	4	55	36	4	17

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively; NS = not significant at P = 0.05.
† Year 1 = 1987; Year 2 = 1988.
‡ Year 1 = 1988; Year 2 = 1989.

or the equivalent of 74 kg N ha^{-1}, remained in the soil of the LIP-CG system after corn harvest. This was significantly higher than the 31 kg N ha^{-1} of fertilizer N left in soil after corn harvest. Loss of fertilizer ^{15}N from the CONV system during the 1988 corn growing season was nearly twice the loss of red clover ^{15}N from the LIP-CG system (57 vs. 27 kg N ha^{-1}). Recovery of residual soil ^{15}N by a second-year barley crop grown in 1989 was higher in the LIP-CG than in the CONV system, although values were small for both legume and fertilizer N sources (Table 2).

There was more red clover N than fertilizer N left in soil after barley harvest in 1989. Since the decline in ^{15}N in soil between corn harvest in 1988 and barley harvest in 1989 exceeded recovery of ^{15}N by barley in both systems, there was loss of both legume and fertilizer N during this period. Expressed as a percentage of residual ^{15}N left in soil after corn harvest, the loss of both legume and fertilizer N during Year 2 was the same (36%).

Total ^{15}N balances after two growing seasons showed that the amounts of fertilizer N and legume N recovered by the crops were not different, more legume N than fertilizer N remained in soil, and similar amounts of N from each source were lost from the cropping systems (45 vs. 55% of input or 56 vs. 68 kg ha^{-1} from legume and fertilizer, respectively).

The weather pattern for each of the 3 yr of our ^{15}N study was very different and probably affected the results. Rainfall in 1987 was close to average and evenly distributed, in what was considered a normal year. In 1988, an extremely dry period from the first of June to mid-July caused 1988 to be known as a drought year. The dry period was followed by twice the monthly average rainfall in the second half of July and normal precipitation for the remainder of the growing season. Above-average rainfall was recorded during May, June, and July of 1989, which was categorized as a wet year.

Loss of N from both sources was greater during the drought year of 1988 than during the normal year of 1987. Loss of fertilizer N was especially high in 1988, when 46% of the applied N was lost. High N losses are usually not observed during a drought year; however, it is possible that both fertilizer and legume N not taken up by corn during the dry period of June and the first half of July were susceptible to loss by denitrification or leaching during the subsequent wet period.

Distribution of Legume and Fertilizer ^{15}N in Soil

More legume N than fertilizer N was recovered in the inorganic, microbial biomass, and nonbiomass organic soil fractions at each soil sampling, except for the inorganic fraction after corn harvest in 1988, when no difference in recovery was detected (Table 3). Only small amounts (<5%) of either legume N or fertilizer N were recovered in the inorganic fraction at each sampling. Between 11 and 19% of the applied legume N was recovered in the microbial biomass compared with a 3 to 6% recovery of fertilizer N in this fraction. The nonbiomass organic fraction contained the most N from the applied sources, averaging 38% of legume N applied and 14% of fertilizer N applied. The amounts of both legume and fertilizer N in each fraction declined between Year 1 and Year 2 for both entry points.

Microbial Biomass Pool Sizes and Activity

Carbon mineralization (respiration) was greater in soils from the LIP-CG than from the CONV system for each sampling date (Table 4). Carbon respiration in both systems was at least twice as high in soils from Entry Point 2 than in soils from Entry Point 1. This could be due either to spatial variability at the experimental site (the two entry point microplots were at different field locations) or to different weather patterns affecting the two entry points. The size of the microbial biomass C pool was significantly greater in the LIP-CG than CONV soils at each sampling. The ratio of biomass C to total soil C was also greater for the LIP-CG than CONV system at each sampling. No difference was detected in specific respiration activity between systems at any soil sampling.

As with C, N mineralization and the size of the biomass N pool was greater in the LIP-CG than in the CONV system at each sampling date (Table 5). Specific N mineralization activity was greater in soil from the LIP-CG than from the CONV system sampled after corn in 1987 (Entry Point 1), but there was no significant difference between systems for the other three sampling times. The ratio of bio-

Table 3. Recovery in three soil fractions of ^{15}N applied to microplots in the long-term cropping systems experiment at the Rodale Institute Research Center in Pennsylvania.

