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Soil Nitrogen Mineralization Potential for Improved Nitrogen
Fertilizer Recommendations and Decreased Nitrate Contamination of Groundwater

ABSTRACT

In order to prevent overfertilization, which could lead to groundwater contamination, rapid and accurate soil testing procedures are needed to evaluate agricultural surface soils for their potential to mineralize C and N. Our objectives were to determine optimum conditions for estimating soil microbial biomass (SMB) from previously dried soils and to identify a quick, reliable biochemical predictor of soil N mineralization potential. Initial evaluations were conducted on a Weswood silty clay loam (fine, mixed, thermic Fluventic Ustochrept) with five levels of soil organic C (SOC) using (i) fresh soil, and (ii) soil that was air-dried, rewetted, and pre-incubated for 0.2, 1, 3, 6, 10, and 15 d. Procedures to estimate C and N mineralization potentials included arginine ammonification (AA), substrate-induced respiration (SIR), cumulative C and net N mineralization, and soil microbial biomass carbon (SMBC) using the chloroform fumigation-incubation (CFI) method. Carbon mineralization was highly correlated to (i) SMBC using CFI determined on fresh and dried soil and (ii) net N mineralization during 21 d for the Weswood soil, as well as for seven additional soil types with 5 to 8 levels of SOC each. Measurement of CO_2-C evolved during the first day after rewetting of dried soil is recommended for rapid estimation of SMBC and potential N mineralization because of its simplicity and precision.

ABBREVIATIONS

AA, arginine ammonification; BSR, basal soil respiration; CFI, chloroform fumigation-incubation; SIR, substrate-induced respiration; SMB, soil microbial biomass; SMBC, soil microbial biomass carbon; SOC, soil organic carbon; SOM, soil organic matter.

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INTRODUCTION

The importance of soil microorganisms in affecting soil fertility is recognized, but rapid, accurate soil testing procedures that reflect potential C and N mineralization have not been routinely adopted (Keeney, 1982). A valid index of soil N availability that is simple, rapid, and reproducible may preclude longer-term laboratory incubations. Incubations lasting two or more weeks for determination of mineral N accumulation are considered too time-consuming for adoption by routine soil testing programs.

The N-supply potential of agricultural soils has been related to SMB and its activity (Carter and Rennie, 1982; Doran, 1987; Franzluebbers et al., 1994a). Measurement of SMB is sensitive to changes in the active fraction of SOM (Powlson et al., 1987; Anderson and Domsch, 1989) and, therefore, should provide insight into the potential of soils to mineralize N. The most commonly used method for estimation of SMB is CFI, although fresh soil and a 10-d incubation are needed (Jenkinson and Ladd, 1981; Nannipieri et al., 1990; Parkinson and Coleman, 1991), which limit its adoption by soil testing programs. Several rapid methods for estimation of SMB and its activity (i.e., C and N mineralization) have been developed over the past few decades including SIR (Anderson and Domsch, 1978) and AA (Alef et al., 1988), which require only one to six hours of incubation. As described, however, these methods require use of fresh soil which is a potential drawback.

Soil testing protocol normally requires that dried soil be used because samples collected by producers and soil testing services may require several days to reach the soil testing facility. The delay may result in an altered biochemical status if samples are kept moist. Our hypothesis was that dried, rewetted, and pre-incubated soil could be used to obtain an estimate of SMB. The optimum pre-incubation period for estimation of SMB and mineralizable N from dried samples,

however, needs to be established.

Our objectives were to (i) evaluate the feasibility of using dried and pre-incubated soil for measurement of AA, SIR, cumulative C and net N mineralization, and SMBC using CFI, (ii) determine the optimum time of pre-incubation for these biochemical estimates, and (iii) determine if these or other methodologies are suitable for rapid estimation of soil N mineralization potential.

MATERIALS AND METHODS

Five soil samples with SMBC levels ranging from 279 to 1260 mg · kg^{-1} soil (Table 1) were collected shortly after planting wheat (*Triticum aestivum* L.) in November 1991 from a long-term field experiment established on a Weswood silty clay loam in 1982 (Table 2). Fifteen composited soil cores (19 mm dia.) per 4 m x 12.2 m plot were collected from three of four replications. Field-moist samples were sieved to pass a 5-mm screen and stored at 4°C for determination of chemical and biological properties of fresh soil (Franzluebbers et al., 1995b). A portion of the soil was air-dried at room temperature, sieved to pass a 2-mm screen, and stored in plastic bags. Analyses of fresh soil were performed in the same manner as those of dried soil, except when noted otherwise.

For determination of AA (Alef and Kleiner, 1986), SIR (Anderson and Domsch, 1978), and net N mineralization, quadruplicate subsamples of 10 g soil each were placed in 70-mL pyrex screw-top tubes, 0.3 kg water · kg^{-1} soil (≈-30 J · kg^{-1} soil) was added, and samples were pre-incubated for 0.2, 1, 3, 6, 10, or 15d. All mineralization and biochemical evaluations were conducted at 25°C. After the respective pre-incubation periods, 1 mL of arginine (120 mg · kg^{-1} soil) plus glucose (200 mg · kg^{-1} soil) solution was added to two of the tubes. To the other two tubes, 1 mL of a solution containing only glucose was added to serve as a control without addition of organic N. After incubation for 3 hr at 25°C, tubes were frozen and stored at -20°C

prior to extraction for mineral N with 40 mL of 2 *M* KCl. The filtered extract was analyzed for NH_4-N and NO_3-N concentrations using autoanalyzer techniques with a salicylic acid modification of the indophenol blue method (Technicon Industrial Systems, 1977a) and the Cd reduction method (Technicon Industrial Systems, 1977b), respectively. For determination of AA, the size of the SMB was inferred from the increase in NH_4-N concentration with the addition of arginine and glucose less the NH_4-N concentration with only glucose.

