Nitrogen Mineralization from Soil Organic Matter and Crop Residues: Field Validation of Laboratory Predictions

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ABSTRACT

Accurate prediction of N mineralization under field conditions would promote optimal N-use efficiency from both organic and inorganic sources. This study was conducted to assess the utility of microplot cylinders with mixed-bed exchange resins for monitoring field N mineralization, to compare laboratory predictions with field measurements of N mineralization, and to determine the impact of using ground (≤1 mm) crop residues in the laboratory to predict N mineralization of unground (≤25 mm) residues in the field. Nitrogen mineralization from soil organic matter and hairy vetch (*Vicia villosa* Roth) residues was followed in the laboratory at 15, 20, and 25 °C with 0, 2150, 4300, and 6450 kg vetch ha^{-1} equivalent loading rates of ≤1 mm particle-size residue. Ground and unground residues were added to microplot cylinders at loading rates equivalent to 0, 4028, and 5010 kg vetch ha^{-1} and installed in potato (*Solanum tuberosum* L. Norwis) crop rows in two growing seasons. Nitrogen mineralization from soil organic matter under field conditions was overestimated by laboratory predictions; however, field measurements of N mineralization from both ground and unground vetch residues were closely predicted by a complementary laboratory study. These data indicate vetch residue N mineralization under these modified field conditions (i.e., microplot cylinders) can be predicted from laboratory studies that use ground residues, constant temperatures, and variable residue quantities. This finding may advance our ability to model and account for residue N mineralization when developing N management recommendations.

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ACCURATE PREDICTION OF N MINERALIZATION under field conditions is requisite for optimizing N use efficiency in many cropping systems (Cabrera et al., 1994; Campbell et al., 1994; Honeycutt, 1994; Rice and Havlin, 1994; Schepers and Meisinger, 1994). Soil thermal units (cumulative mean daily temperature >0°C) have been proposed as a basis for transferring laboratory predictions of N mineralization to the field (Honeycutt et al., 1988). This proposal has only been tested with plant materials that induce net N immobilization, including a papermill sludge, corn (*Zea mays* L.) residue, and lupin (*Lupinus alba* L. Ultra) residue (Honeycutt et al., 1988; Doel et al., 1990; Honeycutt and Potaro, 1990). These studies were not designed to capture NH_4^+ or NO_3^- movement out of the surface 15 cm of soil in field microplots. Consequently, the sole criterion for evaluating laboratory prediction accuracy of thermal unit by N mineralization relationships under field conditions was identification of that degree day when net N mineralization exceeded net N immobilization.

Recently, Honeycutt et al. (1994) proposed using thermal units to link N mineralization from soil organic matter and crop residues with crop N uptake. The dynamic nature of both processes within a growing season requires more than seasonal totals of cumulative N mineralized and cumulative N uptake. A dynamic N-use

Abbreviations: DDAA, soil degree days after residue application.

efficiency relationship with thermal units has been proposed to provide this information (Honeycutt et al., 1994). A fundamental component of this approach is accurate prediction of the entire course of soil organic matter and crop residue N mineralization (i.e., not just when mineralization processes exceed immobilization processes). Consequently, N mineralization by thermal unit relations developed in laboratory studies must be field-tested with readily mineralizable plant materials over the course of N mineralization during an entire growing season.

Techniques for assessing N mineralization in the field have been reviewed by Schepers and Meisinger (1994). A common approach is the buried bag technique, where a soil sample is enclosed in a polyethylene bag, returned to the field, and later retrieved for analysis (Eno, 1960; Van Schreven, 1968; Westermann and Crothers, 1980). Although leaching losses are considered negligible with buried bags, an important disadvantage is their failure to mimic soil water content dynamics. To overcome this limitation, Schnabel (1983) suggested placing anion exchange resin at the base of intact soil cores with their tops open to rainfall input and their bases open to percolation output.

This study was conducted (i) to assess the utility of microplot cylinders with mixed-bed exchange resins for monitoring N mineralization under field conditions, (ii) to compare laboratory predictions with field measurements of N mineralization from soil organic matter and crop residue, and (iii) to determine the effect of using ground crop residues in the laboratory to predict N mineralization of unground residues in the field.

METHODS AND MATERIALS

Laboratory Study

Soil was collected on 30 October 1989 from the Ap horizon (0–20 cm depth) of a coarse-loamy, mixed, frigid Typic Haplorthod in Newport, ME. Soil was collected from field plots previously planted with potato in 1988 and 1989 and fertilized in July of both years with 90 kg N ha^{-1} as NH_4NO_3. The soil was sieved (2 mm) and maintained at room temperature ($\approx$20°C) for 1 wk at field moisture conditions to minimize disturbance of the microbial population (Pramer and Bartha, 1972). Three hundred grams of soil (oven-dry basis) were then pre-incubated at 15, 20, and 25°C for 1 wk in 36, 2-L glass jars. Specific soil properties are provided in Table 1.

Total C was measured by infrared detection and total N by thermal conductivity following combustion at 950°C in a Leco CHN Analyzer[1] (Leco Corp., St. Joseph, MI). Soil pH as measured in a 1:2 soil:water suspension. Soil particle size distribution was estimated by the hydrometer method (Gee and Bauder, 1986). Soil water retention analyses were conducted as described by Klute (1986).

Hairy vetch (*Vicia villosa* Roth) was planted at a rate of 45 kg ha^{-1} on 26 May 1988 with no fertilizer application and was sampled on 27 April 1989. Vetch residue was ground to pass a 1-mm sieve and incorporated at 0, 0.3174, 0.6348, and 0.9522 g (oven-dry basis) per jar. These quantities correspond

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[1] Brand name and distributor are given to provide specific information and do not constitute endorsement by the author or by the USDA-ARS.

Table 1. Selected chemical and physical properties of the soil sampled in 1989.

