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EFFECT OF PLANT MATERIAL PARAMETERS ON NITROGEN MINERALIZATION IN A MOLLISOL[1]

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ABSTRACT: The introduction of plant materials into a soil can impact the nitrogen (N) status and the fertilizer requirement for agronomic crop production. Consequently, an accurate estimate of N mineralization from soil organic matter and incorporated plant material is necessary to adequately make a N fertilizer recommendation. The purpose of this study was to evaluate the effect of plant parameters including type, size, incorporation rate, and time after incorporation on N mineralization and to derive localized values for parameters in a widely used potential N mineralization model. Soil from the Ap horizon of a Latahco silt loam was amended with alfalfa (*Medicago saliva* L.), spring pea (*Pisum sativum* L.), and winter wheat (*Triticum aestivum* L.) plant materials sized to either <1, 1 to 2, or > 2 mm at rates of 0, 2, 4, and 6%. The soils were incubated at 35°C for 20 weeks. The inorganic N in soils was removed by leaching with 100 mL 0.001M $CaCl_2$ in 5- to 10-mL intervals followed by 25 mL of a nutrient solution devoid of N (0.002M $CaSO_4$; 0.002M $MgSO_4$; 0.005M $Ca(H_2PO_4)_2$; and 0.0025M K_2SO_4) at 0, 2,4, 6, 8, 12, 16, and 20 weeks. The main effects of plant material type (PM), size (S), incorporation rate (R), and incubation time (T) and many 2-, 3-, and 4-factor interactions on N mineralization were statistically significant at P=0.05. Based on w^2, incubation time (T), and incorporation rate (R) were the two most important factors affecting N mineralization. The amount of N mineralized increased exponentially with increasing time and linearly with the incorporation rate. In addition, the incorporation of plant material not only increased potentially mineralizable N by as

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much as 5.1 times but also accelerated N mineralization in soil by increasing the N mineralization rate constant 75%.

INTRODUCTION

Plant residues are usually incorporated into soils or left on the soil surface after harvest. Legumes used as green manure are also plowed into soils to improve both soil physical and chemical properties. This practice influences the N fertilizer needs in most farming practices. Accordingly, an accurate estimate of N mineralized from soil organic matter and incorporated plant material is necessary to make satisfactory N fertilizer recommendations for agronomic crops. The incorporation of plant material or residues, especially legume plant materials which often have higher N content than non-legumes, to soils often increases both the total N content and N mineralization potential (Black, 1968). The effect of residue incorporation on soil N availability depends on the plant material, soil properties, and environmental factors. It has been well documented that carbon/nitrogen (C/N) ratio and/or percent N of the plant residues is a key factor affecting the N mineralization and availability of organic N in soils (Harmsen and Van Schreven, 1955; Alexander, 1977; Harper and Lynch, 1981; Reinertsen et al., 1984; Christensen, 1986; Smith and Sharpley, 1990). The incorporation of plant materials with a C/N ratio <20 to 25 will consistently result in both short- and long-term net N mineralization in soils. The amount of plant residue incorporated into a soil also has an important effect on N availability in soils. The more material incorporated, the more N added to the soil N pool, resulting in greater net mineralization over time.

The speed of net mineralization and immobilization processes after residue incorporation has an impact on the quantity of N available for crop growth. The quantity of N mineralized generally increases non-linearly with time. Non-linear mathematical models have been derived to predict N mineralized in soils (Stanford and Smith, 1972; Reddy et al., 1979; Stark and Clapp, 1980; Parker and Sommers, 1983; Cabrera and Kissel, 1988; Sierra, 1990; White and Marinakis, 1991). The most commonly used model is the exponential model based on the first order kinetics, i.e., $N_t = N_o (1 - e^{-kt})$, where N_t is the cumulative net mineralized N at the incubation time t, N_o is the potentially mineralizable N, and k is the N mineralization rate constant. The parameters in this widely used model are dependent on many factors including soil characteristics and plant residue properties. Consequently, values for the parameters should be based on localized data.

The objectives of this laboratory study were to: 1) evaluate the effect of plant material type, size, incorporation rate, and time after incorporation (incubation period) on N mineralization in a Latahco silt loam soil, 2) assess the N mineralization capacity of the soil studied, and 3) derive localized values for parameters in the study model.

