AN INTEGRATED APPROACH TOWARDS SUSTAINABLE SOIL AND WATER QUALITY MANAGEMENT

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Abstract

Understanding the influence of legumes, used as winter cover crops or underseeded in row-crops, on soil N dynamics is critical in developing sustainable soil and water quality management strategies. An incubation experiment was carried out to determine the influence of intrinsic soil properties and bulk density on N-mineralization subsequent to red clover incorporation and to develop equations to predict N-mineralization as a function of intrinsic soil properties. The soils used in this study had different intrisic properties. Air-dried and ground red clover shoot material was mixed with soil,< 4 mm, to provide 140 kg N ha^{-1} (75 mg legume-N kg^{-1}) and incubated for 72 d. The size of the potentially mineralizable resistant N-pool, N_r, in the red clover added treatment ranged from 28.2 to 68.1 mg kg^{-1} and that of the labile pool, Nl, from 10.3 to 27.1 mg kg^{-1}. The corresponding range in rate constant, k_r, of the resistant pool was from 0.0038 to 0.0065 d^{-1} and that of the labile pool, k_l, ranged from 0.0081 0.060 d^{-1}. The pedotransfer function, PTF, analysis indicated that Nl, kl, N_r, and k_r are functions of soil properties; clay, silt, CEC, organic matter, CaC03, total N, C:N ratio, and bulk density. The PTF's approach eliminated the need for labour intensive, laboreous, and time consuming incubation experiments to predict legume N-mineralization, thereby enabling the development of best N-management practices and reduce N leaching.

Introduction

A legume underseeded in cereal or established as a winter cover represents an important source of N to the subsequent summer crop, thereby reducing the dependence on fertilizer-N, and can be effective in improving in soil structural quality. On the other hand, the reduction in dependence on fertlizer-N may also lead to substantial decrease in contamination of water bodies by nitrate-N, particularly ground water. The extent to which the N benefit is realized or leaching depends on the rate of mineralization of legume N in relation to crop N demand. We are, however, unable to predict the rate of mineralization of legume-N across a range of soil conditions.

The ability of legumes, as a cover or as an underseeded crop, to serve as an effective source of N for row crops depends on the amount of N fixed by the legume and the rate of mineralization of legume-N. The amount of N fixed depends primarily on the legume species (Christie et al., 1992; Reeves et al., 1993) and climate (al., 1982; Doran and Smith, 1991). The rate of mineralization depends on the legume species, climate, tillage practices (Wagger, 1989), indigenous organic N and C (Cabrera and Kissel, 1988), soil texture (Herlihy, 1979), soil pH (Schmidt, 1982), C:N ratio (Harmsen and van Schreven, 1955), and NH4 retention capacity (Kowalenko and Cameron, 1976). Even though N-mineralization seems to be influenced by intrinsic soil properties and tillage practices, their influence has not been explored in detail for predictive purposes. Such information is crucial if we were to develop best fertilizer-N management practices to summer crops. Further more, Miller et al. (1992) have shown the amount of N available for leaching depends on the soil type and cover crop species. The objectives of this study were to (i) determine the influence of intrinsic soil properties and bulk density on N-mineralization subsequent to red clover incorporation and (ii) to develop equations to predict N-mineralization as a function of intrinsic soil properties.

Materials and Methods

Equations to predict N-mineralization

The temporal variation in legume N mineralization in a given soil can be modelled using the first-order rate equation proposed by Stanford and Smith (1972)

$$N_m = N_o[1 - \exp(-k_o t)] \quad [1]$$

where N_m is the amount of N mineralized at time t, N_o is the amount of potentially mineralizable N and k_o is the first order rate constant. The estimates for N_o and k_o have usually been obtained from aerobic incubation experiments (Stanford and Smith, 1972; Campbell et al., 1984). Because, different fractions of organic N in soil may be differentially susceptible to mineralization (Cabrera and Kissel, 1988; Cabrera, 1993) the first-order one pool model(Eq.[1]) has often been found to be inadequate to describe N-mineralization in soil, particularly when fresh organic material was incorporated, and has been modified to a two pool model,i.e.,

$$N_m = N_l[1 - \exp(-k_l t)] + N_r[1-\exp(-k_r t)] \quad [2]$$

where Nl and N_r are the amounts of organic N initially present as the labile and resistant N pools, respectively, and kl and k_r are the corresponding first-order rate constants for the two pools.

