DIVISION S-7—FOREST AND RANGE SOILS

Variability of Nitrogen and Carbon in Surface Soils of Six Forest Types in the Oregon Cascades[1]

D. H. McNabb, K. Cromack, Jr., and R. L. Fredriksen[2]

ABSTRACT

Soil samples were collected from sites typical of six forest habitat types in the western Oregon Cascades to determine the variability in total N, C, and mineralizable N. Within each type, 20 samples of surface soil (0–15 cm deep) were removed from around the outside perimeter of a 0.25-ha plot. Averages of 23, 28, and 70 samples were needed to estimate the population mean of total N, C, and mineralizable N, respectively, with an accuracy of ±10% at a 95% probability. Variability was not reduced by reporting data on the basis of mass per area rather than concentration, but the method of reporting data affected the relative ranking of sites. Within-site variability was not generally related to microsite differences in slope or coarse fragment content.

Additional Index Words: **soil sampling, soil variability, mineralizable N, habitat types.**

McNabb, D.H., K. Cromack, Jr., and R.L. Fredriksen. 1986. Variability of nitrogen and carbon in surface soils of six forest types in the Oregon Cascades. Soil Sci. Soc. Am. J. 50:1037–1041.

During the past two decades, substantial progress has been made in quantifying the nutrient cycling processes of forest ecosystems (Cole et al., 1967; Fredriksen, 1972; Bormann et al., 1977; Sollins et al., 1980; Swank and Wade, 1980). These efforts have approached nutrient cycling from the perspective of entire watersheds by determining the elemental content of various nutrient pools and measuring or estimating the flux between or through some of the pools. This approach can identify the nutrients most likely to limit site productivity in current or future rotations.

In the case of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] forests in the Pacific Northwest, available N is the nutrient most apt to limit site productivity. Modeling of N flux within the various pools in response to forest practices and predicting the effect that these changes have on site productivity are, therefore, becoming increasingly important (Kimmins and Scoullar, 1979). Development of an N cycling model, however, is seriously limited by insufficient information on the soil nutrient pool and the processes occurring in it. This pool has not been studied in proportion to its importance. For example, in Douglas-fir forests the soil contains up to 80% of the site's total N and buffers the site against changes from silvicultural treatments (Miller et al., 1976).

Thus, it is particularly important to quantify how silvicultural practices affect soil N cycling. As a first step, the amount of within-site variability and the contributing factors must be determined. This has been done for the litter and duff layers in the Pacific Northwest (Youngberg, 1966; Grier and McColl, 1971) and for mineralizable N over a large number of sites in the northern Sierra Nevada Mountains (Powers, 1980). But variability of total soil N and C, and some of the within-site factors that contribute, have not been investigated.

One objective of the present study was to quantify the variability in total N and C in surface soil of several forest habitat types in the western Cascade Mountains of Oregon. These habitat types have been the subject of numerous ecological studies (Dyrness et al., 1974; Zobel et al., 1976; Grier and Logan, 1977). A second objective was to determine the variability associated with using the anaerobic incubation test for mineralizable N (Waring and Bremner, 1964), including the effects of drying and short-term storage of samples. This soil test is becoming increasingly popular for predicting fertilizer response in the Pacific Northwest (Shumway and Atkinson, 1978).

METHODS

Six habitat types within the central Oregon Cascades (Franklin and Dyrness, 1973; Dyrness et al., 1974) were selected for this study (Table 1). Five of the sites were located within the H. J. Andrews Ecological Reserve (44° N 22° W) and the sixth about 30-km north. The habitat types represent a range of temperature and moisture regimes within the western Cascade Mountains. The forests representing these types were all old-growth conifer stands with dominants greater than 300-yr-old. Zobel et al. (1976) described the relationships of environment to composition, structure, and diversity of these forest communities.

A 50- by 50-m reference stand is permanently maintained within each habitat type. These stands have been intensively studied, but to avoid any potential damage, destructive sampling of stand and soil components is not allowed. Therefore, soil samples were collected from 20 randomly distributed points 1- to 10-m outside the perimeter of each reference stand.

At each sample point, the litter and duff were removed, and a uniform, vertical slice of the soil profile was removed from the 0- to 15-cm depth. Slope was measured over a distance of 1.5 m through the point. The volume of coarse fragments >3-cm diam was estimated visually. This size class was easily recognized during the excavation of the shallow soil pit.