MATERIALS AND METHODS

Soil

Thirty kg of soil was collected from the Ap horizon of a Latahco silt loam (fine-silty, mixed, frigid Argiaquic Xeric Argialboll) from the University of Idaho Plant Science farm 3 km east of Moscow, Idaho in May, 1992. The collected soil was immediately air-dried, crushed to pass a 2-mm sieve, thoroughly mixed, and stored in a covered plastic container at room temperature until the experiment was initiated. Initially, this soil contained 1.97% organic carbon (OC) based on the Walkley-Black method (Nelson and Sommers, 1982), 0.13% total Kjeldahl N (TKN) (Bremner and Mulvaney, 1982), and had a saturation paste pH of 6.05 (Richards, 1954).

Plant Materials

The above ground portions of alfalfa (*Medicago saliva* L., spring pea (*Pisum sativum* L.), and winter wheat (*Triticum aestivum* L.) plant tissue were collected from farm fields on May 15, 1992, dried at 60°C for 5 d, chopped to pass screens of either <1, 1 to 2, or > 2 mm, and then stored at room temperature. Alfalfa, pea, and wheat plant materials contained 3.16, 3.95, and 2.49% N on a dry weight basis. The C/N ratios of the alfalfa, pea, and wheat materials were 14, 13, and 20, respectively.

Study Design and Procedures

This experiment contained three plant materials (alfalfa, pea, and wheat), four amendment levels (0, 2, 4, and 6% w/w), three sizes of plant material (<1, 1-2, and > 2 mm) and four replications. The study design was a randomized complete block factorial design with repeated measures.

Thirty g of soil and the specified treatment (plant material, rate and size) were thoroughly mixed and transferred to a 50-mL leaching tube. The leaching tube was cylindrical and made of PVC material. The bottom of the tube was sealed using a rubber stopper with a 2-mm diameter hole in the center. A 1.5-cm layer of silica sand and a thin glass wool pad were placed between soil and the stopper to avoid both the loss of soil and the formation of channels in soil during leaching. A 0.3-cm thick glass wool pad was placed on the soil surface to prevent dispersion of soil when solution was poured into the tube.

Inorganic N (HH_4 and NO_3) was removed by leaching from the soil prior to incubation and again at 2, 4, 6, 8, 12, 16, and 20 weeks of incubation. The soil tubes were leached with 100 mL 0.001M $CaCl_2$ in 5- to 10-mL intervals followed by 25 ml of a nutrient solution lacking N (0.002M $CaSO_4$; 0.002M $MgSO_4$; 0.005M $Ca(H_2PO_4)_2$; and 0.0025M K_2SO_4). Before a leaching event, the soil was removed from the tube, mixed, and the tube refilled for maximizing the recovery of recently mineralized N. Excess water was removed using a vacuum and water content was gravimetrically maintained near field capacity (-0.03 to -0.04 MPa) throughout the incubation. After each leaching episode, the tubes were covered with Parafilm with a 2-mm diameter hole to provide aerobic conditions and incubated at 35°C. Total inorganic N (NH_4 and NO_3) in the leachates was determined by steam distillation (Keeney and Nelson, 1982).

Data Analysis

Cumulative N mineralized over the 20-week incubation was computed and the SAS-GLM procedure was used to analyze the collected data (SAS Institute Inc., 1985). When appropriate, means were separated using Fisher's Least Significant Difference (LSD). In addition, Omega squared values (w^2), a measure of strength of association between dependent and independent variables, were computed for all parameters evaluated in this study to rank the importance of main effects and their interactions (Kirk, 1982). The SAS-NLIN procedure was used to fit the data to the model: $\mathbf{N_t = N_o (1 - e^{-kt})}$ for estimating $\mathbf{N_o}$ and $\mathbf{k}$, where $\mathbf{N_t}$ is the cumulative net mineralized N at time $\mathbf{t}$, $\mathbf{N_o}$ is the N mineralization potential, and $\mathbf{k}$ is the N mineralization rate constant.