Property	Content
Total C (g kg^{-1})	20.2
Total N (g kg^{-1})	2.6
Total C/Total N	7.8
pH	6.0
Sand (%)	42
Silt (%)	40
Clay (%)	18
Texture	loam
Water content (kg kg^{-1})	
at −0.006 MPa	0.295
at −0.010 MPa	0.281
at −0.033 MPa	0.232
at −0.067 MPa	0.206
at −0.100 MPa	0.195
at −0.200 MPa	0.183
at −0.300 MPa	0.155
at −0.500 MPa	0.130
at −1.500 MPa	0.104

to approximately 0, 2150, 4300, and 6450 kg vetch ha^{-1} incorporated to a 20-cm depth in a soil with a bulk density of 1.0 Mg m^{-3}. The zero application treatment was used to monitor soil N mineralization. Properties of the vetch residue, hereafter referred to as 1989 vetch, are provided in Table 2.

Following residue application, each jar was returned to its respective pre-incubation temperature cabinet and incubated at the same temperature applied during the pre-incubation. All jars were covered with a polyethylene sheet to restrict moisture loss, but to allow some gaseous diffusion (Aulakh and Rennie, 1987). Soil water content was maintained at 0.232 kg kg^{-1} through weekly additions of distilled water. Soil water content, averaged across all treatments, decreased by 0.003 kg kg^{-1} during each 1-wk period between water additions. Fifteen gram samples were removed at 12–16 d intervals for inorganic N (5.000 g) and water content determinations. Inorganic N was determined colorimetrically on a Lachat Autoanalyzer[1] (Lachat Instruments, Mequon, WI) following extraction with 2 M KCl (Keeney and Nelson, 1982). Three treatment replications were used, and the study was conducted for 88 d. Soil thermal units were calculated as the product of incubation temperature and number of days following residue application. This study will hereafter be referred to as the 1989 lab study.

Field Studies

Hairy vetch was planted at a rate of 45 kg ha^{-1} on 3 June 1992 and on 3 June 1993 with no N fertilizer application on either occasion. Vetch residues were sampled from 0.37 m^2 quadrats on 7 May 1993 and 18 April 1994. Vetch samples were analyzed for total C by infrared detection and total N by thermal conductivity following combustion at 950°C in a

Table 2. Chemical properties of hairy vetch residues used in three study years.

Property	Vetch residue		
	1989	1993	1994
	g kg^{-1}		
Total C	423.0 (1.8)†	453.9 (9.1)	411.3 (12.8)
Total N	35.0 (0.3)	38.6 (0.8)	32.5 (1.2)
Hemicellulose	215.8 (0.8)	209.4 (1.2)	195.0 (2.8)
Cellulose	280.6 (1.2)	285.7 (1.0)	247.0 (1.9)
Lignin	175.4 (1.3)	221.2 (0.1)	145.1 (1.2)
Total C/Total N	12.1	11.8	12.7
Lignin/Total N	5.0	5.7	4.5

† Mean (standard error of the mean).

Leco CHN Analyzer[1]. Vetch hemicellulose, cellulose, and lignin contents were determined by the methods of Goering and Van Soest (1970) and Van Soest and Robertson (1979). Selected properties of the vetch residues are provided in Table 2.

Chisel plow tillage operations were performed on 17 May 1993 and on 11 May 1994. Field soils were disked once on 19 May 1993 and again on 16 May 1994. Soil was collected from unfertilized alleyways in a field plot study located on the same 2.5% slope and landscape position, but ≈30 m from the soil collection site of the 1989 lab study. Soil was sampled from the 0- to 20-cm depth, mixed, and passed through a sieve with 2-mm diameter openings on 10 May 1993 and 11 May 1994. In each year, soil was stored at 5°C and at its field-sampled water content for 5–15 d prior to placement in microplot cylinders.

Microplot cylinders were constructed from clear polycarbonate tubing (Portland Plastic Pipe, Winslow, ME[1]). Each cylinder was 23.0 cm long with an internal diameter of 7.3 cm, an external diameter of 7.6 cm, and consisted of a soil compartment 20.0 cm in length and a mixed-bed exchange resin compartment 3.0 cm in length placed in the basal 20.0–23.0 cm section. A resin compartment cylinder with an internal diameter of 6.7 cm, an external diameter of 7.0 cm, and a length of 3.0 cm was firmly placed with rubber gaskets into the lower 3.0 cm of each microplot cylinder. A layer of nylon was placed over the resin compartment prior to its insertion in the microplot cylinder to physically separate the resin and soil compartments. Exchange resin (IONAC[1] NM–60, H^+/OH^- form, 16–50 mesh) was weighed into each resin compartment at a bulk density of 0.5 Mg m^{-3}, covered with a layer of nylon and a layer of plastic screen for support, and then secured with rubber bands and silicone glue. After the glue dried, field moist soil was weighed into each microplot cylinder and packed to an oven-dry equivalent bulk density of 1.0 Mg m^{-3}. A single layer of nylon was placed over the top of each cylinder and secured with rubber bands and silicone glue.

Treatments consisted of soil alone, soil plus residue ground to pass a 1-mm sieve, and soil plus residue chopped into ≤25-mm lengths. In the later treatment care was taken to obtain representative residues, not just those that could be chopped into 25-mm lengths (i.e., this would have resulted in only stems being represented). Thus the residue treatments selected were chosen to represent ground (≤1-mm) and unground (≤25-mm) residues. Residue treatment quantities were based on the mean of 18 vetch-plot residue biomass samples from a complementary field study at the same study site. Vetch residue dry weight applications to each cylinder in 1993 and 1994 were 2.04 and 1.64 g, respectively. These applications correspond to ≈5010 and ≈4028 kg vetch ha^{-1} (65°C oven-dry basis), respectively, incorporated to a depth of 20 cm in a soil with a bulk density of 1.0 Mg m^{-3}. Unamended soil controls, to monitor soil N mineralization, were mixed and weighed into microplot cylinders in the same manner as for soils receiving residue. Treatments were applied within a 36-h period to 84 microplot cylinders that represented three residue treatments (none, ground, unground), four replications, and seven planned sample dates. The top and bottom of each microplot cylinder were temporarily covered with a polyethylene sheet and stored at 5°C until transport to the field.