All soil samples were transported to the laboratory in plastic bags in order to maintain their natural moisture content and thus test the effects of drying and short-term storage on mineralizable N. However, only 10 samples from each habitat type were randomly selected from the original 20 for this part of the study; the remainder were immediately air-dried and stored for 10 weeks prior to analysis.

[1] Paper 2026 of the Forest Research Laboratory, Oregon State University, Corvallis. Received 29 July 1985.

[2] Extension Watershed Specialist, Forestry Intensified Research Program, Dep. of Forest Engineering, Oregon State Univ., Medford, OR 97501; Associate Professor, Dep. of Forest Science, Oregon State Univ., Corvallis, OR 97331; and Principal Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Sta-

Table 1. Habitat types selected from the central portion of the western Oregon Cascades (Franklin and Dyrness, 1973; Dyrness et al., 1974).

Reference stand no.	Habitat type	Site (code)	Soil classification†	Elevation, m	Relative moisture/ temperature regime
1	*Pseudotsuga menziesii/ Holodiscus discolor*	PSME/HODI‡	Loamy-skeletal , mixed, mesic Typic Dystrochrept	490	Dry/hot
2	*Tsuga heterophylla/ Rhododendron macrophyllum/ Berberis nervosa*	TSHE/RHMA/BENE	Fine-loamy, mixed frigid Typic Dystrochrept	490	Mesic/warm
4	*Abies amabilis/ Triarella unifoliata*	ABAM/TIUN	Loamy-skeletal, mixed, frigid Typic Haplumbrept	1325	Moist-mesic/cold
5	*Tsuga heterophylla-Abies amabilis/ Rhododendron macrophyllum/ Berberis nervosa*	TSHE-ABAM/RHMA/ BENE	Fine-loamy and loamy skeletal, mixed, frigid Typic Dystrochrept and loamy, mixed, frigid Typic Haplumbrept	900	Mesic/cool
7	*Tsuga heterophylla-Polystichum munitum-Oxalis oregana*	TSHE/POMU-OXOR	Fine-loamy, mixed, frigid Dystric Entrochrept	460	Moist/warm
14	*Abies amabilis-Tsuga mertensiana/ Xerophyllum tenax*	ABAM-TSME/XETE	Medial, Endic Cryandept	1425	Dry/cold

† Brown and Parsons, 1973. ‡ Garrison and Skovlin, 1976.

term storage on mineralizable N were analyzed moist, immediately after drying (about 4 d later), and after 1, 2, 3, 4, and 10 weeks of storage at room temperature. For the moist analysis, a subsample from each of these samples was removed, the soil separated from the coarse fragments by forcing the sample through a 2-mm sieve, and part of the sieved soil immediately analyzed for mineralizable N. The air-dry moisture content was determined on the sieved soil that remained; this value was used to convert the data on mineralizable N of moist soil to an air-dry basis. Immediately after the subsample for moist analysis was removed, the remaining samples were spread in a 1-cm layer to air dry. These samples were air-dried and analyzed according to the above schedule.

After air-drying, all samples were prepared in a mortar and a mechanically rotated pestle that destroyed aggregates by a grinding action and then sieved to <2 mm; the soil fraction was then weighed. Coarse fragments (2–30 mm diam) remaining after sieving were weighed, and their volume was determined by volume displacement in water. Volume and weight of coarse fragments were used to determine their specific gravity. Specific gravity of coarse fragments and bulk density of the fine soil were used to determine the volume (in percent) of coarse fragments between 2- and 30-mm diam.

Rates of N mineralization were determined by anaerobic incubation (Keeney and Bremner, 1966). The only modifications to the procedure were that soil and solutions used were increased in quantity fourfold and that N concentrations were not corrected for initial NH_4^+ (Powers, 1980). For each analysis, two subsamples of about 20 ± 1 g were separated from the bulk sample with a sample splitter and weighed. The samples were incubated at 313 K for 7 d. Carbon was determined by dry combustion at 1923 K in an induction furnace and total N by micro-Kjeldahl and steam distillation (Bremner, 1965).

Soil cores for determination of bulk density were also collected from around the perimeter of each reference stand. Six samples were taken from each stand with a 10-cm diam by 15-cm long impact core sampler. The fine soil bulk density (<2.0-mm diam) was determined by reducing the whole soil weight and whole soil volume by the weight and volume of coarse fragments >2.0-mm diam. The volume of these coarse fragments was determined by water displacement. The bulk density of fine soil (<2.0-mm) was calculated by dividing the weight of the fine soil by the volume of fine soil.