RESULTS AND DISCUSSION

Several factors had significant influences on the cumulative amount of N mineralized based on analysis of variance (Table 1). One 4-factor, four 3-factor, and six 2-factor interactions were significant at P=0.05. The main effects of plant material type, size, incorporation rate, and incubation time significantly affected the cumulative amount of N mineralized. Although these factors were all statistically significant, their contributions to the cumulative net mineralized N values were different. To rank their relative importance, the strength of association, omega

Table 1. Significance of each variable and their interactions on N *mineralization in laboratory incubation study.*

Variable	df	Significance	ω^{2*}
Block(B)	3	N.S.**	0
Plant Material(PM)	2	0.0001	0.016
Size(S)	2	0.0001	0.015
PM X S	4	0.0001	0.047
Rate(R)	3	0.0001	0.155
PM X R	6	0.0001	0.033
S X R	6	0.0001	0.041
PM X S X R	12	0.0001	0.160
Error(a)	105		
Time(T)	6	0.0001	0.156
T X B	18	N.S.	0
T X PM	12	0.0001	0.014
T X S	12	0.0001	0.011
T X PM X S	24	0.0001	0.026
T X R	18	0.0001	0.185
T X PM X R	36	0.0001	0.028
T X S X R	36	0.0001	0.044
T X P X S X R	72	0.0001	0.069
Error(b)	630		

* Measure of strength of asociation between dependent and independent variables expressed in fraction.
** NS = Not significant at the significance level of $P=0.05$.

squared values (w^2), for each source of variation was computed (Table 1, Kirk, 1982). The greater the w^2, the stronger the association between dependent and independent variables. The sources of variation will be discussed in the order of their importance (highest w^2 value first).

Incubation Time x Incorporation Rate

The incubation time (T) x incorporation rate (R) interaction had the greatest impact on the cumulative N mineralized, as it accounted for 18.5% of the observed variation (Table 1). Net N mineralization values increased with increasing incubation time; however, the incorporation rate of material determined the net mineralization (Figure 1). The incorporation rate had a minimal affect on N mineralization between 8 and 20 weeks compared with the early incubation periods.

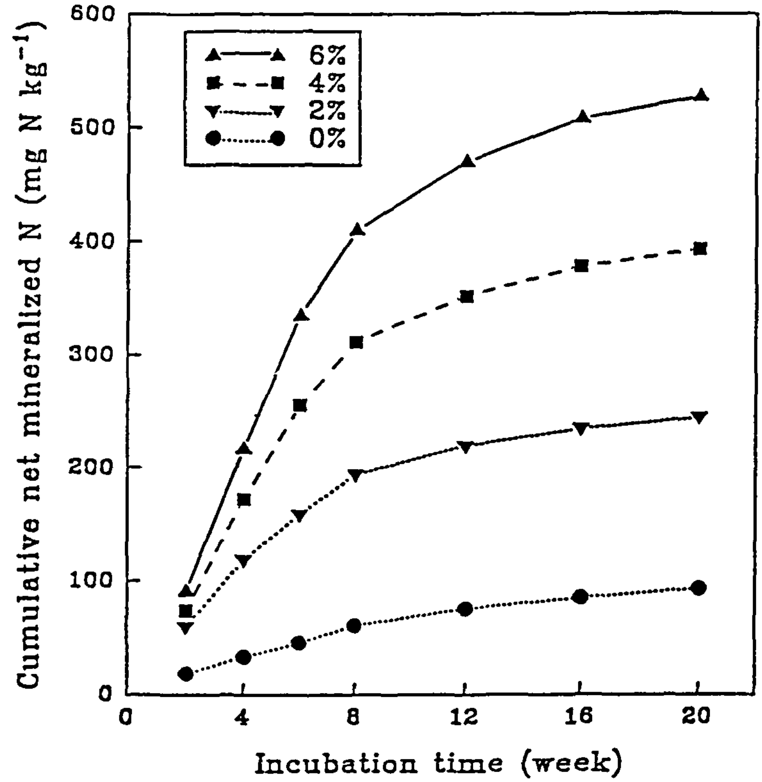

Figure 1. The interaction of incorporation rate X incubation time on cumulative N mineralized in soil over 20-wk incubation period.