Cylinders were installed within a row of a field plot that had been planted with potato (*Solanum tuberosum* L. Norwis) 2–7 d earlier. Potato was hand-planted with 23-cm within-row spacing and 86-cm between-row spacing. The same graduated planting bar utilized to hand-plant potato was also used to ensure that microplot cylinders were installed with 23-cm spacing and were centrally positioned between potato seed pieces.

At each designated cylinder location, a 7.5-cm diameter core was removed to a depth of ≈25 cm with an auger. A handful of soil was returned to the bottom of a given hole, polyethylene sheets were removed from the cylinder, and that cylinder was pressed firmly into the soil to provide contact between the exchange resin at the base of the cylinder and the soil below (to promote drainage). This was repeated until the top of the cylinder was level with the soil surface. Soil was then firmly packed around each cylinder.

The 84 microplot cylinders were installed in this manner on 28 May 1993 and on 1 June 1994. Cylinders were temporarily covered with a cardboard cap immediately before any potato crop cultivation to prevent contamination with additional soil. Covers were removed immediately after cultivation. Cylinder soils were subjected to the natural shading and rainfall interception/throughfall by the potato plants, as experienced by other soils used for potato production. However, microplot cylinder soils were not subjected to water uptake by the crop.

Soil temperatures were monitored at 10-min intervals with thermocouples and a microprocessor-based datalogger. Soil temperatures in the field plot were measured at a depth of 7.5 cm in the center of a potato hill (i.e., ridge). Thermocouples were also placed at a 7.5-cm depth in the center of additional (non-sampled) microplot cylinders manufactured and installed in the same manner as previously described for the experimental unit cylinders. Soil thermal units in the field were calculated by adding the mean daily soil temperatures above 0°C after residue application. Thermal units accumulated during temporary storage at 5°C following residue application, but prior to field installation, were considered in calculating soil degree days after residue application (DDAA).

The first sample (12 cylinders) was returned to the lab within 24 h after installation. Six additional samples were collected at approximately 3-wk intervals in each study year. Cylinders were placed in a cooler and returned to the laboratory for extraction and analysis.

The entire content of each exchange resin compartment was placed in a 1-L Erlenmeyer flask and extracted with 2 M KCl for 1 h with a 10:1 (KCl volume : resin oven-dry weight equivalent) ratio. Soil from each cylinder was mixed, extracted (10.000 g), and analyzed for inorganic N and water content determinations following the same procedures previously described for the laboratory study. Field-plot soil water content in the 0–20 cm depth was determined gravimetrically from approximately 15, randomly sampled, 2.5-cm diameter cores taken from each of six field plots of potato following vetch at the same study site.

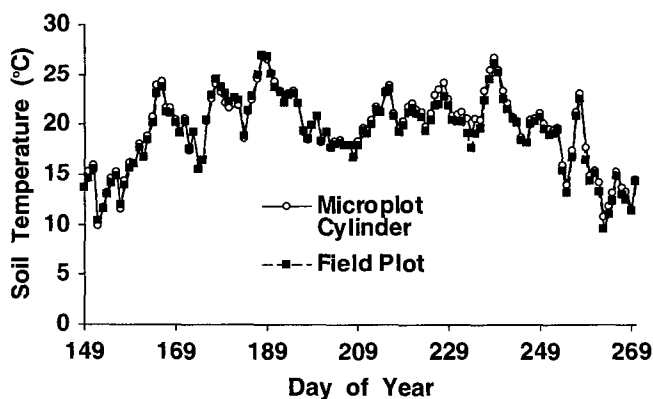Data were analyzed by univariate, repeated measures analy-

Fig. 1. Mean daily soil temperature for 1993 at the 7.5-cm depth in a microplot cylinder and in the same field plot containing the microplot cylinder.

sis of variance. Selected treatment comparisons were performed using orthogonal contrasts. In addition, laboratory and field observations of soil and vetch N mineralization were compared by the following approach.

Data from the 1989 lab study (previously described) was used to predict N mineralization in field microplot cylinders in 1993 and 1994. Nitrogen mineralization was regressed with DDAA separately for both laboratory and field data. The 95% confidence interval for the slope of each relationship was calculated from the parameter estimate (i.e., coefficient) ±2 (standard error) for the independent variable, DDAA. Overlapping 95% confidence intervals for the coefficient of DDAA from the lab and field studies were interpreted as nonsignificant differences in the slope of these N mineralization by DDAA relationships. The same approach was used to compare y-intercepts of laboratory and field N mineralization by DDAA relationships.

RESULTS AND DISCUSSION

Microplot Cylinder Evaluation

Extrapolating N mineralization data from microplot cylinders to field plots requires comparing soil and climatic properties within and outside of the cylinders. Average daily soil temperatures were similar within and outside of the cylinders at the 7.5-cm depth, as exemplified by the 1993 data in Fig. 1. Mean daily soil temperature at 7.5 cm never varied by >1.1°C between soil in the cylinder and soil in the field plot, with less difference in temperature variation being the common observation (Fig. 1). Field plot daily soil temperature was therefore closely represented by microplot cylinder daily soil temperature.

Soil water content in the surface 20 cm of potato field plots was similar to that measured in microplot cylinders in 1993 (Table 3). Field plot soils were wetter on the last three sample dates of 1994 compared with microplot cylinder soils on those dates. Field plot and cylinder soils possessed similar water contents at 451, 916, and

1436 DDAA in 1994 (Table 3). It must be acknowledged, however, that sieving to remove coarse fragments >2 mm prior to placing soil in microplot cylinders may have also removed soil aggregates, disrupted pore continuity, and therefore, altered soil water and aeration properties. Consequently, the field validation efforts described herein are acknowledged to have resulted in modified field conditions.