Soil test data were converted to an areal basis by using the following equation:

$$Q = T \times \rho_{bf} \times (1 - V_g/100) \times C \times D \quad [1]$$

where

Q = quantity of nutrient, kg ha^{-1};
T = soil test result, mg kg^{-1};
ρ_{bf} = bulk density of <2-mm soil fraction, Mg m^{-3};
V_g = coarse fragment volume, L L^{-1};
C = constant for mass and area correction, 10^5; and
D = soil depth sampled, 15 cm.

Effects of different times of storage on mineralizable N and differences in all variables among sites were determined by analysis of variance. Duncan's multiple range test was used to determine differences among storage times or sites. The number of samples needed to estimate the population mean within 10% with a probability of 95% was determined by using the following equation (Snedecor and Cochran, 1967, p. 58).

$$N = t^2 \times CV^2 / E^2 \quad [2]$$

where N = number of samples needed; t = Student's t-value, approximately 2 at $p = 0.05$; CV = coefficient of variation of these data, %; and E = allowable error from the mean, %.

RESULTS

The site and soil data are summarized in Table 2. In most cases, the data did not vary over a wide range but were probably typical of the soil and site conditions of the central portion of the western Oregon Cascades. The data, however, were not necessarily typical of the individual habitat types because only one site within each was sampled.

The 20 samples collected from each site were generally insufficient to estimate the population mean within ±10% with a 95% probability (Table 2). On the average, more samples would be needed to estimate total N than C (23 vs. 28), but the relationship was not consistent among sites. The C/N ratio required fewer samples to estimate the mean than did either total N or C. The number of samples needed to estimate the population mean of mineralizable N was much higher (avg, 70) than the number needed

Table 2. Nitrogen and C in the surface 15 cm of soil and some physical and physiographic properties of six sites in the western Oregon Cascades. Equation [1] was used to calculate N and C on a mass/area basis.†

Site (reference stand)	Statistic	Total N		C		Mineralizable N		C/N ratio	Soil volume >2 mm	Slope	Bulk density of soil <2 mm
		g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	mg kg^{-1}	kg ha^{-1}		L L^{-1}	%	Mg m^{-3}
PSME/HODI	$\bar{x}$	2.02b	706c	50.6b	17 597d	33.11b	10.7c	25.39b	0.476a	64.0a	0.446b
(1)	CV %	30.9	38.7	27.4	34.1	55.4	56.3	14.0	24.4	24.4	19.8
	No.‡	39	60	30	47	123	127	8	24	24	16
TSHE/RHMA/BENE	$\bar{x}$	1.81b	1 351a	34.5c	25 695bc	34.33b	25.6a	19.06c	0.215c	33.5b	0.632a
(2)	CV %	16.7	18.5	23.5	24.4	31.2	33.4	16.5	29.3	47.5	9.7
	No.‡	12	14	23	24	39	45	11	35	91	4
ABAM/TIUN	$\bar{x}$	2.73a	1 537a	65.1a	36 567a	42.79a	24.0a	23.95b	0.148d	34.2b	0.439b
(4)	CV %	19.0	20.9	19.6	20.5	27.6	28.2	11.3	33.0	17.4	5.0
	No.‡	15	18	16	17	31	32	6	44	13	1
TSHE-ABAM/RHMA/	$\bar{x}$	1.82b	1 494a	34.0c	27 895b	23.95c	19.5b	18.59c	0.124d	14.6c	0.629a
BENE (5)	CV %	18.9	16.3	24.9	22.8	32.3	28.4	12.9	55.2	121.5	8.6
	No.‡	15	11	25	21	42	33	7	122	591	3
TSHE/POMU-OXOR	$\bar{x}$	1.98b	1 136b	37.6c	21 297cd	40.62ab	23.1a	18.92c	0.329b	60.4a	0.592a
(7)	CV %	26.2	32.3	34.1	33.3	33.4	37.2	20.6	49.4	37.4	10.3
	No.‡	28	42	47	45	45	56	17	98	56	5
ABAM-TSME/XETE	$\bar{x}$	1.69b	1 090b	52.8b	34 074a	17.42c	11.2c	31.66a	0.140d	44.0b	0.507b
(14)	CV %	26.1	27.8	24.5	25.8	58.2	57.9	12.6	69.6	33.6	12.6
	No.‡	28	31	24	27	136	135	7	194	46	7

† Within a column, means followed by the same letter are not significantly different at $p = 0.05$.
‡ Number of samples needed to estimate the true means within ± 10% at $p = 0.05$; estimates calculated according to Eq. [2].

to estimate total N. Variability in total N and C was generally less than that in coarse fragment volume or microslope. Bulk density had the least variability of any property measured.