Substrate-induced respiration was determined from the CO_2-C evolved from the quadruplicate samples used for AA determination. At the time 1 mL of arginine/glucose or glucose only solution was added, 3 mL of 0.5 *M* KOH was dispensed into a 4-mL plastic vial and suspended ≈5 cm above the soil. The CO_2-C absorbed in the alkali was determined by titration with 0.15 *M* HCl after addition of $BaCl_2$ (Anderson, 1982). No difference in respiratory response between duplicate samples receiving arginine/glucose and glucose only was observed (Franzluebbers et al., 1995b). Gilmour and Gilmour (1985) did not find any difference in respiratory activity during 8 hr of incubation of a soil with only glucose and glucose plus $(NH_4)_2SO_4$. The relative size of the SMB was inferred from the CO_2-C evolved during the 3-hr incubation with added substrates. There was a six- to 22-fold increase in respiration rate due to added substrates compared to BSR. We assumed that both AA and SIR procedures determined a response to added substrate due to existing SMB and that detectable growth of SMB due to substrate addition did not occur during 3 hr.

Nitrogen mineralization from fresh soil was determined from mineral N (NH_4-N, NO_3-N, and NO_2-N) accumulation during 10 d. Net N mineralization during 15 d of incubation after rewetting of dried soil was determined from the NH_4-N concentration of soil receiving glucose only plus the NO_3-N concentration of soil receiving arginine/glucose and glucose. No difference

in NO_3-N concentration between subsamples receiving arginine/glucose and glucose only was observed. Nitrification of the small amount of NH_4^+ mineralized from added arginine during the 3-hr incubation was apparently not detectable. Net N mineralization was described using the non-linear regression equation (Cabrera, 1993):

$$N_t = N_i + N_0 \quad (1 - e^{-k \cdot t})$$

where N_t = inorganic N concentration (mg N · kg^{-1} soil) at time t (d), N_i = initial inorganic N concentration (mg N · kg^{-1} soil), N_0 = N mineralization potential (mg N · kg^{-1} soil), and k = non-linear mineralization constant (d^{-1}).

Basal soil respiration of fresh soil was determined from the CO_2-C evolved during 10 d. Cumulative C mineralization of dried soil was determined from duplicate subsamples of 20 g soil placed in 50-mL beakers, with 0.3 kg water kg^{-1} soil added, and incubated for 0.2, 1, 3, 6, 10, or 15 d at 25°C in 1-L air-tight sealed jars along with 10 mL 0.5 *N* KOH. The quantity of CO_2-C evolved was determined by titration with 0.5 *M* HCl. Cumulative C mineralization was described using the non-linear regression equation (Santruckova et al., 1993):

$$C_t = C_f \cdot (1 - e^{-k \cdot t}) + BSR \quad t$$

where C_t = C mineralization (mg C · kg^{-1} soil) at time t (d), C_f = C mineralization potential of the flush after rewetting of dried soil (mg C · kg^{-1} soil), k = non-linear mineralization constant (d^{-1}), and BSR = basal soil respiration (mg C · kg^{-1} soil).

Soil microbial biomass C was determined at 0.2, 1, 3, 6, 10, and 15 d after rewetting of dried soil from the duplicate samples that were previously used for cumulative C mineralization by exposing soil to alcohol-free chloroform vapor for 24 hours (Jenkinson and Powlson, 1976). Following removal of vapors by evacuation, samples were incubated in 1-L air-tight sealed jars along with 10 mL 0.5 *N* KOH for 10 d at 25°C. The CO_2-C evolved during the 10-d incubation

following fumigation without subtraction of a control was divided by an efficiency factor of 0.41 (Voroney and Paul, 1984). Soil microbial biomass C calculated with subtraction of a 10-d control sample was also evaluated.

Air-dried soil that was further ground to pass a 0.5-mm screen was analyzed for SOC with the modified Mebius method (Nelson and Sommers, 1982) and total Kjeldahl N (Gallaher et al., 1976).

Soil samples of seven additional soil types (Table 2) with five to eight levels of SOM within each soil type were collected during 1993 and 1994, air-dried, and sieved to pass a 5-mm screen. Within each soil type, SOM content differed due to cropping history, tillage management, manure application, and/or sampling depth (Table 2). These 52 additional samples were analyzed for SOC, SMBC using CFI, and cumulative C and net N mineralization as previously described, except for the following modifications. Soil water content was adjusted to near field capacity (i.e., 0.075 kg · kg^{-1} for Bowie fsl, 0.125 kg · kg^{-1} for Windthorst fsl, 0.25 kg · kg^{-1} for Orelia scl, 0.325 kg · kg^{-1} for Pullman sicl, 0.40 kg · kg^{-1} for Burleson sic, 0.425 kg · kg^{-1} for Krum c, and 0.45 kg · kg^{-1} for Branyon c). Cumulative C and net N mineralization were determined from 40 g subsamples for Bowie fsl and Windthorst fsl at 1, 3, 10, 20, and 30 d of incubation and from 20 g subsamples for Orelia scl, Pullman sicl, Burleson sic, Krum c, and Branyon c at 1, 4, 10, and 27 d of incubation. Inorganic N was determined at 0, 10, 20, and 30 d for Bowie fsl and Windthorst fsl and at 0, 4, 10, and 27 d for Orelia scl, Pullman sicl, Burleson sic, Krum c, and Branyon c after oven-drying (60°C, 24 hrs). Cumulative C and net N mineralization were determined using non-linear regression as described previously. Regression equations were used to predict cumulative C and net N mineralization at 21 d of incubation for all soils. Soil microbial biomass C was determined after 10 d of pre-incubation.

Biochemical estimates with each method for each pre-incubation period were correlated to SMBC using CFI and BSR of fresh Weswood soil. Soil microbial biomass using CFI and BSR from fresh soil were assumed to be the most reliable methods currently available to estimate SMB size and potential activity, respectively. Significance is at $P \leq 0.01$ or unless otherwise indicated.