Pedotransfer functions, PTF, have been used to define the parameters of models such as Eq.[2] as function of intrinsic soil properties (Bouma, et al., 1987). These functions enable the computation of values for the parameters which could then be used to model N-mineralization.

Site description

The soils used in this study were collected from a farm near Clinton, Ontario. The site is a 500 m transect and soil samples were collected from 7 locations, to represent a range in clay content, from 8 to 40% (Table 1). The sample collected from each location was air-dried to constant moisture content and sieved to obtain material c 4.00 mm and this material was used for soil characterization and incubation.

Bulk density

Each soil was packed to two bulk density, the low and high. The low density for soil one through seven is 1.288, 1.288, 1.327, 1.264, 1.288 g cm^{-3}, respectively, and the corresponding high

Table 1. Intrinsic properties of the soils

Selected properties									
Soil#	Clay	Silt	Sand	OM	TN	$CaCO_3$	pH	CN	CEC
	(.................. %....................)								meq/100
1	8.5	18.4	73.1	2.3	0.088	5.7	7.2	15.0	21.0
2	24.1	50.8	25.1	3.3	0.158	1.1	7.2	12.0	18.5
3	25.7	49.7	24.6	3.7	0.130	3.7	7.3	11.7	21.1
4	25.8	54.5	19.7	3.2	0.153	2.3	7.3	12.3	21.2
5	27.6	52.5	19.9	2.7	0.100	5.7	7.4	15.7	22.0
6	35.3	47.3	17.4	4.3	0.188	1.7	7.5	13.4	33.4
7	36.7	50.4	12.9	3.7	0.180	1.4	7.4	11.8	30.0

OM =organic matter, CN = C:N ratio, TN = total-N, and CEC = cation exchange capacity.

density condition is 1.45 1, 1.433, 1.433, 1.415, 1.433, 1.362, and 1.362 g cm^{-3} respectively.

Characteristics of the red clover material

Red clover shoot biomass was collected in early September 1993. The shoot biomass was dried at 80^oC for 2 to 3 d and ground to , 2 mm and used in subsequent studies. The total N content in the ground material was 2.4% and the C content was 45.9%. The amount of red clover N added to the soil was equivalent to about 140 kg ha^{-1} (75 mg legume-N kg^{-1}soil).

Incubation

Soil columns for incubation were packed in cylindrical aluminum rings, 4.8 cm internal diameter and 2.5 cm high, to low and high densities for each soil. Before packing, the required amount of red clover material was mixed with the soil for the treatment. The control in the experiment was no red clover incorporation. There were four replicates for each treatment. Subsequent to packing, the amount of water required to bring a given soil to - 15 KpA was applied. The soil column was then transferred to a zip-lock air-tight polythene bag in order to reduce evaporation during incubation. However, two to three pin-prick holes were made on the bag to ensure sufficient aeration. There were 612 columns, i.e, 7 soil x 2 bulk density x 2 treatment x 4 replicates x 6 time of sampling. Nitrate- and ammonium-N were measured after incubation for 14, 21, 32, 42,56, and 70 d using the procedure described by Keeney and Nelson (1986). The incubation was conducted in a room maintained at a temperature of 23 ± 1^oC.

Results and Discussion

N-mineralization

The temporal variation in inorganic-N (ammonium plus nitrate) for soil 1 with red clover treatment is shown in Fig. 1a. The corresponding data for the control is shown Fig. lb. For comparison and contrast the data is shown in Fig. 2 for soil 6. Until day 21 the N-mineralization from the control was greater than the treatment (Figs. **1** & 2). The biomass-N data during this period indicated that biomass N in the treatment was twice much as that in the control (not shown). Thus, until day 21, N-immobilization was greater than N-mineralization in the treatment, therefore the amount of inorganic-N in the treatment was less than that in the control. Increases in bulk density resulted in increases in N-mineralization both in the treatment and in the control in soil 1 (Fig. la & b). An opposite trend was observed in soil 6 (Fig. 2 a & b).