This effect may have partially resulted from the different N contents in various incorporated plant materials. The priming effects and pretreatment of soil samples (drying, grinding, sieving, etc.) might also play an important role in the enhanced N mineralization observed early in the incubation (Stanford et al., 1974; Nordmeyer and Richter, 1985; Molina et al., 1990).

Plant Material Type x Size x Incorporation Rate

The 3-factor interaction of plant material type (PM) x size (S) x incorporation levels (R) was found to account for 16% of the total variation in cumulative net mineralized N values (Table 1). This interaction, which had the second greatest impact on variation, showed that for each plant material there was a unique S x R interaction for net N mineralization (Figure 2). The difference in cumulative net mineralized N values between plant material sizes was the smallest in 2% wheat plant material treatment, but greatest in 6% alfalfa and pea plant material treatments.

Incubation Time

The main effect, incubation time (T), accounted for 15.6% of the observed variation in cumulative net mineralized N (Table 1). Cumulative N mineralization values increased exponentially with increasing incubation time and concformed to the model: $N_t = N_o (1 - e^{-kt})$, derived from the first-order kinetics (Figure 3). The mineralization rate reached a maximum (37 mg N/kg/wk during the third and fourth weeks of the incubation. Based on pooled data, cumulative N mineralization is predicted at 342.3 mg/kg over an infinite incubation time period (N_o = N mineralization potential).

After the 20-week incubation period, 84% of the potentially mineralizable N (N_o) in the control soil was mineralized (Table 2). Conversely, in the soils amended with plant materials, 88 to 95% of the N_o was minerali:zed. These values were statistically higher than the 84% of N_o value in the control. Alfalfa plant material resulted in the greatest percent of applied material minerialized, while wheat plant material had the least impact on mineralization. Plant material incorporation levels had less of an effect than incubation time, although differences were often statistically not significant.

The amount of N mineralized from the incorporated plant materials ranged from 16 to 31% (Table 21. The 2% alfalfa plant material treatment resulted in the greatest recovery of added N (30.9%) compared to only 16% recovery in the 2% wheat treatment after an incubation period of 20. The difference in recovery was probably related to C/N ratio as the narrow ratio in the alfalfa and pea material resulted in a higher recovery. The difference in C/N ratio between alfalfa and pea plant materials could not be used to explain N recovery differences. This suggests that other factors are influencing N mineralization. One factor could be lignin content, since it has been suggested that lignin content is a better N mineralization predictor than C/N ratio or N content (Muller et al., 1988).

Incorporation Level

Incorporation level (R) accounted for 15.5% of the total variation in cumulative net mineralized N values (Table 1), having the largest effect on mineralization of the factors studied. The cumulative net mineralized N values had a significantly positive