RESULTS AND DISCUSSION

Pre-Incubation Period for Biochemical Determinations

Soil microbial biomass with the CFI method, BSR, and net N mineralization determined from fresh soil were highly related to SOC and TKN, but AA and SIR were not. Only with a larger data set were estimates with AA and SIR correlated to SOC and TKN (Franzluebbers et al., 1995b). The coefficient of variation for analysis on fresh soil was 80% for AA, 62% for SIR, 42% for net N mineralization, 13% for BSR, and 8% for SMBC. Soil organic C and total Kjeldahl N had coefficients of variation of 7%. Inherent soil and methodological variability appeared to be a major limitation in describing the relatively small response in NH_4-N mineralization with AA and CO_2-C evolution with SIR during the 3-hr incubation.

Estimates of SMB using AA on rewetted soil were correlated with SMBC using CFI on fresh soil for most pre-incubation periods (Table 3). Although relationships were statistically significant, they were not strong enough to be used to predict SMB. At some pre-incubation periods, correlations were even negative, indicating purely statistical significance. Despite methodological rapidity, AA determined on rewetted soil cannot be recommended for routine soil testing unless further modifications are made to reduce variability.

Estimates of SMB using SIR were best correlated with SMBC using CFI on fresh soil at 1 and 15 d of pre-incubation (Table 3). Correlations were variable at other pre-incubation periods, indicating that this method may not be reliable for rewetted soil without an extended pre-

incubation. Long pre-incubation would exclude this method as a rapid soil testing procedure. The reliability of SIR and AA for rewetted soil appears to be questionable with coefficients of variation for both assays of 70 to > 100%.

Carbon mineralization and SMBC using CFI at all pre-incubation periods, except C mineralization during 0.2 d, were highly related to SMBC using CFI on fresh soil (Table 3). Soil microbial biomass C using CFI on rewetted soil compared to fresh soil was an average of 43% greater at 0.2 d of pre-incubation, 6% greater at 1 d ($P \leq 0.1$), 10% greater at 3 d, 29% greater at 6 d, 17% greater at 10 d, and not different at 15 d (Fig. 1c). The overestimation at 0.2 d of pre-incubation increased with decreasing level of SMBC. The flush of CO_2-C during the first three days after rewetting (Fig. 1a) probably caused this overestimation in SMBC. Soil microbial biomass C determined immediately after rewetting of dried soil resulted in values 25% greater than from fresh, undisturbed soil (Shen et al., 1987). Estimation of SMBC using CFI with subtraction of a 10-d control value on fresh soil was highly related to the same procedure without subtraction of a control ($r=0.99$). A similarly close correlation ($r=0.99$) has been observed previously (Jenkinson and Powlson, 1976). Estimates of SMBC using CFI on rewetted soil with a control subtracted averaged 49% greater than on fresh soil at 0.2 d of pre-incubation, 10% less at 1 d, 24% greater at 3 d, 76% greater at 6 d, 58% greater at 10 d, and 18% greater at 15 d.

We recommend that soils be pre-incubated for ≥10 d in order to stabilize the SMB following disturbance caused by drying and rewetting because 90% of the flush of CO_2-C due to rewetting of dried soil was evolved within four to 10d (Figs. 1a, b). Carbon and N mineralization rates were similar for continuously moist soils and dried soils which had been moistened for 10d. Symbols were placed only at 10d to distinguish various treatments and to show that the C and N flush had subsided by that time (Figs. 1a, b). Samples with lower SOM took longer time to reach

a steady-state BSR. However, the length of the pre-incubation period mattered little in separating relative differences in SMBC using CFI among samples with different SOM levels. This is of importance since the determination of SMBC using CFI and other methods should be considered a relative rather than an absolute estimate.

A Rapid Test for N Mineralization

Carbon mineralization from Weswood soil during the first day after rewetting was highly related to cumulative C and net N mineralization from 0 to 15 d (Fig. 1a, b):

$$CMIN_{0\text{-}15d} = 22 + 5.7(CO_2\text{-}C_{0\text{-}1d}),\ r^2=0.99 \text{ and}$$

$$NMIN_{0\text{-}15d} = 3.4 + 0.35(CO_2\text{-}C_{0\text{-}1d}),\ r^2=0.87.$$

Therefore, the flush of CO_2-C captured during the first 24h following rewetting of dried soil may be a reliable method to estimate the potential of a soil to mineralize C and N. Prediction of C mineralized during 15 d by C mineralized during 1 d is supported by previous observations in which relative differences in cumulative C mineralization among soils early in incubations are often maintained throughout extended incubations (Honeycutt et al., 1988; Franzluebbers et al., 1995c).

Carbon mineralization during the first day after rewetting of dried soil as a predictor of net N mineralization was evaluated further with seven additional soils from Texas (Table 2). The CO_2-C evolved during the first day after rewetting of dried soil was highly related in most cases to the cumulative C and net N mineralization during 21 d and to SMBC (Table 4). Differences in relationships among soils were significant, although these differences were not related to soil texture or pH. Despite these differences among soils, strong relationships between the CO_2-C evolved during the first day after rewetting of dried soil and SMBC (r^2=0.87) and net N mineralization during 21 d (r^2=0.85) were observed (Fig. 2). Ranges for the measured parameters

from the eight soils were 12 to 245 mg CO_2-C kg^{-1} for 1d CO_2 evolution, 11 to 224 mg N kg^{-1} for N mineralization, 78 to 1508 mg C kg^{-1} for C mineralization, and 149 to 6190 mg C kg^{-1} for SMBC (Table 5). These wide ranges occurred due to differences in soil organic C concentration, management practices, and soil chemical and physical properties.