Microplot cylinders were designed and constructed so that N leached from a cylinder's soil compartment would be captured and retained by the exchange resin. Examination of inorganic N levels in both soil and resin compartments suggests that soil N mineralized in 1993 accumulated in the soil compartment with minimal transport to the resin (Fig. 2a). In 1994 soil inorganic N levels in the soil compartment increased until 1436

Table 3. Soil water content in microplot cylinders and field plots in 1993 and 1994.

Degree days after application	Field plots	Soil water		
		Microplot cylinder treatment		
		Control soil	Ground residue	Unground residue
		— kg kg⁻¹ —		
		1993		
0	—†	0.206 (0.001)	0.207 (0.001)	0.206 (0.001)
312	–	0.200 (0.004)	0.210 (0.012)	0.189 (0.005)
618	–	0.173 (0.003)	0.181 (0.004)	0.177 (0.002)
1023	0.169 (0.012)‡	0.158 (0.012)	0.187 (0.013)	0.179 (0.007)
1440	0.128 (0.010)	0.142 (0.005)	0.147 (0.014)	0.172 (0.005)
1907	0.114 (0.007)	0.129 (0.009)	0.133 (0.013)	0.126 (0.005)
2291	0.183 (0.005)	0.183 (0.012)	0.163 (0.017)	0.180 (0.014)
		1994		
145	–	0.215 (0.001)	0.214 (0.001)	0.218 (0.001)
451	0.268 (0.006)	0.291 (0.017)	0.259 (0.009)	0.282 (0.009)
916	0.206 (0.006)	0.198 (0.012)	0.188 (0.006)	0.205 (0.004)
1436	0.153 (0.007)	0.174 (0.009)	0.182 (0.015)	0.153 (0.009)
1913	0.177 (0.025)	0.056 (0.003)	0.052 (0.004)	0.059 (0.002)
2265	0.220 (0.005)	0.064 (0.004)	0.055 (0.011)	0.054 (0.006)
2537	0.274 (0.003)	0.111 (0.013)	0.148 (0.024)	0.128 (0.029)

† Not determined.
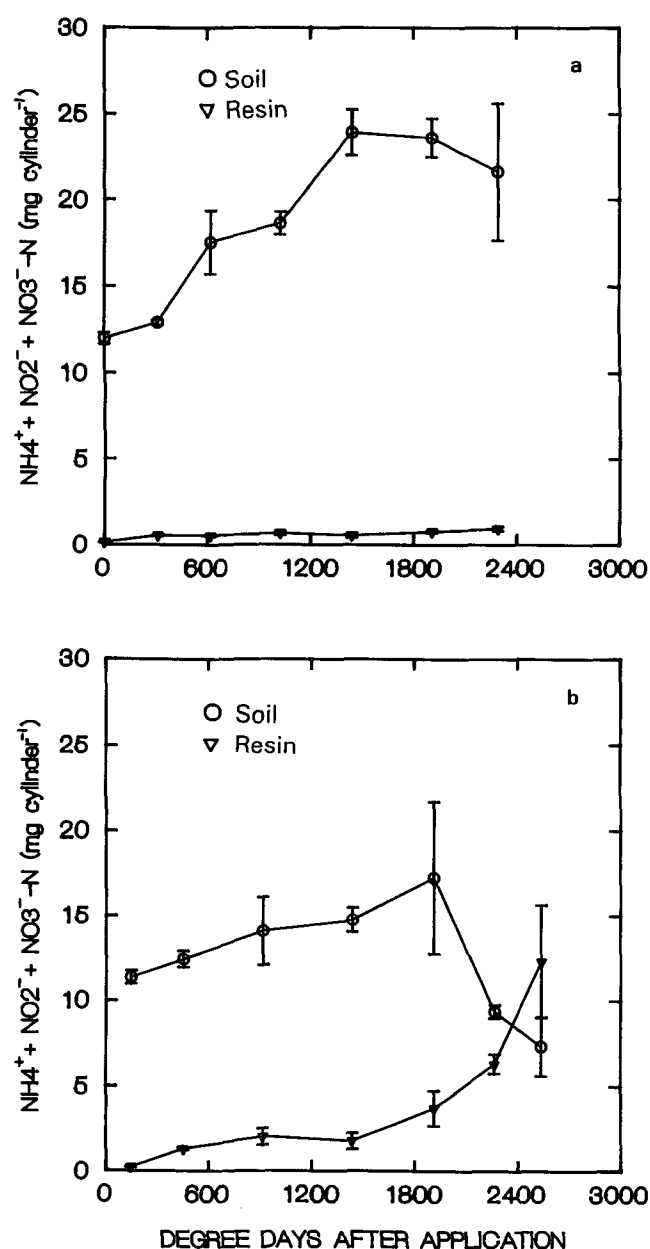‡ Mean (standard error of the mean).

Fig. 2. Inorganic N levels in microplot cylinder soils and resins in (a) 1993 and (b) 1994. Vertical bar indicates standard error of the mean.

DDAA (Fig. 2b). Soil inorganic N declined 9 mg between 1913 and 2537 DDAA (Fig. 2b). This decline coincided with a 9 mg increase in inorganic N found in the exchange resin during the same period (Fig. 2b). These data, although limited, indicate the microplot cylinders were effective in trapping inorganic N.

Soil N Mineralization

Soil N mineralization from unamended (control) microplot cylinder soils was calculated by summing the total content of inorganic N in the soil and resin compartments. Data were then expressed as a percent of total soil N that had mineralized to account for differences in total N concentration and to allow data comparison between the 1989 laboratory study and each field study.