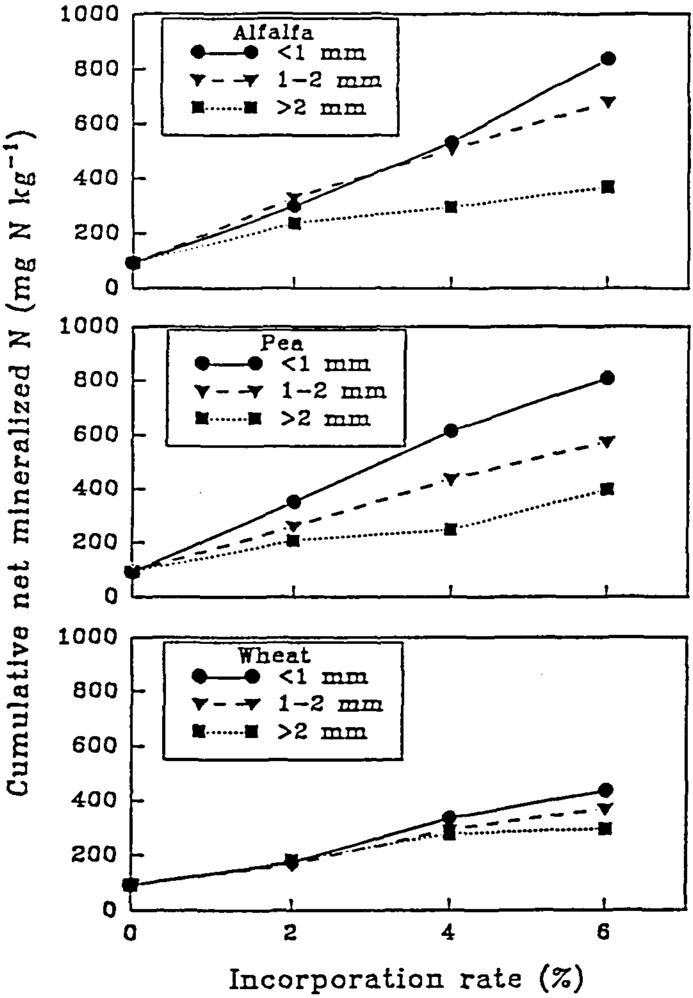

Figure 2. The interaction of plant material X incorporation rate on cumulative N mineralized in soil over a 20-wk incubation period. Plant material was applied at levels of 0, 2, 4 and 6% on a w/w basis.

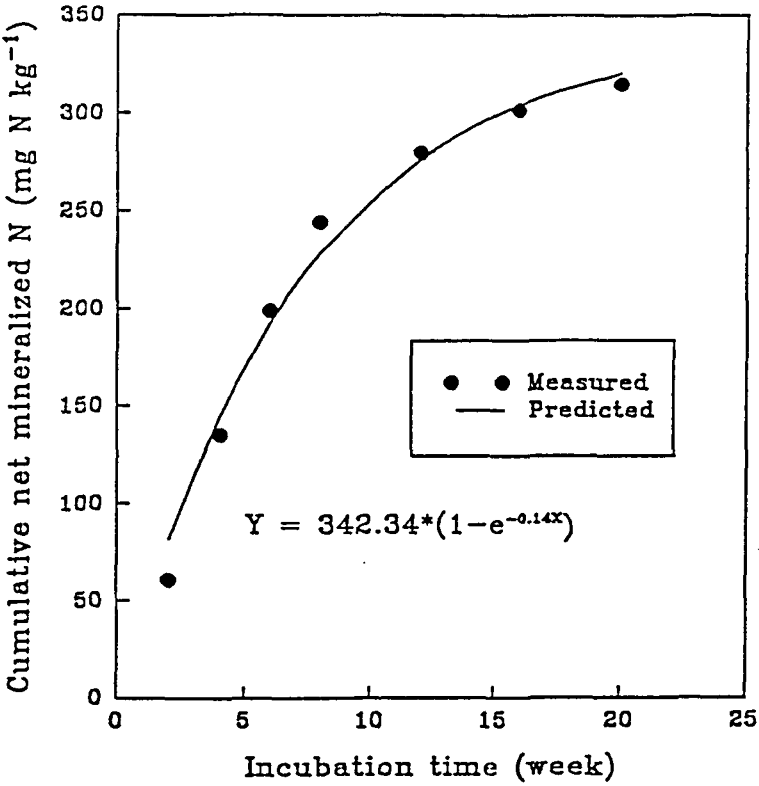

Figure 3. The relationship between incubation time and cumulative N mineralized in soil over a 20-wk incubation period.

linear correlation with incorporation level based on pooled data of three plant materials (Figure 4). Regardless of other factors, the model: $y = 95.57 + 72.75x$, can be used to predict the amount of N mineralized in 20 weeks after incorporating less than 6% plant materials to soils.

The effect of incorporation level on the cumulative net mineralized N values was due to the amount of N added to soil with the incorporated plant materials. The more plant material incorporated, the more N added to the soil N pool and the more N released to soil as inorganic N. This factor demonstrated net N mineralization in soil after the incorporation. The narrow C/N ratio values (high N) in all three plant

Table 2. Cumulative N mineralized from plant material and soil after 20-week incubation.