We attempted to validate the relationship between CO_2-C evolved during the first day after rewetting and net N mineralization with several published reports (Table 6). The CO_2-C evolved during the first day after rewetting predicted net N mineralization with a standard deviation of ±8 mg N · kg^{-1} soil. Six of 15 observations were predicted ±5 mg N · kg^{-1} soil and 13 of 15 observations were predicted ±10 mg N · kg^{-1} soil.

Prediction of SMBC and net N mineralization from CO_2-C evolved during the first day after wetting dried soil has a firm theoretical basis. Drying soil kills part of the SMB (Jenkinson, 1966), as well as rendering some non-living SOM mineralizable due to chemical and physical disturbance (Kieft et al., 1987; van Gestel et al., 1991). The flush of activity during the first day, therefore reflects the contribution of both the SMB and active SOM pools that are readily mineralizable. Prediction of net N mineralization from CO_2 evolution has been suggested for plant residues added to soil (Gilmour et al., 1985). The relationship between C and N mineralization during 30 d differed among plant residues due to the initial C/N ratio of the residue, as well as the C/N ratio of the residue remaining after decomposition of the rapidly-mineralizable fraction (Gilmour et al., 1985). The overall C/N ratio of most soils is relatively stable between 8 and 12 (Alexander, 1991), therefore variation in the relationship between C and N mineralization among soils would be more a function of the active fraction of SOM, including the SMB, its metabolic by-products, and recently introduced organic residues. Differences in the relationships among soils presented in Table 4 were probably due to differences in active SOM, as well as chemical

and physical differences that remain to be defined.

Net N mineralization was also highly related to SOC for all soils, with the relationship:

$$NMIN_{0\text{-}21d} = -13.9 + 3.78(SOC),\ r^2=0.87.$$

Differences in this relationship among soils were not significant. Except for the Pullman soil, the proportion of SOC as SMBC did not influence the relationship between net N mineralization and the flush of CO_2-C during the first day after rewetting, suggesting that active fractions of SOM other than the SMB probably contributed more to differences in net N mineralization among soils.

A potential limitation for using the relationship between the CO_2-C evolved during the first day after rewetting and net N mineralization may be that soils sampled during a period after addition of organic material with a high C/N ratio (e.g., cereal straw or rhizodeposition products) may lead to an overestimation of the short-term N availability due to immobilization of N (Franzluebbers et al., 1994b; 1995a). Limiting this relationship to soil samples collected only in spring, as is typical for summer crops, could alleviate this potential problem.

Net N mineralization during the first two weeks after rewetting dried soil was closely related to the potentially mineralizable N during 30 weeks of successive leaching-incubation (Fig. 3; relationship derived from data presented in Stanford and Smith, 1972) and during 24 weeks of incubation (relationship derived from data presented in Smith et al., 1994b):

$$NMIN_{0\text{-}14d} = 25 + 2.8(NMIN_{0\text{-}168d}),\ r^2=0.85.$$

More intensive sampling of a Windthorst soil near Stephenville, TX was made in May 1994 prior to spring growth of Coastal bermudagrass. This site has received varying rates of dairy cattle manure for several years. Two quarterly waste applications were made prior to sampling and one further application was made during the growing season. Several biochemical parameters were determined on these samples and correlated with total Coastal bermudagrass dry

matter yield for the growing season (Table 7). All determined parameters were very highly correlated with bermudagrass yield. Carbon dioxide evolution (C mineralization) for 1-day following rewetting of dried soil is proposed as a soil test procedure because of its rapidity and simplicity compared to other procedures. Determination of CO_2-C evolution under controlled conditions is considerably simpler and less time consuming than periodic determination of inorganic N from aerobic or anaerobic incubations, whether conducted with short-term destructive sampling or with long-term leaching incubations. Prediction of potential N mineralization from the CO_2-C evolved during the first day after rewetting of dried soil may be a valuable procedure for use in routine soil testing laboratories where simplicity, rapidity, and reproducibility are important criteria.

Further research is needed to identify the factors controlling the differences in relationships between the CO_2-C evolved during the first day after rewetting and net N mineralization among soils. However, due to its relative simplicity, rapidity, and reliability, we recommend that the quantity of CO_2-C evolved during the first day after rewetting of dried soil be considered as a rapid test to estimate net N mineralization potential associated with the size and potential activity of the SMB.

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Table 1. Soil properties of the five Weswood samples determined on fresh soil (Franzluebbers et al. 1995a).

Sample	Tillage†	Crop Sequence‡	Depth	Soil Property§						
				SOC	TKN	SMBC	BSR	NMIN	SIR	AA
			mm	-------	$g \cdot kg^{-1}$	--------	$mg \cdot kg^{-1} \cdot d^{-1}$		$mg \cdot kg^{-1} \cdot h^{-1}$	
VH	NT	Wheat/Soybean	0-50	16.8	1.7	1.26	25.6	2.5	4.3	0.9
H	NT	Wheat/Soy-Sorghum	0-50	15.5	1.6	1.00	19.6	1.9	2.5	1.2
M	NT	Wheat	0-50	11.6	1.2	0.75	17.2	2.4	2.6	1.3
L	CT	Wheat/Soybean	50-125	8.3	1.0	0.48	9.8	1.0	3.4	0.5
VL	NT	Wheat	125-200	7.4	0.8	0.28	7.7	0.8	1.8	0.4
Standard Error				0.5	0.1	0.04	1.2	0.4	1.0	0.4

† Tillage regimes are NT = no tillage and CT = conventional tillage.

‡ Crops are sorghum [*Sorghum bicolor* L. (Moench.)], soybean [*Glycine max* L. (Merr.)], and wheat (*Triticum aestivum* L.).

§ Soil properties are SOC = soil organic carbon, TKN = total Kjeldahl nitrogen, SMBC = soil microbial biomass carbon, BSR = basal soil respiration, NMIN = nitrogen mineralization, SIR = substrate-induced respiration, and AA = arginine ammonification.

