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Estimates of Potentially Mineralizable Soil Nitrogen Based on Short-Term Incubations[1]

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ABSTRACT

Nitrogen mineralization potentials were determined for a large number of soils by a method involving determination of N mineralized after several consecutive incubations at 35C under optimum soil water conditions. The determination of N mineralization potential, N_0, based on the first-order equation, $\log (N_0 - N_t) = \log N_0 - kt/2.303$, is laborious and usually requires incubation periods of 8 weeks or more. From the present study, involving soils from major agricultural areas throughout the United States, it was demonstrated that N_0 could be estimated reliably from the amounts of N mineralized during 2-week incubations following preliminary incubations of 1 to 2 weeks. From the above first-order equation, $N_0 = N_t/(1\text{-}10^{-kt/2.303})$. Hence, for a 2-week incubation ($t = 2$), $N_0 = 9.77N_t$ (N_t = N mineralized in 2 weeks and k is the rate constant, weeks^{-1}). Estimates of N_0 from short-term incubations were similar to those derived after extensive periods of incubation. Preincubation of soils is required in order to decompose plant residues and for other possible reasons noted. Estimates of N_0 from preliminary incubations are meaningless. The implications of N_0 as a basis for predicting amounts of soil N mineralized under fluctuating temperature and soil water conditions are discussed.

Additional Index Words: plant residue decomposition, temperature, soil drying, kinetics of soil N mineralization.

THE SOIL nitrogen mineralization potential, N_0, has been defined as the quantity of soil organic N that is susceptible to mineralization according to first-order kinetics (11). Stanford and Smith (11) presented a method for obtaining N_0 based on the equation, $\log (N_0 - N_t) = \log N_0 - kt/2.303$ in which N_t denotes the cumulative amount of N mineralized during a specified period of incubation, t, and k is the rate constant. After several consecutive incuba-

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Table 1—Nitrogen mineralization potentials and other characteristics of soils from eight locations in Idaho (fall sampling, 1972)

Location	Depth	Soil pH (avg)	Total soil N content	N_0(=6.5 × $\Delta N_t/\Delta t^{1/2}$)	N_0 (est. from 2-week incubation)	N_0 as % of total N
	cm		%	ppm	ppm	
	0-15	7.8	0.058 ± 0.003*	101 ± 2	100 ± 10	17.4
P10. Truesdale l	15-30		0.060 ± 0.003	105 ± 8	100 ± 4	16.7
	30-45		0.042 ± 0.002	44 ± 2	55 ± 4	10.5
	0-15	8.0	0.048 ± 0.003	85 ± 6	91 ± 5	17.7
P20. Bahem vfsl	15-30		0.048 ± 0.002	80 ± 3	73 ± 6	16.7
	30-45		0.046 ± 0.002	52 ± 8	57 ± 10	11.3
	0-15	7.3	0.096 ± 0.003	156 ± 6	155 ± 28	16.3
P21. Power sil	15-30		0.080 ± 0.002	125 ± 3	124 ± 11	15.6
	30-45		0.052 ± 0.003	60 ± 1	69 ± 5	11.5
	0-15	7.4	0.087 ± 0.001	136 ± 14	148 ± 6	15.6
P110. Portneuf sil	15-30		0.085 ± 0.001	119 ± 17	108 ± 2	14.0
	30-45		0.061 ± 0.002	53 ± 2	70 ± 1	8.6
	0-15	7.5	0.092 ± 0.005	178 ± 23	195 ± 36	19.3
P111. Portneuf sil	15-30		0.078 ± 0.006	124 ± 9	128 ± 14	15.9
	30-45		0.046 ± 0.004	49 ± 7	58 ± 12	10.7
	0-15	7.4	0.085 ± 0.004	134 ± 4	124 ± 22	15.8
P160. Declo l	15-30		0.080 ± 0.004	122 ± 4	108 ± 4	15.3
	30-45		0.060 ± 0.003	57 ± 10	54 ± 27	9.5
	0-15	7.5	0.081 ± 0.001	123 ± 15	118 ± 10	15.2
P220. Portneuf sil	15-30		0.070 ± 0.0	59 ± 6	59 ± 2	8.4
	30-45		0.050 ± 0.001	29 ± 0	43 ± 7	5.8
	0-15	7.6	0.097 ± 0.005	144 ± 5	138 ± 8	14.8
P222. Pancheri sil	15-30		0.092 ± 0.003	136 ± 12	135 ± 12	14.7
	30-45		0.045 ± 0.009	43 ± 12	37 ± 11	9.6

* Standard deviation of mean of three replicates.

tions at 35C over a period of 30 weeks with intermittent leachings and determinations of N mineralized, N_o was estimated from the regression of log ($N_o - N_t$) on t.