Fitting N-mineralization data

The N data obtained for the 7 soils during the 70 day incubation period was fitted to Eq.[2]. The model converged to solution, i.e, produced estimates for the N-mineralization parameters, for the treatment, i.e., with red clover, (Fig. la) but not for control, i.e., without clover. The N-mineralization data for control fitted only to Eq.[1]. Each best fit was significant at $P < 0.05$ and the R^2 values for the best fits ranged from 0.63 to 0.99 (Table 2).

The N-mineralization data were regressed with soil properties and time to determine whether a multiple regression could be used to predict N instead of Eq.[2]. The best fit was not significant indicating that Eq.[2] was the most appropriate form to predict legume-N mineralization.

Estimates of N-mineralization parameters

The size of the potentially mineralizable resistant N-pool, N_r, obtained using Eq.[2], ranged from 28.2 to 51.3 mg kg^{-1} for the low density condition, and that of the labile pool, Nl, ranged from 14.3 to 20.6 mg kg^{-1} (Table 2). The corresponding range in the rate constant of the resistant pool, k_r, was from 0.0038 to 0.0056 d^{-1} and that of the labile, kl, was from 0.017 to 0.060 d^{-1}. The ranges in values of N_r, Nl, k_r, and kl obtained for the high density condition were similar to that obtained for the low density condition. However, in general, the values of N_r obtained for high density condition were greater than the corresponding values obtained for low density and an opposite trend was observed for the values of Nl. Higher bulk densities decreased the values of kl to a larger extent than that of k_r.

The size of the potentially mineralizable N-pool, N_o, obtained for the control at low density ranged from 14.4 to 27.2 mg kg^{-1} and the corresponding range in rate constant, k_o, was from 0.056 to 0.13 d^{-1} (Table 2). The range in values of the N-pool size and the corresponding rate constant obtained for the high density condition for the control was less than the corresponding range obtained for the low density. A comparison of the values of N_r plus Nl, for a given soil, with the corresponding value of N_o indicates the size of the potentially mineralizable N-pool substantially increased following incorporation of red clover. Value of k_o, for a given soil and at a give bulk density, was greater than the corresponding values of k_r or kl. It appears that clover incorporation substantially altered the nature and size of the potentially mineralizable N-pool and the rate constant of these pools.

Influence of soil properties on N-mineralization parameters

The stepwise variable selection analysis indicated that from 58 to 93% of the variability in the values of N-mineralization parameters was accounted for by intrinsic soil properties (Table 3). Based on the values of R^2 for the PTF's it is evident that soil properties had significance influence on legume N dynamics. In addition to intrinsic soil properties, values of Nl, N_r, kl, and k_r, were also influenced by bulk density which may change subsequent to changes in tillage practices.

Table 2. Values of N-mineralization parameters for the 7 soils.

Soil	N_o	N_r	N_l	k_o	k_r	k_l	R^2_o	R^2_2
	Values at low bulk density							
1	22.21	33.69	14.93	0.1245	0.0044	0.0596	0.84	0.91
2	22.01	51.3	14.94	0.1313	0.0056	0.0176	0.63	0.99
3	22.63	33.43	20.34	0.1279	0.0038	0.0329	0.84	0.97
4	21.74	49.47	14.49	0.0987	0.0060	0.0165	0.96	0.99
5	25.41	31.25	20.55	0.0923	0.0040	0.0299	0.98	0.97
6	18.82	28.16	17.04	0.0693	0.0050	0.0243	0.85	0.89
7	14.42	43.68	14.34	0.0561	0.0044	0.0247	0.88	0.95
	Values at high bulk density							
1	25.41	34.71	27.11	0.0872	0.0051	0.0375	0.89	0.86
2	19.18	68.12	10.32	0.0414	0.0065	0.0112	0.99	0.92
3	20.72	54.40	16.42	0.0981	0.0050	0.0253	0.80	0.96
4	21.32	61.84	11.84	0.0626	0.0052	0.0149	0.71	0.98
5	23.87	35.83	20.62	0.0529	0.0063	0.0299	0.98	0.97
6	11.81	67.41	11.22	0.0614	0.0051	0.0081	0.79	0.89
7	13.97	46.66	8.32	0.0179	0.0045	0.0200	0.83	0.96

N=potentially mineralizable nitrogen, k=rate constant. The subscript o refers to N-mineralization parameters for the one pool model (control), r and 1 refer to the resistant and labile N-pools, respectively, of the two pool model (red clover treatment) and the corresponding rate constants. The subscript 2 refers to the two pool model.