Table 2. Physical and chemical characteristics of the eight soil types.

Soil classification	Location	Clay	Sand	pH	Number of Samples	Land management/sampling
		$g \cdot kg^{-1}$				
Bowie fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudult	Overton TX	70	740	5.9	8	Bermudagrass [*Cynodon dactylon* (L). Pers.]; poultry manure applied at 0, 10, 20, and 40 g N $\cdot$ m^{-2}; 0-50 and 50-100 mm soil depths
Windthorst fine sandy loam (fine, mixed, thermic Udic Paleustalf)	Stephenville TX	120	660	6.5	8	Bermudagrass; cattle manure applied at 0, 10, 20, and 40 g N $\cdot$ m^{-2}; 0-50 and 50-100 mm soil depths
Orelia sandy clay loam (fine-loamy, mixed, hyperthermic Typic Ochraqualf)	Corpus Christi TX	270	560	8.0	5	Maize (*Zea mays* L.); conventional disk, moldboard, and no tillage; 0-50, 50-125, and 125-200 mm soil depths
Pullman silty clay loam (fine, mixed, thermic Torrertic Paleustoll)	Bushland TX	360	130	6.0	8	Wheat (*Triticum aestivum* L.) and sorghum [*Sorghum bicolor* (L.) Moench]; stubble mulch and no tillage; 0-75, 75-150, and 150-300 mm soil depths
Weswood silty clay loam (fine, mixed, thermic Fluventic Ustochrept	College Station TX	360	110	8.2	5	Wheat, sorghum, and soybean [*Glycine max* (L.), Merr.]; conventional disk and no tillage; 0-50, 50-125, and 125-200 mm soil depths
Burleson silty clay (fine, mont-morillonitic, thermic Udic Pellustert)	Taylor TX	400	150	8.1	7	Cotton (*Gossypium hirsutum* L.), sorghum, and bermudagrass; cattle manure feeding area; 0-100 and 100-200 mm soil depths
Krum clay (fine, montmorillonitic, thermic Vertic Haplustoll)	Hillsboro TX	440	170	8.2	8	Cotton, sorghum, and bermudagrass; 0-100 and 100-200 mm soil depths
Branyon clay (fine, montmorillonitic, thermic Udic Pellustert)	Hillsboro TX	450	190	8.1	8	Cotton, sorghum, and bermudagrass; 0-100 and 100-200 mm soil depths

Table 3. Correlation coefficients relating biochemical estimates determined on dried Weswood soil preincubated for 0.2, 1, 3, 6, 10, and 15 d to soil microbial biomass C using chloroform fumigation-incubation on fresh Weswood soil.

Determination†	Condition‡	Correlation Coefficient§	Determination	Condition	Correlation Coefficient
SOC	dried	0.965***	TKN	dried	0.976***
AA	fresh	0.428	SIR	fresh	0.330
AA	D/W, 0.2 d	0.629*	SIR	D/W, 0.2d	0.111
AA	D/W, 1 d	0.788**	SIR	D/W, 1 d	0.874***
AA	D/W, 3 d	-0.694*	SIR	D/W, 3 d	0.719**
AA	D/W, 6 d	-0.576*	SIR	D/W, 6 d	0.521*
AA	D/W, 10 d	0.636*	SIR	D/W, 10 d	0.703***
AA	D/W, 15 d	0.710*	SIR	D/W, 15 d	0.933***
CMIN	fresh, 0-10 d	0.960***	NMIN	fresh, 0-10 d	0.699**
CMIN	D/W, 0-0.2 d	0.575	NMIN	D/W, 0.2 d	0.934***
CMIN	D/W, 0-1 d	0.956***	NMIN	D/W, 1 d	0.911***
CMIN	D/W, 1-3 d	0.974***	NMIN	D/W, 3 d	0.917***
CMIN	D/W, 3-6 d	0.990***	NMIN	D/W, 6 d	0.806**
CMIN	D/W, 6-10 d	0.954***	NMIN	D/W, 10 d	0.948***
CMIN	D/W, 10-15 d	0.949***	NMIN	D/W, 15 d	0.960***
CFI	D/W, 0.2 d	0.981***	CFI	D/W, 6 d	0.975***
CFI	D/W, 1 d	0.984***	CFI	D/W, 10 d	0.975***
CFI	D/W, 3 d	0.975***	CFI	D/W, 15 d	0.938***

† Determinations were SOC = soil organic carbon, CMIN = C mineralization, AA = arginine ammonification, CFI = chloroform fumigation-incubation, TKN = total Kjeldahl nitrogen, NMIN = net nitrogen mineralization, and SIR = substrate-induced respiration.

‡ Condition of soils were fresh (without drying) and D/W (air-dried and subsequently rewetted with a pre-incubation period between 0.2 and 15 d).

§ *, **, and *** indicate significance at $P \leq 0.1$, 0.01, and 0.001, respectively.

Table 4. Regression equations relating the CO_2-C evolved during the first day after rewetting of dried soil to cumulative C and net N mineralization during 21 d and to soil microbial biomass C for eight soils from Texas.

	$CMIN_{0\text{-}21d}$ = $a + b \cdot (CO_2\text{-}C_{0\text{-}1d})$			$NMIN_{0\text{-}21d}$ = $a + b \cdot (CO_2\text{-}C_{0\text{-}1d})$			SMBC = $a + b \cdot (CO_2\text{-}C_{0\text{-}1d})$		
	Intercept	Slope		Intercept	Slope		Intercept	Slope	
Soil	(a)	(b)	r^2	(a)	(b)	r^2	(a)	(b)	r^2
Bowie fsl	-22	11.0	0.94 ***	-0.3	1.21	0.89 ***	-56	21.3	0.92 ***
Windthorst fsl	-86	10.4	0.95 ***	10.0	0.59	0.62 *	-205	17.4	0.85 ***
Orelia scl	-25	5.8	0.93 **	* 12.4	0.27	0.62	24	15.8	0.95 **
Pullman sicl	-49	6.0	0.94 ***	4.0	0.60	0.66 **	2	20.4	0.74 **
Weswood sicl	7	7.5	0.99 ***	2.5	0.46	0.99 ***	** 149	15.3	0.99 ***
Burleson sic	* -74	6.3	0.99 ***	-10.0	1.04	0.91 ***	-126	25.2	0.97 ***
Krum c	-15	7.7	0.90 ***	** 19.1	0.32	0.78 **	* 601	18.3	0.79 **
Branyon c	-42	6.2	0.97 ***	6.8	0.66	0.91 ***	*** 885	12.4	0.91 ***

*, **, and *** indicate significance at $P \leq 0.1$, 0.01, and 0.001, respectively.