The foregoing study, involving 39 diverse soils, provided a reliable basis for exploring less laborious, alternative means of estimating N_o. For example, with each soil the regression of N_t on $t^{1/2}$ was essentially linear. The slopes of these regressions, in turn, were linearly related to N_o according to the equation, $N_o = 6.5\ (\Delta N_t/\Delta t^{1/2})$. The latter relationship provides an indirect means of estimating N_o based on incubation periods much shorter than 30 weeks. However, the time required (8 weeks) still is excessive.

A recent greenhouse study (10) indicated that N_o has intrinsic value in predicting amounts of soil N mineralized under specified environmental conditions. However, successful application of the concept will hinge on developing a reliable short-term method for determining N_o. In the present study, a method of estimating N_o from amounts of soil N mineralized during short-term incubations is proposed.

MATERIALS AND METHODS

Soils—In 1972, eight rate-of-N field experiments on sugar beets (*Beta vulgaris*) were conducted in southern Idaho. The experimental sites were interspersed in an area bordering the Snake River and extending from Caldwell to Idaho Falls (approximately 480 km). After harvest in 1972, soil borings from each site were taken by 15-cm depths to 45 cm. Sampling was restricted to plots that had received well before planting (November 1971, or early March 1972) fertilizer N rates of 0, 112, and 224 kg/ha. Plots that received additional N applications at time of planting were not sampled. Twenty-four cores from two replicates of plots treated alike were composited, giving nine samples per site (three treatments × three depths). After air-drying, soils were ground to pass a 20-mesh sieve. Certain physical and chemical characteristics of these soils (pH and total N) are given in Table 1.

Since other soils included in the present study have been described in an earlier report (11), it suffices to note that this group comprised 39 soils differing widely in various characteristics.

Table 2—Regression of N mineralization potential, N_o, derived from five consecutive incubations (*Y*) on N_o calculated from 2-week incubations following preliminary 1-week incubations (*X*)

Soil and location symbol	Number of soil samples	Means (ppm N) Y	Means (ppm N) X	Regression coefficient, ΔY/ΔX†	r^2
P10. Truesdale l	9	83	85	1.24 ± 0.33	0.92
P20. Bahem vfsl	9	73	73	0.94 ± 0.36	0.84
P21. Power sil	9	113	116	1.00 ± 0.31	0.90
P110. Portneuf sil	9	103	109	1.05 ± 0.49	0.78
P111. Portneuf sil	9	117	127	0.89 ± 0.22	0.94
P160. Declo 1	9	104	95	0.89 ± 0.33	0.87
P220. Portneur sil	9	70	73	1.16 ± 0.33	0.91
P222. Pancheri sil	9	108	103	0.97 ± 0.16	0.97

* Common regression based on covariance (6):
$Y = 0.6 + (0.98 \pm 0.09)X;\ r^2 = 0.90.$
Total (pooled) regression, ignoring covariance:
$Y = 2.1 + (0.96 \pm 0.09)X;\ r^2 = 0.90.$

† Value following ± is the product of the standard deviation of the regression coefficient, S_b, and $t_{0.05}$, i.e., the fiducial limits of the slope (6). Note: $t_{0.05}$ for 7df = 2.365.