Treatment	Rate (%)	Nitrogen mineralized (% of N_0)	(% of total added)
Check	0	84.0*	-
	2	95.2_a**	30.9_b
Alfalfa	4	93.0_a	28.1_a
	6	92.8_a	28.0_a
	LSD(0.05)	3.0	1.3
	2	95.2_b	22.7_b
Pea	4	92.2_a	21.5_a
	6	89.5_a	21.1_a
	LSD(0.05)	2.9	1.1
	2	94.3_b	16.1_a
Wheat	4	91.8_{ab}	20.9_c
	6	88.5_a	18.3_b
	LSD(0.05)	3.3	1.2

* *Significantly lower than all plant material treatment at significance level* $P=0.05$.

** Means within the same column for each plant material followed by the same letter are statistically similar at $P=0.05$. The letters a to c represent the lowest to highest values of variables, respectively.

materials used resulted in less immobilization because plant material with a C/N ratio less than 20 to 30 usually generates net mineralization over a short time period.

Incubation Time x Plant Material x Size x Rate

This 4-factor interaction was found to account for 7% of the variation in this study (Table 1). This significant interaction suggests that all four factors used in this study influenced each other. The effect of any one factor on cumulative net mineralized N values would depend on the other three factors.

Plant Material x Size

The plant material (PM) x size (S) interaction accounted for 5% of the variation in this study (Table 1). The smaller than 1-mm pea material produced the highest amount of N mineralized, while the wheat material larger than 3 mm produced the

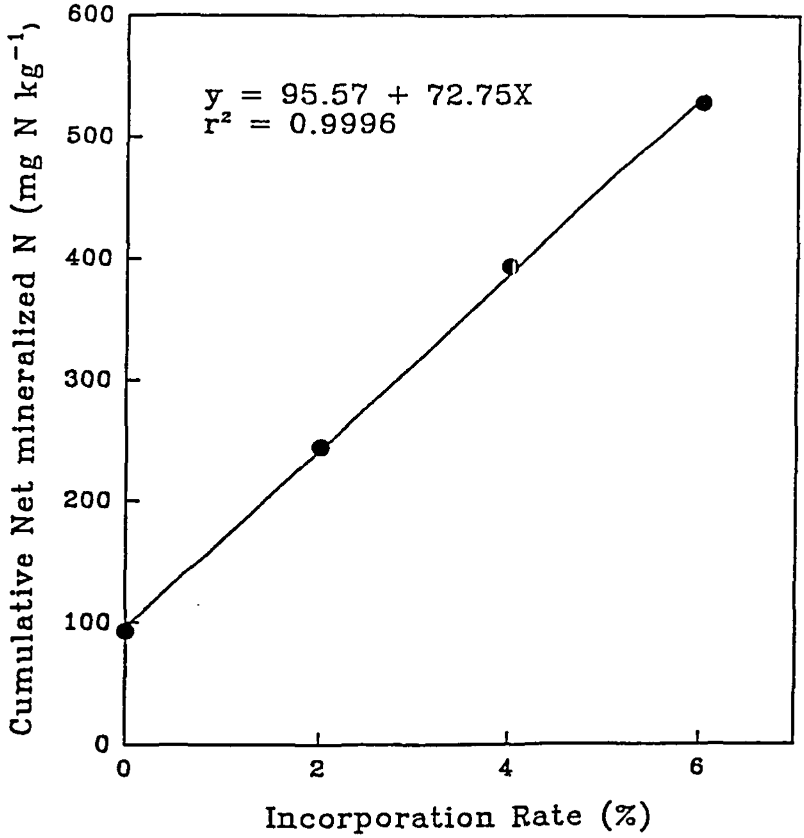

Figure 4. The relationship between incorporation rate of plant material and cumulative N mineralized in soil over a 20-wk period.

least amount of inorganic N (Table 3). When the plant material was larger than 2 mm, alfalfa released the most N. The N mineralization differences between plant materials was greatest when the size was less than 1 mm.

Other Significant Interactions and Main Effects

Although the 3-factor interactions of (i) incubation time (T) x size (S) x incorporation rate (R), (ii) incubation time (T) x plant material type (PM) x incorporation rate (R), (iii) incubation time (T) x plant material type (PM) x size (S); and 2-factor interactions of (iv) incubation time (T) x size (S), (v) incubation time

Table 3. Comparison of the effect of size of incorporated plant material on the cumulative mineralized N with each plant material.