Table 5. Mean 1 day CO_2 evolution following rewetting of dried soil, C and N mineralization for 0-21d, and soil microbial biomass C for eight Texas soils.

Soil	1-d CO_2-C	N Min.	Cmin.	SMBC
	mg C kg^{-1}	mg N kg^{-1}	mg C kg^{-1}	
Bowie fsl	30	36	368	777
	41	39	413	766
	45	65	420	798
	32	35	389	676
	12	13	83	153
	12	11	90	169
	11	17	90	153
	11	14	94	149
Windthorst fsl	66	55	589	743
	62	54	592	942
	66	69	701	1268
	94	49	873	1433
	58	38	410	555
	30	24	219	275
	28	24	206	308
	25	19	188	292
Orelia scl	34	22	169	541
	29	19	156	483
	26	20	121	468
	20	16	78	344
	19	19	95	293
Pullman si cl	67	47	340	1537
	61	35	311	1068
	54	37	272	1010
	46	41	275	1171
	41	20	178	585
	38	30	177	849
	31	17	140	600
	28	24	102	644
Weswood si cl	81	40	601	1365
	61	29	474	1114
	45	25	342	828
	33	17	247	668
	19	11	151	431
Burleson si c	245	224	1508	6190
	172	204	933	3907
	127	141	786	3585
	104	67	573	2034
	82	93	429	1844
	70	53	360	1420
	47	40	247	1346
	40	24	175	966
Krum c	85	48	646	2078
	80	40	710	2517
	59	36	312	1317
	49	44	373	1478
	44	35	268	1171
	16	26	138	1068
	12	18	115	893
Branyon c	149	95	910	2854
	106	86	661	2283
	89	67	426	1712
	61	64	300	1507
	46	27	186	1449
	28	18	132	1302
	22	20	152	1434
	20	20	109	980

Table 6. Prediction of net N mineralization during 21 d from previously published data as a function of the predicted CO_2-C evolved during the first day after rewetting [$NMIN_{0\text{-}21d} = -4 + 0.89 (CMIN_{0\text{-}21d})$].

Reference, Location	Soil type, pH	$CMIN_{0\text{-}1d}$	$NMIN_{0\text{-}21d}$	Predicted $NMIN_{0\text{-}21d}$	Experimental conditions
		----------mg · kg^{-1} soil----------			
Bowman et al. (1990), Colorado	sandy loam, 6.8	58.8 12.7 15.9 18.0	41.4 12.4 14.2 12.0	48.3 7.3 10.2 12.0	30°C, 0-21 d prairie,cultivated
Boyle & Paul (1989), California	loam, 5.4	12.9 32.4 35.3	5.1 33.2 36.5	7.4 24.7 27.3	25°C, 0-11 wks 0, 1.8, and 4.5 Mg sludge · m^{-2}
DeBruin et al. (1989), Mali	loamy sand, 5.3	32.2	15.8	24.5	30°C, 0-28 d
Hadas & Portnoy (1994), Israel	clay, 7.8 clay, 8.1	42.0 38.7	17.3 16.3	33.3 30.4	30°C, 0-28 d
Nicolardot et al. (1994), France Belgium	silt loam, 8.3 loamy, 7.6 loamy, 7.3	22.8 16.8 8.9	13.8 7.9 10.3	16.2 10.9 3.9	28°C, 0-28 d
Robertson et al. (1988), Sweden	sandy clay loam, 6.9	40.4	22.5	31.8	37°C, 0-28 d
Smith et al. (1994a), Washington	silt loam (N/A)	57.1	51.7	47.1	23.5°C, 0-21 d
Mean (n=15)		29.7	20.7	22.4	

Carbon mineralization (CMIN) and N mineralization (NMIN) were predicted from the equations reported in Boyle and Paul (1989) and Smith et al. (1994a) and predicted with the equations [$C_t = C_f \cdot (1 - e^{-k \cdot t}) + BSR \cdot t$; $N_t = N_i + N_0 \cdot (1 - e^{-k \cdot t})$; described in methods section] using data available from 0 to 28 d in all other studies.

Table 7. Correlation coefficients relating soil biochemical estimates determined on Windthorst soil from near Stephenville, TX to 1994 Coastal bermudagrass dry matter yields on this soil. Soil samples were taken in May 1994 prior to bermudagrass growth.

Determination†	Correlation Coefficient‡
SMBC	0.985 ***
SMBN	0.976 ***
AA	0.986 ***
BSR	0.946 ***
CMIN, 0-1d	0.913 ***
NMIN, 0-21 d	0.941 ***

†SMBC = soil microbial biomass C, SMBN = soil microbial biomass N, AA = arginine ammonification, BSR = basal soil respiration, CMIN = C mineralization, NMIN = N mineralization.
‡***indicates significance at $P<0.001$.