N Mineralization Procedure—The mineralization procedure described by Stanford and Smith (11), involving initial removal of mineral N by leaching with 0.01*M* $CaCl_2$, followed by a series of incubations at 35C with intermittent leachings and determination of mineral N, applies to the group of 39 soils. For the Idaho soils, the procedure was modified as follows: (i) The soil sample (40 g) was mixed with 7 g of exfoliated vermiculite (ground to pass a 20-mesh sieve) and placed in a leaching tube (approximately 100 ml; inside diameter, 42 mm). [Note: 15 g of soil mixed with 15 g of sand was placed in a 50-ml leaching tube in the earlier study (11)]; (ii) Following an initial 1-week incubation and leaching, samples were incubated, with intermittent leaching, for periods of 2, 1.6, 2.3, and 3.7 weeks (two upper 15-cm layers) and 2, 3, 2, and 3.4 weeks (30- to 45-cm layer). (Note: Cumulative incubation periods are 1, 3, 4.6, 6.9, and 10.6 weeks and 3, 6, 8, and 11.4 weeks as plotted in Fig. 1, respectively); and (iii) Incubated samples were leached with 150 ml of 0.01*M* $CaCl_2$ and 15 ml of minus-N nutrient solution instead of 100 ml and 25 ml, respectively, as in the previously reported method (11).

Chemical Analyses—Idaho soils were analyzed for total N by a standard macro-Kjeldahl method (5). Soil pH was determined with the glass electrode using a 1:2 soil/water suspension. Following each incubation, mineral N,(NH_4 + NO_3)-N, was determined by a modified Conway method (7). The volume of leachate was adjusted to 170 ml with distilled water, and a 4-ml aliquot was taken for analysis. The other 39 soils were analyzed for mineral N by a macrodistillation method previously described (11).

Methods of Estimating N_o—Estimates of N_o for 39 soils, based on 30-week incubations, are recorded elsewhere (11). Since, as discussed earlier, $N_o = 6.5 \cdot (\Delta N_t/\Delta t^{1/2})$, this expression was used to estimate N_o for the Idaho soils, based on all incubations.

Estimates of N_o from short-term incubations were made as follows. Solving for N_o in the equation, $\log (N_o - N_t) = \log N_o - kt/\ 2.303$ gives the expression, $N_o = N_t/1-10^{-kt/2.303})$. Hence, for a 1-week period of incubation at 35C ($k = 0.054$), $N_o = 19.05\ N_t$, and, for a 2-week incubation, $N_o = 9.77\ N_t$.

RESULTS

N_o Estimated From $\Delta N_t/\Delta t^{1/2}$

For the Idaho soils, estimates of N_o derived from $N_o = 6.5\ (\Delta N_t/\Delta t^{1/2})$ are shown in Table 1 as the means based on incubations of three soil composites from each site (± the standard deviations of the means). Illustrations of the procedure used in estimating the slope, $\Delta N_t/t^{1/2}$, are given in Fig. 1 where the regressions of N_t on $t^{1/2}$ are based

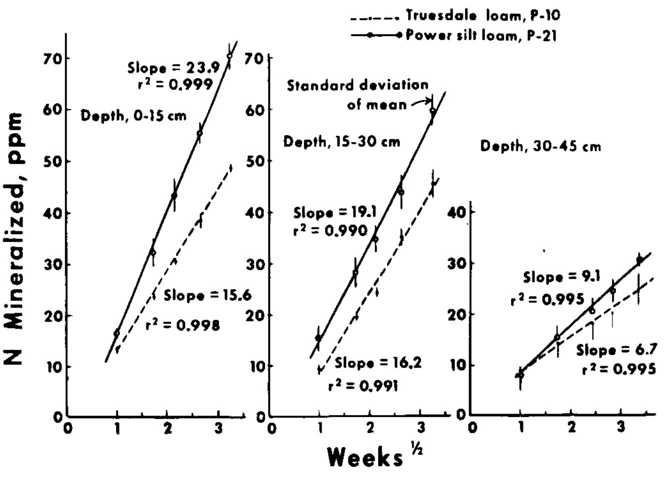

Fig. 1—The relation between N mineralized, N_t, and $t^{1/2}$ for two soils and three depths of sampling, based on mean values of N_t from three incubations (fall sampling, Idaho soils, 1972).