Material size	Alfalfa	Pea	Wheat
(mm)		(mg N kg^{-1})	
<1	439.4$_c$*	465.5$_c$	258.9$_c$
1-2	398.2$_b$	340.9$_b$	230.6$_b$
>2	252.8$_a$	236.1$_a$	211.1$_a$
LSD(0.05)	9.8	10.0	5.9

* Means within the same column followed by the same letter are statistically similar at $P=0.05$. The letters a to c represent the lowest to highest values of variables, respectively.

(T) x plant material type (PM), (vi) size (S) x incorporation rate (R), (vii) plant material type (PM) x incorporation rate (R), and (viii) main effects of plant material type (PM) and size (S) were statistically significant with each contributing less than 5% variation. They collectively accounted for about 23% of the variation in this study. The low C/N ratio in all three plant materials may explain the small influence of plant material type in this study compared to previous work.

Nitrogen Mineralization Potential

Many studies have employed similar procedures to study potentially mineralizable soil N. Several mathematical models have been used to derive soil N mineralization potential; however, the most commonly used model is the exponential model, $N_t = N_o (1 - e^{-kt})$, based on first order kinetics. This model suggests that variation in cumulative net mineralized N values is a function of some portion of the organic N concentration in the soil and incorporated plant materials. This expression also best fits the data collected in this study. As a result, this model was used to derive estimates of N_o (N mineralization potential) and k (N mineralization rate constant).

Incorporation of plant material into soil significantly increased the soil N mineralization potential (Table 4). Without the addition of plant materials, the soil used in this study had a N mineralization potential of 110.72 mg N/kg. This is equivalent to 8.5% of the TKN in soil. Incorporation of alfalfa material increased

Table 4. The effect plant materials and incorporation rate on N mineralization potential and rate constant.

Treatment	Rate (%)	N_0* (mg N kg^{-1})	k* (wk^{-1})	N_0 (% of TKN)
Check	0	110.72	0.093	8.52
	2	302.07	0.159	15.64
Alfalfa	4	479.81	0.144	18.71
	6	675.48	0.145	21.14
	2	286.02	0.163	13.69
Pea	4	469.05	0.145	16.29
	6	662.07	0.127	18.04
	2	183.64	0.149	10.21
Wheat	4	329.23	0.135	14.34
	6	413.27	0.119	14.79

* N_0 and k are derived from the model of $N_t = N_0(1-e^{-kt})$ where N_t is cumulative mineralized N at incubation time t in week, N_0 is the N mineralization potential, and k is the rate constant.

the N_0 between 173 and 510% depending on the amount of material incorporated. Pea results were similar while wheat material resulted in N_0 values of 66 to 273% greater than that in the control. Obviously, incorporation of plant material into soils enhanced potentially mineralizable N.

In addition, the N mineralization rate constant increased from 0.093/wk in the control soil to a range of 0.119/wk in the 6% wheat material treatment to 0.163/wk in the 2% pea material treatment. Apparently, the incorporation of plant material to soils may promote the N mineralization in soil not only through the increase in potentially mineralizable N but also by accelerating the release of soil N as well. The increase in the "k" value may be due to the stimulation of microbial activity in soil by the plant material incorporation, since this increases both the C source and improves the soil physical conditions such as aeration and source of reactive organic N to act upon.

CONCLUSIONS

Plant material incorporation into soil significantly enhanced N mineralization. All four factors evaluated in this study (plant material, material rate, material size, and incubation time) statistically affected the amount of N mineralized; however, time after the incorporation and incorporation levels were the two most important effects. Increasing time and level enchanced the amount of N mineralized. Plant material type and size had significant impacts on mineralization, but this impact was not important as they only accounted for 3.1% of the observed variation in N mineralization in this study. In addition, the models derived, based on the collected data in this study, can be used to predict the potentially mineralizable N in this northern Idaho soil with or without the incorporation of plant material.

Plant material incorporation not only increased the quantity of N mineralized by up to 510% but also the rate of the N mineralization in soil. The N mineralization rate constant was increased about 75% compared to the soil without plant material. The incorporation of plant material to soil increased soil N capacity and enhanced soil N intensity.

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