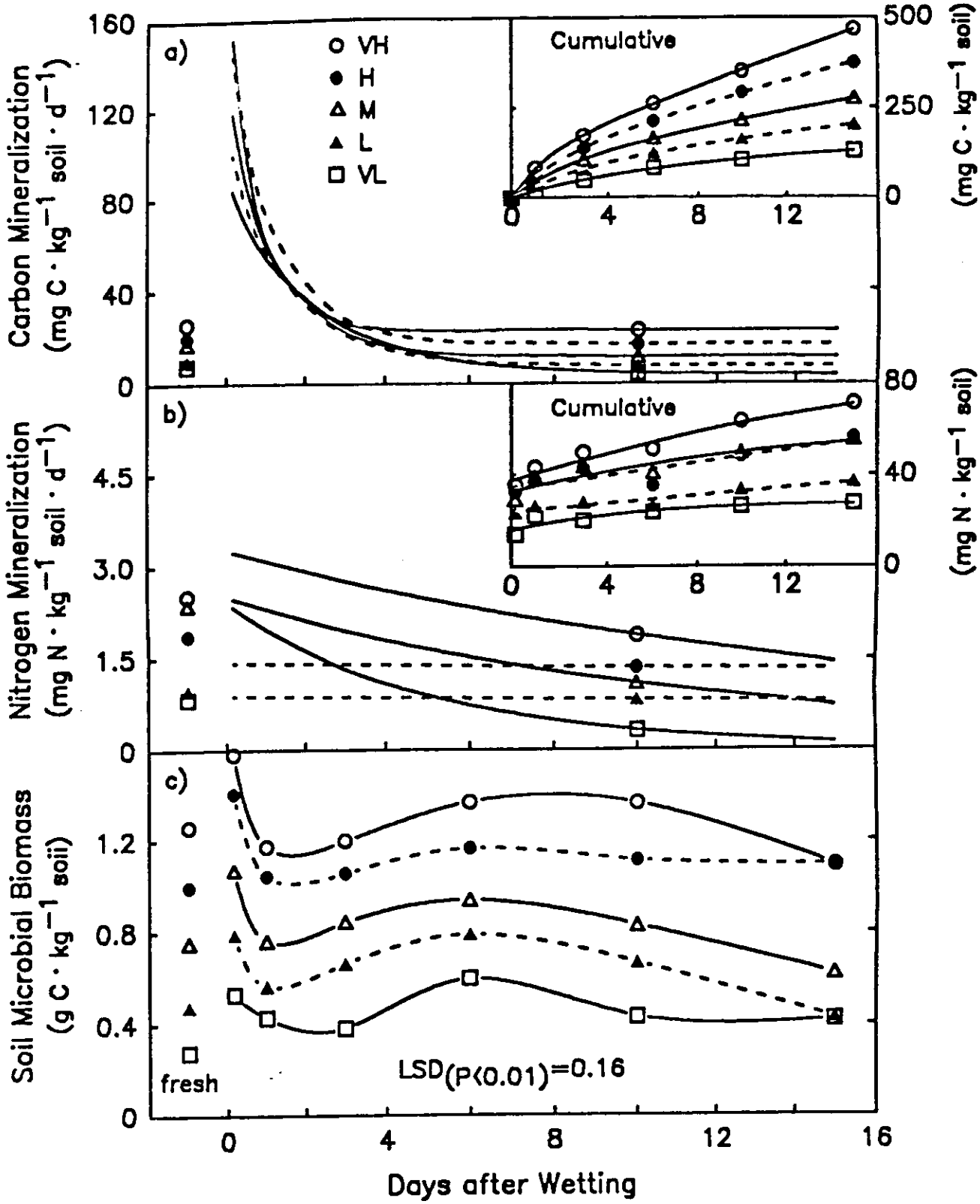

Figure 1. Carbon mineralization (a), net N mineralization (b), and soil microbial biomass C (c) as a function of time after rewetting of dried soil. (Values for fresh soil are indicated as symbols only).