Cropping system	Year 1 (corn)			Year 2 (barley)		
	Inorganic	Microbial biomass	Nonbiomass organic	Microbial inorganic	Biomass	Nonbiomass organic
	% of input					
Entry Point 1†						
LIP-CG	4.4	19.8	47.9	1.2	15.6	40.3
CONV	1.7	5.8	12.7	0.4	4.5	14.3
Significance	*	***	**	**	***	**
CV, %	31	3	19	10	7	13
Entry Point 2‡						
LIP-CG	3.4	16.0	40.8	1.8	11.2	24.4
CONV	4.3	4.4	16.0	0.9	3.1	11.1
Significance	NS	**	*	**	***	*
CV, %	75	18	18	10	3	36

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively; NS = not significant at $P = 0.05$.
† Year 1 = 1987; Year 2 = 1988.
‡ Year 1 = 1988; Year 2 = 1989.

Table 4. Soil microbial biomass activity and pool size parameters for carbon in the low input–cash grain (LIP–CG) and conventional (CONV) cropping systems in the long-term experiment at the Rodale Institute Research Center in Pennsylvania.

Cropping system	Year 1 (corn)				Year 2 (barley)			
	CO_2–C respiration	Biomass C	Specific respiration activity†	Biomass C : soil C ratio	CO_2–C respiration	Biomass C	Specific respiration activity	Biomass C : soil C ratio
	μg g^{-1}				μg g^{-1}			
Entry Point 1‡								
LIP-CG	81	929	0.089	0.042	66	777	0.087	0.035
CONV	34	658	0.050	0.033	45	574	0.080	0.029
Significance	*	*	NS	*	**	*	NS	NS
CV, %	34	10	33	10	8	11	11	11
Entry Point 2§								
LIP-CG	186	758	0.217	0.034	185	675	0.275	0.030
CONV	86	403	0.228	0.020	116	412	0.287	0.021
Significance	**	***	NS	***	**	**	NS	*
CV, %	3	6	7	5	7	10	14	11

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively; NS = not significant at $P = 0.05$.
† CO_2–C respiration/biomass C.
‡ Year 1 = 1987; Year 2 = 1988.
§ Year 1 = 1988; Year 2 = 1989.

Table 5. Soil microbial biomass activity and pool size parameters for nitrogen in the low input–cash grain (LIP–CG) and conventional (CONV) cropping systems in the long-term experiment at the Rodale Institute Research Center in Pennsylvania.

Cropping system	Year 1 (corn)				Year 2 (barley)			
	N mineralization	Biomass N	Specific mineralization activity†	Biomass N : soil N ratio	N mineralization	Biomass N	Specific mineralization activity	Biomass N : soil N ratio
	μg g^{-1}				μg g^{-1}			
Entry Point 1‡								
LIP-CG	13.6	182	0.075	0.051	6.2	186	0.034	0.054
CONV	8.2	133	0.060	0.044	4.6	132	0.035	0.042
Significance	***	*	**	*	*	*	NS	*
CV, %	7	8	5	4	11	9	9	10
Entry Point 2§								
LIP-CG	11.6	186	0.063	0.052	4.6	188	0.025	0.057
CONV	5.4	86	0.064	0.030	2.6	103	0.026	0.035
Significance	*	**	NS	**	NS	**	NS	**
CV, %	25	3	33	7	26	9	26	9

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively; NS = not significant at $P = 0.05$.
† N mineralization/biomass N.
‡ Year 1 = 1987; Year 2 = 1988.
§ Year 1 = 1988; Year 2 = 1989.

mass N to soil N was greater in soil from the legume-based than from the fertilizer-based system at every sampling.

Due to its critical role as a source–sink and transformer of soil N, the size of the microbial biomass is considered to be a good indicator of soil quality (McGill et al., 1986). Microbial biomass C and N pool sizes were not only greater, but a greater portion of the soil C and N was made up of biomass C and N in the LIP-CG system.

The greater microbial activity in the LIP-CG system was due to the larger pool size of microbial biomass C. This is true because: (i) the biomass C pool was significantly greater in the LIP-CG system, (ii) there was no difference between systems in specific respiratory activity, and (iii) C mineralization is the product of biomass C times specific respiratory activity.

Following similar results and logic as stated above for microbial C, our results also suggest that N mineralization, or the N-supplying power of soil, was greater in the LIP-CG system than in the CONV system primarily due to the larger pool size of microbial biomass N.

CONCLUSIONS

In both the CONV and LIP-CG systems, substantial amounts of N were lost during the year of application, although loss of fertilizer N was generally higher than loss of legume N. More legume N than fertilizer N was lost the year after application and is thought to be related to the larger amount of legume N left in soil after Year 1.

Soil microbial biomass was larger in the legume-based than in the fertilizer-based system, but specific respiratory activity was the same. We conclude that a larger, but not necessarily more active, soil microbial biomass is responsible for the greater soil N supplying capacity in the legume-based compared with fertilizer-based system and that similar amounts of legume N and fertilizer N may be lost from cropping systems during the first 2 yr after incorporation.

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