Nitrogen mineralization from soil organic matter proceeded at a slower rate in the field, as compared to the lab, in both 1993 and 1994 (Fig. 3). These differences are significant, as indicated by the non-overlapping 95% confidence intervals of field and lab N mineralization degree day rates (Table 4). Orthogonal contrasts revealed that soil N mineralization relationships with thermal units in the field studies did not differ between 1993 and 1994 ($P = 0.98$).

Field microplot soils were considerably drier and more variable than the 0.232 kg water kg^{-1} soil constantly maintained in the laboratory study (Table 3). Doel et al. (1990) reported lupin (*Lupinus alba* L. Ultra) residue N mineralization to be similarly related to thermal units at −0.03 and −0.01 MPa. However, incubation at −0.30 MPa significantly slowed lupin residue N mineralization (Doel et al., 1990), indicating a soil water factor should be considered for thermal unit predictions under nonirrigated conditions (Honeycutt, 1994). Previous water retention analyses (e.g., Honeycutt and Potaro, 1990) indicated gravimetric water content is approximately related to water potential for this soil in

the following manner:

$$\psi = -0.00007809 \ (\theta^{-4.356833631})$$

where ψ = soil water potential (−MPa) and θ = gravimetric soil water content (kg kg^{-1}). Thus, water potentials in control soils ranged from approximately −0.586 to −0.076 MPa in 1993 and from −22.209 to −0.017 MPa in 1994 (Table 3). Consequently, the drier soils under field conditions may have perhaps limited microbial activity and soil organic N mineralization (Sommers et al., 1981; Schomberg et al., 1994).

Differences in soil N mineralization between the 1989 laboratory study and the field microplot studies may also reflect differences in the management history of those soils. Although the soils were collected only ≈30 m apart on the same 2.5% slope and landscape position, soil collected in 1989 had received 90 kg N ha^{-1} as NH$_4$NO$_3$ in 1988 and 1989. The soil used in 1993 and 1994 had not received N fertilizer since 1990.

Vetch Residue N Mineralization

Field N mineralization from vetch residues was calculated by subtracting the total content of inorganic N in control soils and resins from that in residue-treated microplot cylinder soils and resins. This calculation assumes no priming effect of residue addition on N mineralization of indigenous soil organic matter (Stevenson, 1986). Vetch N mineralization was then expressed as a percentage of total residue N added so that N mineralization from different residue quantities could be compared (Honeycutt et al., 1993).

Ground Residues

Nitrogen mineralization from ground vetch residue was linearly related ($P = 0.01$) to thermal units when averaged across all field study years (data not shown). Laboratory observation of vetch N mineralization vs.
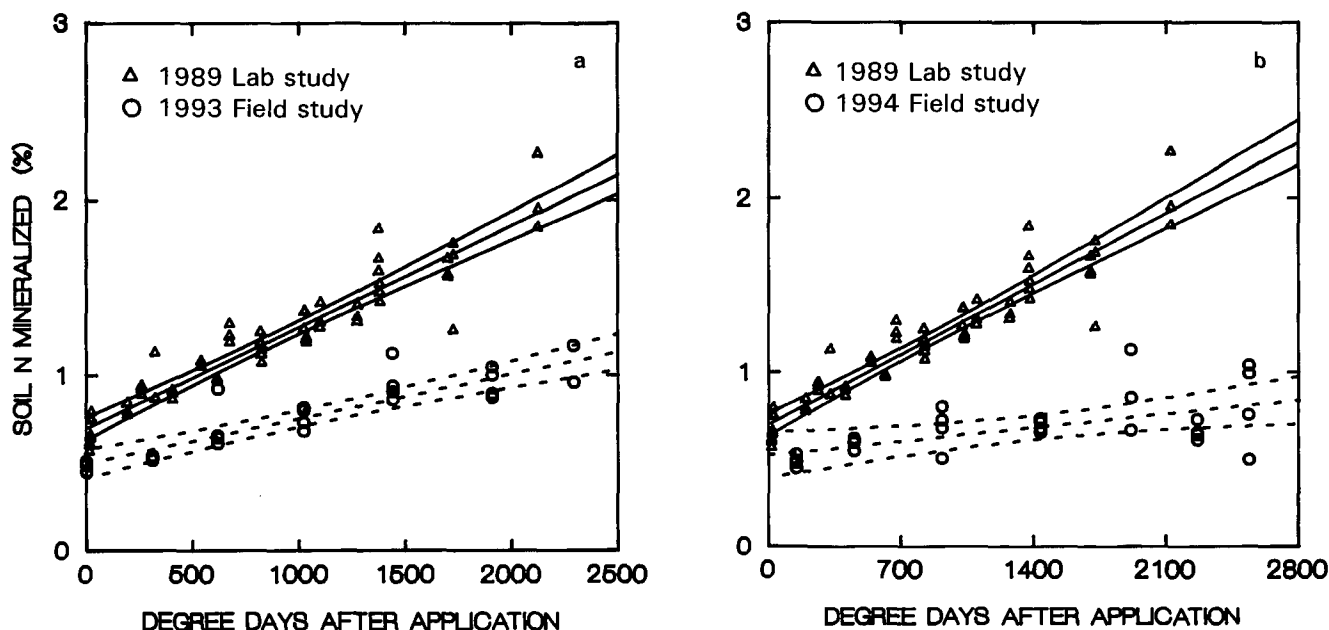

Fig. 3. Percentage of total soil N mineralized in relation to thermal units as predicted by a 1989 laboratory study (solid line) and measured in field studies (dashed lines) conducted in (a) 1993 and (b) 1994. Confidence bands of 95% are shown for each study.

Table 4. Laboratory and field study comparisons of y-intercepts and slopes for N mineralization from soil and two vetch residues.