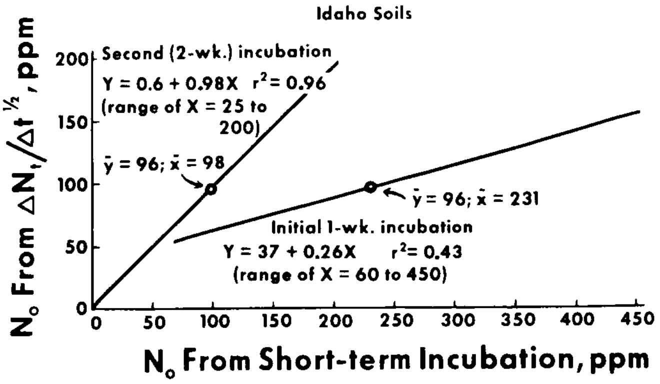

Fig. 2—Comparison of the regressions of N_0 (= 6.5 × $\Delta N_t/\Delta t^{1/2}$), Y, on N_0 estimated from 1-week and from 2-week incubations, X, based on 72 soil samples (eight locations × three composites × three depths) (fall sampling, Idaho soils, 1972).

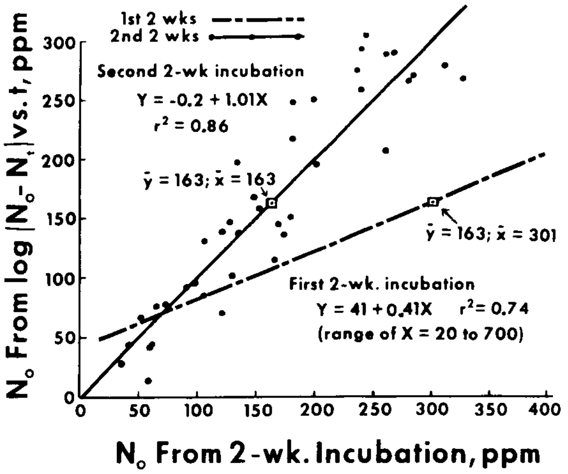

Fig. 3—Comparison of the regressions of N_0 derived from 30 weeks of incubation, Y, on N_0 estimated from the first and from the second 2-week incubations of 39 soils, X.

on the mean values of N_t. In Fig. 1 and Table 1 the standard deviations largely reflect within-site sampling variations of N_t as revealed in separate incubations of three composites.

Considering all 72 samples from Idaho (eight sites x three treatments x three depths), regressions of N_t on $t^{1/2}$ based on five consecutive incubations were highly linear in most instances. For the 24 surface soils, the coefficient of determination, r^2, for N_t vs. $t^{1/2}$ ranged from 0.990 to >0.999. Also included in this range were 17 samples from the 15- to 30-cm layer and 13 samples from the 30- to 45-cm layer. For 15 of the remaining 18 samples, r^2 fell between 0.98 and 0.99; and between 0.95 and 0.98 for the last three samples from the 30- to 45-cm layer. Thus, the precision of estimating $\Delta N_t/\Delta t^{1/2}$ tended to decrease as sampling depth increased, probably because amounts of N mineralized decreased with depth.

N_0 Estimated from Short-term Incubations

Shown in the next-to-last column of Table 1, are values of N_0 estimated from amount of N mineralized during the first 2-week incubation, following a preliminary 1-week incubation. Comparison of the mean N_0 values estimated by two methods, in Table 1, indicates relatively good agreement. Based on the nine samples from each location (three composites x three depths) regressions of N_0 (=6.5 × $\Delta N_t/\Delta t^{1/2}$) on N_0 (2-week incubations) are summarized in Table 2. The Y and X means are similar, and regression coefficients (slopes) fall within a relatively narrow range. In fact, neither the slopes nor the elevations of the regressions differ significantly (95% level) according to analysis of covariance (6). Hence, the common regression, $Y = 0.6 + 0.98\,X$, best describes the relationship for all sites (72 samples). In Fig. 2, the latter regression is compared with the regression of N_0 (= 6.5 × $\Delta N_t/\Delta t^{1/2}$) on N_0 derived from the initial 1-week incubation (= 19.05 N_t). Obviously, N_0 cannot be estimated or predicted accurately from the amount of N mineralized in the first week. In contrast, values of N_0 estimated from the N mineralized during the ensuing 2-week incubation are remarkably similar to those derived from all incubations.

The inadequacy of the initial incubation as a basis for estimating N_0 is further demonstrated with the 39 soils (Fig. 3) where the regressions of N_0 derived from 30-week incubations (11) (Table 3, Column 4) on N_0 estimated from the first and second 2-week incubations, respectively, are compared. In common with Fig. 2, the regressions differ greatly. The mean N_0 based on the first 2-week incubation is almost twice, while the mean N_0 derived from the second 2-week incubation is equal to, the N_0 derived from long-term incubation. Although there is a considerable scatter of plotted points about the regression line ($r^2 = 0.86$), the equation, $Y = -0.2 + 1.01X$, closely resembles its counterpart in Fig. 2.

