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Measuring Soil Nitrogen Mineralization Under Field Conditions[1]

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ABSTRACT

The amount and rate of soil N mineralization are important components that can be used to predict preplant N fertilizer application and to evaluate the need for N fertilization during crop growth. This study's purpose was to evaluate the buried polyethylene bag technique as a method for characterizing the N mineralized under field conditions during the cropping season. Soil (Xerollic Calciorthids) was placed in polyethylene bags and buried in the 0 to 45 cm root zone of fallowed soils and where corn (*Zea mays* L.) and potato (*Solanum tuberosum* L.) were being grown. The NO_3-N content of the soil in the bags was compared with that in the root zone at selected time intervals (10 to 14 days) from April to October.

The soil NO_3-N concentrations in the buried polyethylene bags were similar to those in irrigated fallow soils from April to October after correction for different soil water contents. The N-mineralization rate between sampling intervals had an average temperature coefficient (Q_{10}) of 2.3 between 10 C and 30 C. The relative N-mineralization rate was proportional to the soil water content expressed as a percentage of the available water-holding capacity. The N uptake by corn and potato crops predicted from NO_3-N changes in the rooting zone and in the buried polyethylene bags resembled those measured by plant sampling. The buried polyethylene bag technique has potential for monitoring the soil N-mineralization process during the cropping season and for estimating N uptake by crops. It also provides an alternative method for estimating soil N availability for future crops and its use should maximize N-fertilizer efficiencies.

***Additional index words:* N uptake and fertilization., Temperature, Polyethylene bags.**

NITROGEN fertilizer management is an important aspect of crop production practices because of the relatively large amount of N required by plants and N mobility in the soil. The residual N amount, the rate and amount of N mineralized from soil organic sources, and individual crop needs must be considered when predicting optimum N fertilizer applications. A recent N fertilization study of some Idaho soils showed that the mineralizable soil N can be an important component of the N nutrition of crops. In that study, an average of 168 kg N/ha was mineralized for sugarbeet production (6). The soil N mineralized under optimal temperature and moisture for an infinite time has been suggested as a basis for predicting the amount of soil N mineralized (13, 15, 19); however, the modifying effects of soil temperature (17) and water content (16) under field conditions must also be considered (10).

The buried polyethylene bag technique has been used to validate the soil N-mineralization potential approach to predicting N mineralization under field conditions (13), to study soil aeration effects on N transformations in situ (1), and to evaluate nitrification in different environments (7). The purpose of this study was to evaluate this technique as a method for measuring the N mineralized under field conditions and to use the soil N mineralized to estimate total N uptake during crop development.

METHODS AND MATERIALS

A method using soil contained in buried polyethylene bags was used to measure soil N-mineralization (increase in NO_3-N concentration) from April to October in fallowed (non-cropped) soil (1975 and 1976) and in soils were corn (*Zea mays* L.) and potatoes (*Solanum tuberosum* L.) were being grown (1976, 1977, and 1978). Several random 5.7-cm diam soil cores were taken to a 45-cm depth (30 cm in 1975) in April from each study site (Table 1), combined, and screened through a 0.6-cm screen. Organic residue retained by the screen was returned to the soil. The screened soil was mixed and its water content adjusted to 18 to 20% (1.0 to 0.5 bar tension) with distilled water and then used to fill precut lengths (45 or 30 cm) of 5-cm diam, 5.9 μm thick polyethylene bags sealed on one end. The bags were hand shaken during filling and sealed when filled. Then they were inserted vertically into the original 5.7-cm core holes and back filled with soil around the bag. The bag's top was then covered with 2 to 4 cm of soil. The N-mineralization (NM) bags were placed within the rows of the corn and potato crops shortly after planting or plant emergence. The soil sample temperature during preparation was kept near or slightly below its presampling field temperature. Original sampling and installation was usually completed in 1 day. Soil samples were taken to a 152-cm depth before and at the end of each fallow study for NO_3-N analysis. Most soils in the study areas have a calic horizon beginning at about the 45-cm depth which restricts root growth but not water movement.

Three or more individual NM bags were withdrawn along with 15 to 20 soil cores, 1.3 cm by 45 cm (30 cm in 1975), from each study site at predetermined time intervals (10 to 14 days). The soil cores were combined, while the soil in the NM bags was kept separated for NO_3-N and soil water content determination. All soil samples were air-dried at an air temperature of about 35 C and then crushed to pass a 0.2-cm screen before NO_3-N analysis (11). The soil organic matter (21), total N (2) and N mineralized in 3 weeks at 30 C (5) were also determined on the soil initially placed in the polyethylene bags. The NH_4-N concentration was determined in the initial and selected soil samples (3). The NH_4-N concentrations will not be discussed since they were less than 2 μg/g. The coefficient of variation for the NO_3-N concentrations between individual NM bags at a given site and sampling was usually less than 8%.