Residue treatment	Dependent variable	Study	Independent variable	Parameter estimate†	Standard error	Parameter estimate		Lab and field 95% confidence interval overlap
						−2(Std. error)	+2(Std. error)	
Control	Soil N	1989 Lab	Intercept	0.693690	0.025497	0.642697	0.744683	–
	mineralized		DDAA‡	0.000580	0.000025	0.000530	0.000630	–
Control	Soil N	1993 Field	Intercept	0.495307	0.031910	0.431488	0.559126	No
	mineralized		DDAA	0.000255	0.000025	0.000205	0.000305	No
Control	Soil N	1994 Field	Intercept	0.520377	0.051557	0.417264	0.623491	No
	mineralized		DDAA	0.000113	0.000032	0.000049	0.000177	No
Ground	Vetch N	1989 Lab	Intercept	2.006272	0.795942	0.414389	3.598155	–
(≤1 mm)	mineralized		DDAA	0.010785	0.000778	0.009229	0.012341	–
Ground	Vetch N	1993 Field	Intercept	4.347081	1.983047	0.380987	8.313175	Yes
(≤1 mm)	mineralized		DDAA	0.004938	0.001485	0.001968	0.007908	No
Ground	Vetch N	1994 Field	Intercept	−1.088853	3.281145	−7.651142	5.473436	Yes
(≤1 mm)	mineralized		DDAA	0.008031	0.002026	0.003978	0.012084	Yes
Unground	Vetch N	1993 Field	Intercept	5.883810	1.739563	2.404685	9.362935	Yes
(≤25 mm)	mineralized		DDAA	0.012280	0.001303	0.009675	0.014885	Yes
Unground	Vetch N	1994 Field	Intercept	5.951860	4.597715	−3.243570	15.147290	Yes
(≤25 mm)	mineralized		DDAA	0.007996	0.002840	0.002317	0.013675	Yes

† Parameter estimate = coefficient.
‡ DDAA = Degree Days after Application.

thermal units was also linearly related for the 1989 ground vetch (Fig. 4), with the quadratic coefficient determined to be nonsignificant at the $\alpha = 0.05$ level.

Orthogonal contrasts indicated N mineralization from ground vetch residues did not differ between 1993 and 1994 ($P = 0.37$). Field measurements of ground vetch N mineralization in relation to thermal units were similar to 1989 laboratory predictions of this relationship for approximately the first 1100 DDAA in 1993, as indicated by their overlapping 95% confidence bands (Fig. 4a). However, N mineralization rate over thermal time was slower in the 1993 field study than in the laboratory, as shown by non-overlapping 95% confidence intervals of parameter estimates (i.e., slopes) for DDAA (Table 4). Similar y-intercepts of ground vetch N mineralization were observed for the 1989 laboratory and 1993 field studies (Table 4), apparently reflecting similar quantities of inorganic N present in both residues. Similar y-intercepts and slopes were observed for vetch N mineralization vs. thermal units in the 1994 field study, as

compared to the 1989 laboratory study (Fig. 4b, Table 4). These results indicate general agreement between laboratory-predicted and field-measured N mineralization from ground vetch residues in both 1993 and 1994.

Unground Residues

Laboratory predictions of vetch N mineralization in relation to thermal units were developed using residues ground to pass a 1-mm diameter opening (Honeycutt et al., 1993). Consequently, differences in residue particle size could contribute to differences in field and laboratory inorganic N observations (Sims and Frederick, 1970; Cheshire et al., 1974). This hypothesis was tested by comparing N mineralization from ground residues in the laboratory with unground residues in field microplot cylinders.

Field observations of unground vetch residue N mineralization in 1993 were closely predicted by 1989 laboratory measurements utilizing ground vetch (Fig. 5, Ta-
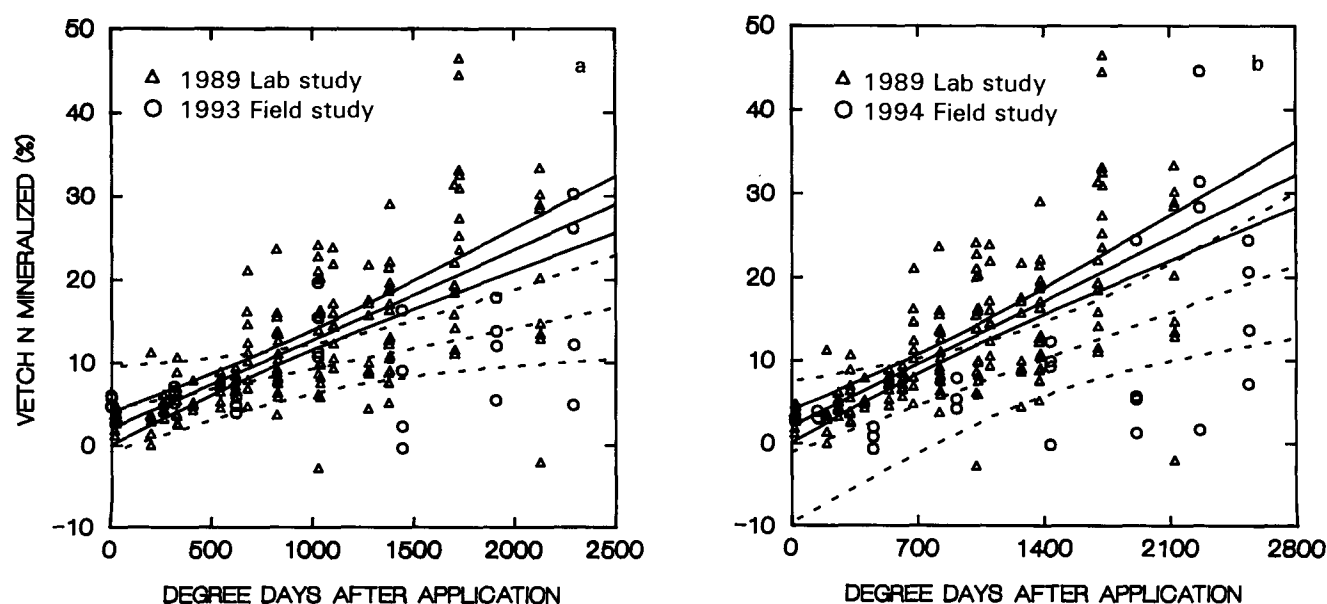