Correlations among total N, mineralizable N, and C were generally highly significant ($p = <0.001$), but significant correlations with these variables and microsite physical properties were few (Table 3). At the two sites where total N or mineralizable N was correlated with a microsite feature, that feature was affected by a change in macrosite landform. The correlation of C with C/N ratio was significant for only the hotter but moister habitat types.

High within-site variation was expected; however, we hypothesized that some of the variability within a site was associated with microsite variation in coarse fragment content. The larger volume of inert, coarse fragments was expected to concentrate more of the nutrients and organic matter that was presumably moving from the duff layers and from root turnover into the surface soil, where there was a proportionally smaller volume of fine soil. Correcting for this variation by converting concentration data to a mass-per-area basis, however, failed to reduce the variation. Except for reference stand 5, variation in coarse fragment content within a site was small and concentration data were not significantly correlated with coarse fragment content (Table 3). In most instances, reporting data on a mass-per-acre basis caused only a small increase in variability (Table 2).

Table 3. Correlation coefficients among mineralizable N, total N, and C, and physical and physiographic variables.† Only significant correlations are reported.

Variable	PSME/ HODI	TSHE/ RHMA/ BENE	ABAM/ TIUN	TSHE-ABAM/ RHMA/ BENE	TSHE/ POMU-OXOR	ABAM-TSME/ XETE
Mineralizable N						
N	0.84***	0.57*	0.77***	0.80***	0.81***	0.82***
C	0.83***	0.50*	0.70***	0.52*	0.70***	0.80***
Gravel				0.73***		
Nitrogen						
C	0.90***	0.70***	0.79***	0.85***	0.81***	0.89***
% Slope					−0.45*	
Carbon						
C/N		0.67**		0.64**	0.61**	

†$p = <0.05$*, $p = <0.01$**, $p = <0.001$***.

Mineralizable N varied irregularly with drying and subsequent storage of the soil over a period of a few weeks (Table 4). Most of the variability occurred in the first 2 weeks after air drying; however, samples from half the sites were not affected by the drying and storage process. For each site, mean values for mineralizable N varied considerably from week to week, but these differences were not always significant.

DISCUSSION

The 20 samples collected from each site were insufficient to estimate the mean concentration of N and C with a sampling error of 10% or less at a probability of 95%. Equation [2] can be used to calculate the number of samples needed to estimate the mean at a lower level of accuracy; however, sufficient samples must be taken to detect treatment-caused differences and thus avoid nonsignificant conclusions resulting from inadequate sampling (Lloyd and McKee, 1983).

The within-site variability of mineralizable N in the present study was similar to values reported by Powers (1980) for a larger number of sites in northern California. Unlike the California sites, however, the standard error did not appear to increase as the mean increased. The variability among mineralizable N samples was also within the range reported for mineral soil in western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] stands in northwest Oregon (Boyle, 1982).

Although the correlations between total N, mineralizable N, and C were all significant, the variability of each could seldom be related to differences in mi

Table 4. Effects of drying and short-term storage on mineralizable N as determined by anaerobic incubation at 40°C for 7 d.†

Site	Moist	Air-dried (weeks)					
		0	1	2	3	4	10
	mg kg^{-1}						
PSME/HODI	33.1a	47.9bc	50.5c	39.8abc	38.2a	33.5a	34.1a
TSHE/RHMA/BENE	26.6a	41.9bc	46.0c	38.6bc	37.3b	34.3ab	33.5ab
ABAM/TIUN	52.8a	37.7a	40.4a	43.0a	39.1a	40.9a	41.8a
TSHE-ABAM/RHMA/BENE	36.7c	26.5ab	28.9abc	32.1bc	23.6ab	24.8ab	22.9a
TSHE/POMU-OXOR	38.3a	47.0a	55.0a	49.7a	42.7a	45.1a	42.9a
ABAM-TSME/XETE	25.3a	18.1a	19.6a	19.6a	15.4a	16.4a	19.8a

† Within a row (individual site), means followed by the same letter are not significantly different at $p = 0.05$.

crosite slope and coarse fragment volume. The correlation of mineralizable N and coarse fragments at reference stand 5 may reflect differences in drainage. The stand was on an old, slump-earth flow with wet flats and better drained, small ridges. A plausible explanation of the negative correlation between N and slope on reference stand 7 is that a thinner layer of soil parallel to the slope was sampled as slope increased. This site had some of the steepest slopes as well as the widest range of slopes. Because N concentration decreases with soil depth, the thinner surface soil layers should have a higher N concentration, hence the negative correlation.