DISCUSSION

The present study has demonstrated the feasibility of estimating potentially mineralizable soil N, N_0, from amount of N mineralized during short-term incubation. However, the rate of N mineralization during the initial period of incubation at 35C (1 to 2 weeks) often differed markedly from that attained in subsequent incubations. There are various reasons why N_0 cannot be estimated from amount of N mineralized during the preliminary incubation. One involves the nature and amount of undecomposed or partially decomposed plant residues present in the soil. For example, decomposition of residues having low C/N ratios (e.g., alfalfa) might well result in mineral N accumulation in excess of that mineralized from soil organic N. On the other hand, high-C/N residues (wheat straw) would tend to immobilize mineral N produced by the soil during initial stages of decomposition. Factors affecting N mineralization-immobilization relationships in various systems of soil and crop residues have been discussed by Bartholomew (2).

Although the populations of microorganisms responsible for ammonification and nitrification in soils normally do not appear to be primary limiting factors in N mineralization, the possibility that initial lags in activity might influence N mineralization rate, especially in subsurface soils, should not be ruled out on the basis of existing information (1). Another factor often considered to exert a dominant influence on initial N mineralization rate is the method of pretreating the soil before incubation (4). For example, drying may greatly enhance N mineralization, and this effect varies with intensity of drying.

In the present study, the reasons why preliminary incubation is a prerequisite to use of short-term mineralization in calculating N_0 are expected to differ among the 101 soils employed. While results amply confirm the necessity for preincubation, they do not clearly show how long the preliminary incubation should be in order to most reliably estimate N_0 from a subsequent incubation. The data suggest, however, that 1 to 2 weeks is sufficient. Undoubtedly, situations can occur in which even longer preincubation periods are required (e.g., excessive amounts of low-N, high-C plant residues).

With the Idaho soils, the percentage of total soil N comprising N_0, in the upper 15-cm layer, ranged from 14.8 to 19.3; in the 15- to 30-cm layer, from 8.4 to 19.3; and in the 30- to 45-cm layer, from 5.8 to 11.5 (Table 1). The abrupt drop in potentially mineralizable N as percent of total soil N, below 30-cm, suggests a concomitant change in the chemical nature of the total N. One possible explanation might be that the proportion of clay-fixed ammonium increased with depth (3). One might also speculate that reduced microbial activity in the subsoils contributed to the lower mineralization rates. In any case, the results indicate a consistency among sites in the amounts and profile distribution of the mineralizable fraction. The range in the Idaho surface soils is much narrower than was reported by Stanford and Smith (11) for 39 diverse soils (5 to 41%).

The possible significance of N_0 as a basis for predicting amounts of N mineralized under fluctuating temperatures and soil water contents has been suggested in recent studies (8, 9, 10). The basic concept is that amount of N mineralized is proportional to N_0, i.e., $-dN/dt = kN$ (N = potentially mineralizable N; t = time, e.g., weeks; and k = t^{-1}). The rate constant, k, is influenced markedly by temperature and soil water content. The temperature coefficient, Q_{10}, is 2 (9). Relative N mineralization is a linear function of soil water content, expressed as percent of the optimum for biological activity (8).

An example will illustrate how N_0 may be employed to estimate N mineralization while taking into account the effects of temperature and soil water content. For a given weekly period, assume that antecedent potentially mineralizable N = 200 kg/ha; average temperature = 25C; average soil water content = 75% of field capacity (field capacity is considered to be optimum for N mineralization). At 25C, $k = 0.027$ weeks^{-1} (11), and the amount of N mineralized during 1 week, kN, at optimum soil water content is 200 × 0.027, or 5.4 kg/ha. At 75% of field capacity, however, the amount mineralized is 0.75 kN, or 4.1 kg/ha. Estimates based on daily average temperatures and soil water contents might be more appropriate than weekly estimates in certain instances. Although the validity of the foregoing views has not yet been verified under field conditions, limited evidence from greenhouse studies involving fluctuating temperature and near-optimum soil water tends to support the concept (10).

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