Fig. 4. Percentage of vetch N mineralized in relation to thermal units as predicted by a 1989 laboratory study (solid line) and measured in field studies (dashed lines) of ground (≤1 mm) vetch residue conducted in (a) 1993 and (b) 1994. Confidence bands of 95% are shown for each study.
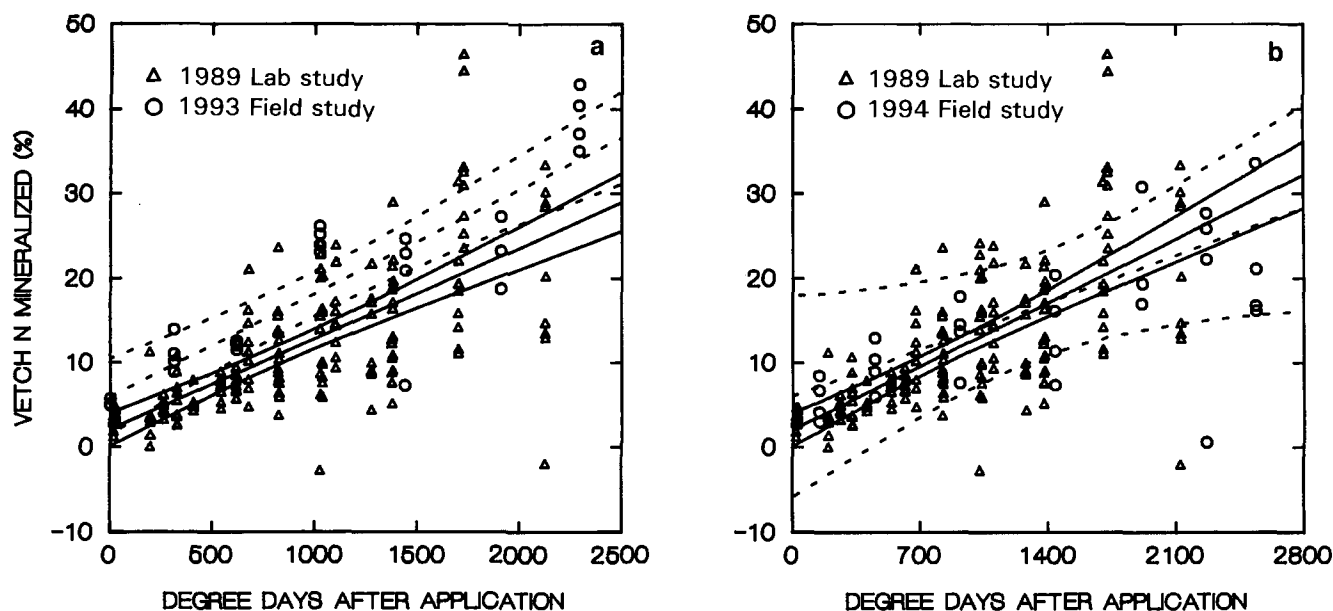
Fig. 5. Percentage of vetch N mineralized in relation to thermal units as predicted by a 1989 laboratory study with ground (≤1 mm) residue (solid line) and measured in field studies of unground (≤25 mm) vetch residues (dashed lines) conducted in (a) 1993 and (b) 1994. Confidence bands of 95% are shown for each study.

ble 4). Thermal unit rates of N mineralization (slopes) and initial inorganic N contents (y-intercepts) did not differ between laboratory-predicted and field-measured values (Table 4). Observations in 1994 again confirmed close prediction of unground vetch N mineralization in the field with ground residues in the laboratory upon employing thermal units (Fig. 5, Table 4).

Residue and Soil Organic Matter Comparison

Laboratory predictions of N mineralization from soil organic matter developed in 1989 were previously shown to overestimate field soil N mineralization in 1993 and 1994. However, N mineralization from both ground and unground vetch residues in the field was closely predicted by laboratory incubations conducted in 1989. Several possibilities may be considered to account for this discrepancy.

Drier soils and more variable soil water contents under field conditions were previously offered as one explanation for overestimating field soil N mineralization with laboratory studies. It should, therefore, follow that higher water contents were maintained in residue-amended soils. Certainly, this is a common observation for soils with both surface and incorporated residues (Steiner, 1994). However, orthogonal contrasts of residue-amended (ground + unground residues) vs. control microplot cylinder soils (Table 3) revealed no differences (α = 0.05) in soil water content at any sample date in any year.

Another possible explanation related to water content involves the water retention character of these residues. It must be acknowledged that the relationship between water potential and gravimetric water content may differ between residue-amended and unamended soil. Consequently, results of orthogonal contrasts for

gravimetric water content may not reflect such differences in water potential.

A third possible explantion is related to substrate differences. It may be speculated that the more readily available substrate, vetch residue, promoted microbial biomass production to the extent that water limitations on N mineralization were not as evident as when soil organic matter was the primary substrate. This possible interaction is currently under investigation.

It should be acknowledged that differences in soil N mineralization between the 1989 laboratory study and the field microplot studies may reflect differences in management histories of soils used, as previously described. Soil and crop management obviously play important roles in influencing the transfer of soil N mineralization predictions from the lab to the field.

Although vetch residue properties did vary somewhat from one year to the next, especially in their lignin content (Table 2), vetch N mineralization could be predicted under modified field conditions in 1993 and 1994 from vetch residues sampled and incubated in 1989. This observation was made despite the use of ground and unground residues; a range of residue quantities; constant laboratory, yet variable field soil temperature; and constant laboratory, yet variable field soil water content.