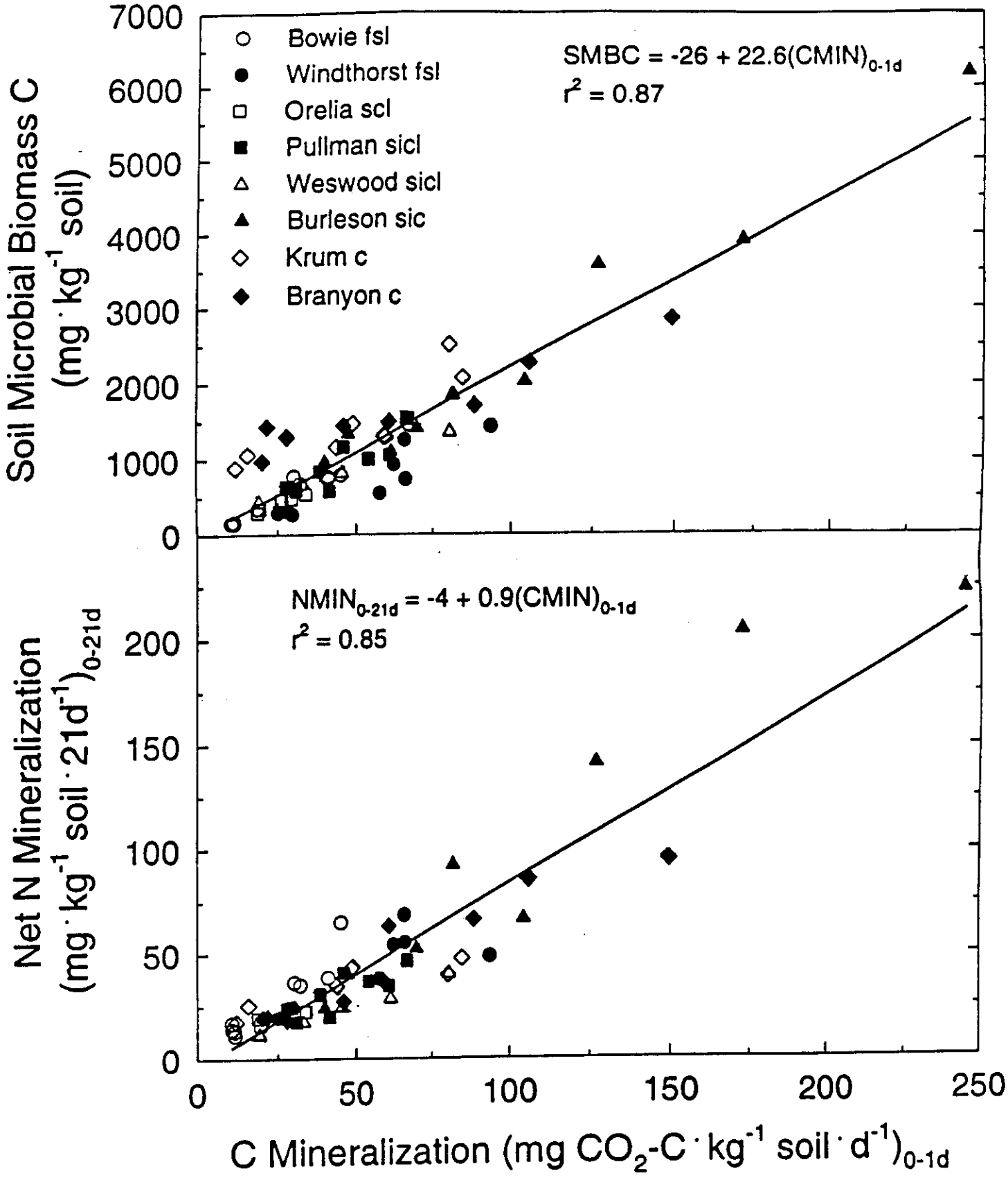

Figure 2. Relationship of soil microbial biomass C and net N mineralization during 21 days to the CO_2-C evolved during the first day after rewetting of dried soil from eight soils in Texas.

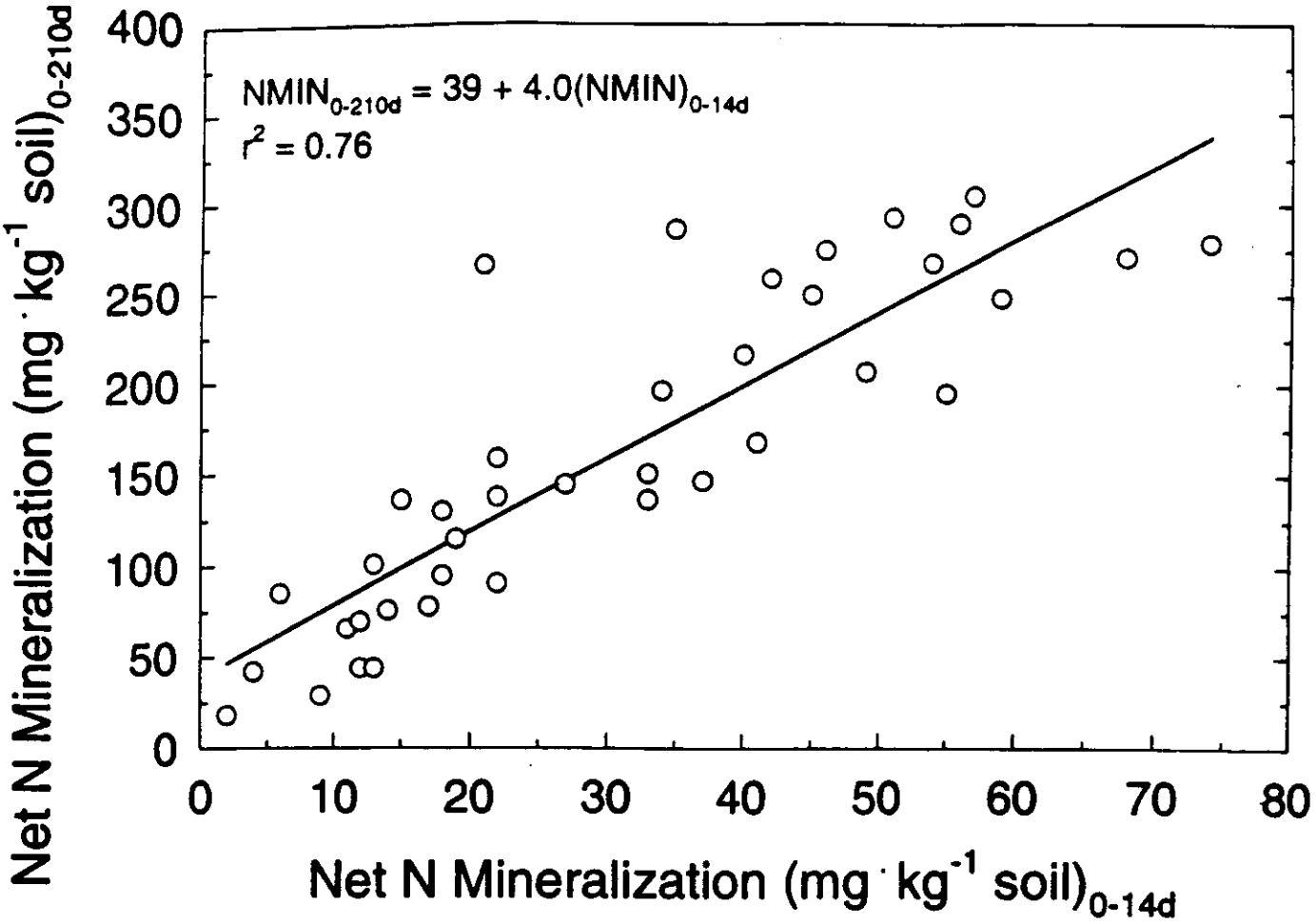

Figure 3. Relationship of net N mineralization during 210 days to the net N mineralization during 14 days from 39 soils in the USA.