Table 3. The pedotransfer functions to predict N-mineralization parameters from soil properties.

Equation	R2
N_r = 79.03 BD - 2.20 CEC + 355.80 TN- 61.52	0.85
Nl = 6.27 clay + 106.29 BD + 1.72 CaC03 - 4.70 clay BD -13 1.75	0.88
k_r = 0.0014 OM + 0.0067 BD - 0.00014 CEC - 0.0051	0.58
kl = 0.2113 + 0.0062 CaC03 - 0.0868 BD - 0.0045 CN - 0.00065 Silt	0.93
N_o = 148.81 BD + 225.56 TN - 192.37	0.77
k_o = 0.135 -0.00028 Silt - 0.181 TN - 0.0581 BD	0.90

N=potentially mineralizable nitrogen, k=rate constant. The subscript o refers to one pool model and r and 1 refer to the resistant and labile N pools, respectively, of the two pool model and the corresponding rate constants. CN = carbon to nitrogen ratio, BD = bulk density (g cm^{-3}), TN = total N (%), CaC03 and clay contents in %, CEC = cation exchange capacity in meq/100 g, and clay in %. The equations are significant at $P \leq 0.05$.

The PTF presented in Table 3 for Nl indicate that it increased with increasing caly and CaC03 contents and bulk density. A strong interaction involving clay and BD indicate the values of Nl increased with increasing clay, at constant density, at low clay content and the trend got reversed at high clay content.

This suggests the influence of changes in bulk density caused by changes in tillage systems on the size of labile N-pool largely depends on the clay content. The increase in Nl with bulk density may be due to increased accessibility of the organic substrate to decomposers and their predators. At higher clay contents an increase in bulk density lead to an increasing proportion of smaller pores which may physically protect organic substrates from decomposition. Values of N_r increased with increasing bulk density and total-N and decreasing CEC. An increase in the size of the labile N-pool resulted in a decrease in the size of resistant N-pool (Table 2). Thus, increases in clay content resulted in larger size of resistant N-pool. Increases in bulk density at high clay content also resulted in larger resistant N-pool.

The rate constant of the labile N-pool, kl, was influenced by silt, C:N ratio, and CaC03, and by bulk density. Decreases in kl with increasing bulk density suggests the mineralization of legume-N under reduced till management system is slower than under conventional till. The influence of soil properties on the rate constant of the resistant N-pool, k_r, showed a trend opposite to that of kl for changes in bulk density (Table 3). This suggests, that changes in tillage practices had the opposite impact on the amounts of legume-N released from the corresponding pools.

The size of the N-pool in the control, N_o, was influenced by total-N and bulk density (Table 3). This sensitivity to bulk density suggests that management changes has an impact on the size of potentially mineralizable N even in the absence of substrate addition, i.e, without red clover. The rate constant k_o, was influenced by total-N, silt content, and bulk density.

Conclusions

The following conclusions relate to the influence of soil properties and soil management changes on the production of N from legumes:

Clay and CaC03 contents, bulk density, and an interaction term involving clay and bulk density determined the size of the labile-N pool, Nl, ie. the readily available legume-N. The rate constant of this pool, kl, was influenced, in addition to bulk density and CaC03, by C:N ratio and silt content.

The size of the resistant N-pool, N_r, was determined by bulk density, CEC and total-N. In addition to bulk density and CEC, organic matter content determined the rate constant, k_r, of the resistant pool.

The procedure followed in this study shows that legume-N mineralization, from underseeded or winter cover legumes, can be predicted using the information in soil inventory data. This information can be used to develop appropriate fertilizer-N management strategeies, thereby reducing N leaching.

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