Table 1. Cropping history and soil properties of the N-mineralization study sites.

Study site and crop†	Sampling depth	o.m.	Total N	N-min‡
	cm	%	%	μg/g
1. Fallow	30	1.41	0.087	23
2. Fallow	45	0.91	0.060	30
3. Corn	45	1.08	0.075	15
4. Potatoes	45	1.01	0.066	17
5. Potatoes	45	1.22	0.085	23
6. Potatoes	45	1.28	0.082	24
7. Potatoes	45	1.08	0.074	28
8. Potatoes	45	2.01	0.127	38
9. Potatoes	45	1.18	0.080	21

† All soils are Xerollic Calciorthids, except Site 8 is a Haploxerollic Durargid. ‡ N mineralized at 30 C for 3 weeks (5).

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Plant tops, easily recoverable roots, and potato tubers from three uniform 1.5-m rows were sampled for N uptake at the time soil samples were taken. Roots and tubers were washed with distilled water. All plant samples were dried at 65 C for dry matter determination and ground to pass a 40 mesh sieve. Total N in the plant samples was determined by a semi-micro Kjeldahl procedure modified to include NO_3-N (2). The soil water content of each fallow area was maintained near 0.3 bar with a solid-set sprinkler irrigation system. All crops were irrigated on a schedule based on evapotranspiration.

Soil temperatures were recorded with a two point recording thermograph with mercury sensor probes placed at one-third and two-thirds of the soil sampling depth. Within each sampling interval, the maximum and minimum daily soil temperatures were averaged and used to estimate the temperature coefficient (Q_{10}) of the N-mineralization rate. A 1-mm ID, polyethylene tubing was also sealed in selected NM bags in two potato fields in 1977. A septum capped rubber stopper was placed in the tubing end above ground while the other end was in the center of the buried NM bags. Gas samples were removed with a gas tight syringe during crop growth and analyzed for O_2 and CO_2 by gas chromatograph techniques. Values for O_2 include ambient Ar in the atmosphere (~0.9%).

RESULTS

The soil NO_3-N concentration in the fallow area increased from 6 to 28 μg/g in 1975 and from 10 to 36 μg/g in 1976. This corresponds to an average daily increase of 0.12 and 0.14 μg/g, respectively. The NO_3-N increase was due to mineralization since no N fertilizer was added and the NO_3-N content of the irrigation water was low (<0.2 μg/g). Nitrogen-mineralization in the fallow soil may have been greater if there were denitrification losses and if the soil water content was less than optimum between irrigations. Comparisons of the initial and final NO_3-N concentrations below the sampling depth to 152 cm indicated that leaching losses were probably not significant.

The relationship between the soil NO_3-N concentrations in the fallow area and in the buried NM bags was linear (Fig. 1); however, the NO_3-N concentration in the fallow soil averaged 24% greater than that in the NM bag. The water content of the soil in the NM bags in 1975 and 1976 was initially adjusted from 74 to 80% of the available soil water capacity. This adjustment would cause a proportional decrease in the N-mineralization rate since a 1:1 relationship between N-mineralization (expressed as a percentage of the maximum) and the soil water content (expressed as a percentage of that held between 0.3 and 15 bars) has been reported (16). Evaluation of the effect of different soil water contents on N-mineralization within the NM bags during 1977 and 1978 showed a similar relationship (% relative N-mineralization/% available water = 1.12).

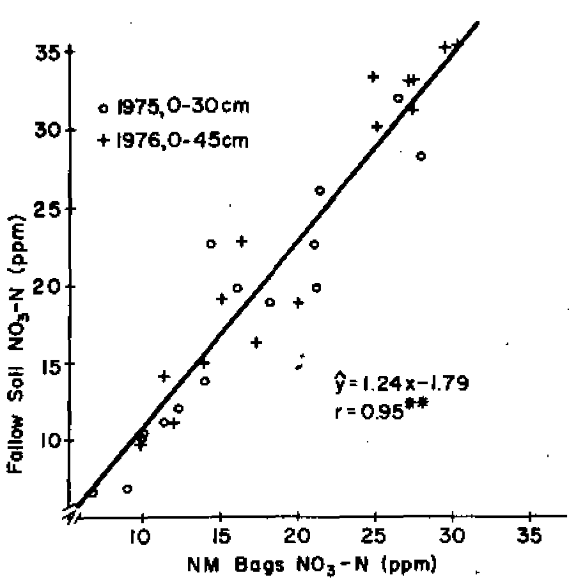

Fig. 1. Relationship between NO_3-N concentration in a fallow soil and in soil buried in polyethylene bags.