SUMMARY AND CONCLUSIONS

Nitrogen mineralization from soil organic matter and ground (≤1 mm) vetch residue was determined in the laboratory. These data were used to predict N mineralization from soil organic matter, ground vetch, and unground (≤25 mm) vetch in the field. Microplot cylinders with mixed-bed exchange resin were used to monitor N mineralization under field conditions, as modified by the microplot cylinders. Nitrogen mineralization from

soil organic matter in field microplot cylinders was over-estimated by laboratory predictions. However, field measurements of N mineralization from both ground and unground vetch residues in 1993 and 1994 agreed with 1989 laboratory predictions that were developed utilizing ground residues, three residue quantities, three constant incubation temperatures, and one constant soil water content. Consequently, vetch residue N mineralization under these modified field conditions can be predicted from laboratory studies using ground residues and thermal units.

REFERENCES

Aulakh, M.S., and D.A. Rennie. 1987. Effect of wheat straw incorporation on denitrification of N under anaerobic and aerobic conditions. Can. J. Soil Sci. 67:825–834.

Cabrera, M.L., D.E. Kissel, and M.F. Vigil. 1994. Potential nitrogen mineralization: Laboratory and field evaluation. p. 15–30. In J.L. Havlin and J.S. Jacobsen (ed.) Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. 40. ASA, CSSA, and SSSA, Madison, WI.

Campbell, C.A., Y.W. Jame, O.O. Akinremi, and H.J. Beckie. 1994. Evaluating potential nitrogen mineralization for predicting fertilizer nitrogen requirements of long-term field experiments. p. 81–100. In J.L. Havlin and J.S. Jacobsen (ed.) Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. 40. ASA, CSSA, and SSSA, Madison, WI.

Cheshire, M.V., C.M. Mundie, and H. Shepherd. 1974. Transformations of sugars when rye hemicellulose labelled with ^{14}C decomposes in soil. J. Soil Sci. 25:90–98.

Doel, D.S., C.W. Honeycutt, and W.A. Halteman. 1990. Soil water effects on the use of heat units to predict crop residue carbon and nitrogen mineralization. Biol. Fertil. Soils 10:102–106.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Sci. Soc. Am. Proc. 24:277–279.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:383–411.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analysis. USDA-ARS Agric. Handb. No. 379. U.S. Gov. Print. Office, Washington, DC.

Honeycutt, C.W. 1994. Linking nitrogen mineralization and plant nitrogen demand with thermal units. p. 49–79. In J.L. Havlin and J.S. Jacobsen (ed.) Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. 40. ASA, CSSA, and SSSA, Madison, WI.

Honeycutt, C.W., W.M. Clapham, and S.S. Leach. 1994. A functional approach to efficient N use in crop production. Ecol. Model. 72:51–61.

Honeycutt, C.W., and L.J. Potaro. 1990. Field evaluation of heat units for predicting crop residue carbon and nitrogen mineralization. Plant Soil 125:213–220.

Honeycutt, C.W., L.J. Potaro, K.L. Avila, and W.A. Halteman. 1993. Residue quality, loading rate and soil temperature relations with hairy vetch (Vicia villosa Roth) residue carbon, nitrogen and phosphorus mineralization. Biol. Agric. Hortic. 9:181–199.

Honeycutt, C.W., L.M. Zibilske, and W.M. Clapham. 1988. Heat units for describing carbon mineralization and predicting net nitrogen mineralization. Soil Sci. Soc. Am. J. 52:1346–1350.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen: Inorganic forms. In A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:643–698.

Klute, A. 1986. Water retention: Laboratory methods. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:635–662.

Pramer, D., and R. Bartha. 1972. Preparation and processing of soil samples for biodegradation studies. Environ. Lett. 2:217–224.

Rice, C.W., and J.L. Havlin. 1994. Integrating mineralizable nitrogen indices into fertilizer nitrogen recommendations. p. 1–13. In J.L. Havlin and J.S. Jacobsen (ed.) Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. 40. ASA, CSSA, and SSSA, Madison, WI.

Schepers, J.S., and J.J. Meisinger. 1994. Field indicators of nitrogen mineralization. p. 31–47. In J.L. Havlin and J.S. Jacobsen (ed.) Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. 40. ASA, CSSA, and SSSA, Madison, WI.

Schnabel, R.R. 1983. Measuring nitrogen leaching with ion exchange resin: a laboratory assessment. Soil Sci. Soc. Am. J. 47:1041–1042.

Schomberg, H.H., J.L. Steiner, and P.W. Unger. 1994. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. Soil Sci. Soc. Am. J. 58:372–381.

Sims, J.L., and L.R. Frederick. 1970. Nitrogen immobilization and decomposition of corn residue in soil and sand as affected by residue particle size. Soil Sci. 109:355–361.

Sommers, L.E., C.M. Gilmour, R.E. Wildung, and S.M. Beck. 1981. The effect of water potential on decomposition processes in soil. p. 97–119. In J.F. Parr et al. (ed.) Water potential relations in soil microbiology. SSSA Spec. Publ. 9, ASA, CSSA, SSSA, Madison, WI.

Steiner, J.L. 1994. Crop residue effects on water conservation. p. 41–76. In P.W. Unger (ed.) Managing agricultural residues. Lewis Pub., CRC Press, Boca Raton, FL.

Stevenson, F.J. 1986. Cycles of soil carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley & Sons, Inc., New York.

Van Schreven, D.A. 1968. The production of mineral nitrogen by soil samples, contained in polyethylene bags, under field conditions and in the laboratory. Plant Soil 29:170–183.

Van Soest, P.J. and J.B. Robertson. 1979. System of analysis for evaluating fibrous feeds. p. 49–60. In W.J. Pigden et al. (ed.) Standardization of analytical methodology for feeds. Int. Dev. Res. Centre, Ottawa, Canada.

Westermann, D.T., and S.E. Crothers. 1980. Measuring soil nitrogen mineralization under field conditions. Agron. J. 72:1009–1011.