Effect of different drying and storage times on mineralizable N cannot readily be attributed to differences in site, soil, sample collection, or transportation characteristics. The three soils in which mineralizable N did not change with drying and storage may have had higher soil-water potential because of either moist location (reference stand 7) or high elevation (reference stands 4 and 14), which delayed snowmelt until late spring.

The effects of drying and storage on mineralizable N were different from those reported by Keeney and Bremner (1966). They reported significant increases in mineralizable N the first weeks after storage; after about 4 weeks, the rates were generally stable for about 1 yr. Our own rates indicate that significant differences may also occur during the first 4 weeks of storage but that they appear to stabilize after about 4 weeks. This is an important point to consider when scheduling the analysis of recently collected soil for mineralizable N; if soils are dried for analysis, they should be stored dry for at least a month before they are analyzed in order to avoid this potential variation in data. How long this measure of N mineralization remains stable was not investigated, but Powers (1984) reported that it remained stable for at least 1 yr. In his case, however, the apparent stability of mineralizable N was the result of a slow increase in NH_4^+ concentration prior to incubation; that increase offset a slow decrease in the actual amount of N mineralized.

The greater variability in mineralizable N relative to total N for the same soils has important implications for use of the anaerobic incubation procedure in predicting fertilizer response. The mineralizable N test is currently the most commonly used soil test for selecting Douglas-fir stands for fertilization (Shumway, 1984). However, unless more samples are collected for determining mineralizable N than are collected for determining total N, the accuracy of the test for predicting fertilizer response is doubtful.

In our study except for reference stand 5, when bulk density and coarse fragment volume were used to convert data on nutrient concentration to a mass-per-area basis, the number of samples required to estimate the mean was increased. The increase in variability, however, was generally small and did not affect the necessity of making the conversion. The conversion is necessary for interpreting ecosystem processes such as quantities in, and transfers among, various stand and site components. The conversion is particularly important whenever sites with different bulk densities or coarse fragment contents are compared or site-specific interpretations are made. Shumway (1984) and Blake (1984) have both improved correlations between data on mineralizable N and on Douglas-fir response to N fertilizer in western Washington by correcting soil data for coarse fragment content. They did not correct for bulk density but simply reduced the concentration data by the arithmetic fraction calculated by dividing the weight of soil <2 mm by the weight of the whole soil. The effect of this correction, or more correctly of using both bulk density and coarse fragment content, is often to change the relative ranking of sites when reporting data on a concentration vs. a mass-per-area basis. This point can be illustrated with our data. Although our study was not set up to test for differences among habitat types, a simple analysis-of-variance test based on individual concentration and mass-per-area measures of mineralizable N, total N, and C of each soil sample often resulted in significantly different rankings and combinations of sites. For total N and C, more sites were significantly different when reported on a mass-per-area than when reported on a concentration basis.

Although most nutrient data are currently reported as concentrations, the presentation of soil nutrient data on a mass-per-area basis could improve data interpretation. This is particularly true for forest soils where bulk density and coarse fragment content are often highly variable. Soil nutrient data reported on a mass-per-area basis from values for bulk density and coarse fragment content have a specific unit of measure and quantitatively describe the amount of nutrient present. Such reporting, however, will increase the cost of collecting data because the bulk density used must be the bulk density of the soil fraction <2-mm diam (or the size of the soil material analyzed) and the volume of coarse fragments must be determined on the whole soil. Depending on the size of coarse fragments, measuring these variables may also require more specialized sampling techniques. But until this approach is taken, all nutrient data including total N and C will

remain a poorly defined index of the amount of nutrients present in a forest soil.

CONCLUSION

Considerable variation exists in the N and C concentrations of surface soil within small forested sites in the Cascade Mountains of Oregon. This variation cannot be accounted for by the simple characterization of the microsite around the sampling point. Substantially higher variation in mineralizable N than in total N needs to be considered when assessing this nutrient by the anaerobic incubation method. Adjusting concentration data for bulk density and coarse fragment volume can alter ranking of several sites and, potentially, the interpretation of ecosystem processes and other uses of soil test data.

ACKNOWLEDGMENT

This work was done under Oregon State University's Cooperative Aid Agreement no. 211 between Oregon State Univ. and the USDA Forest Service.

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