Figure 2 shows the relationship between soil temperatures and N-mineralization rates. The temperature (K) is expressed as the average absolute soil temperature; whereas the N-mineralization rate (k), is the average daily change in soil NO_3-N concentration in the NM bags between sampling intervals. Calculated k rates for 10, 20, and 30 C, gave Q_{10} values of 2.4 and 2.3 for 10 to 20 C and 20 to 30 C, respectively. These agree with reported N-mineralization Q_{10} values under constant temperatures (17). Temperature fluctuations compared to constant temperatures do not seem to influence soil N-mineralization (NH_4-N plus NO_3-N) if average temperatures are similar (4, 18).

The N-mineralization rate (k) shown in Fig. 2, may vary between soils at the same temperature since it depends upon the potentially mineralizable N of each soil. The temperature coefficient of soil N-mineralization has previously been defined as the fraction of N mineralized per unit time from the total quantity of soil organic N susceptible to mineralization. It is a constant for most soils at a given temperature (17, 19).

The relative fraction of soil N mineralized for the upper and lower 22 cm of the sampling depth in the 1976 fallow site was estimated using the average daily soil temperatures recorded at the 15 and 30-cm depths from April to October, the N-mineralization temperature coefficients (17), and an optimum soil water content. The fraction of N mineralized was 51 and 49% for the upper and lower soil depths, respectively. This indicated that mixing the 0 to 45 cm soil layer would not cause a N-mineralization difference between the soil in the NM bags and in the fallow soil because of different daily soil temperatures at the two soil depths.

Nitrogen uptake by corn and potatoes was estimated using the NO_3-N concentration difference between the soil in the NM bags and that in the plant root zone. These estimates generally agreed with amounts measured by plant analysis (Fig. 3), except at Site 8 where high rates of animal manure had been applied in previous years. Denitrification losses might be expected where large amounts of manure were applied and where soils were wet and warm (9). This may explain the differences between the two estimates of N uptake. The inability to measure all N in the plant roots is another explanation. If deni-

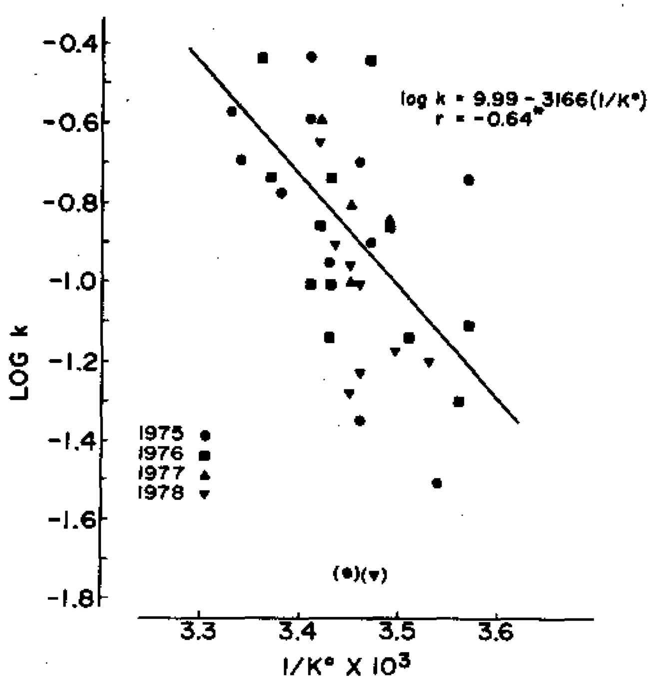

Fig. 2. Relationship between average absolute soil temperature (K) and average N-mineralization rate during a sampling interval. Points in parentheses are not included in the regression equation.

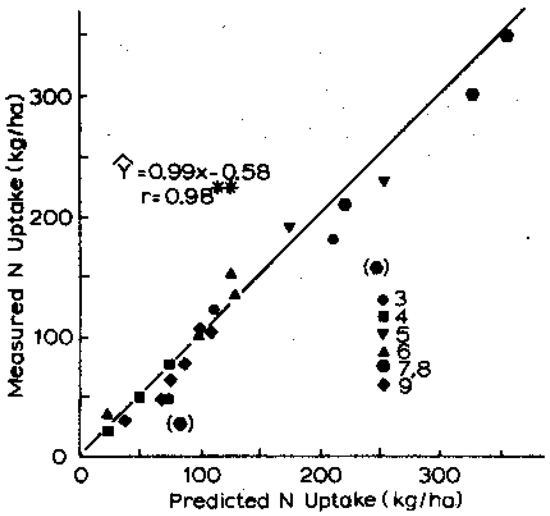

Fig. 3. The relationship between N uptake by corn and potato plants and that predicted from the soil NO_3-N concentration differences between that in the NM bags and in the plant rooting zone. Points in parentheses are not included in the regression equation.

trification losses did occur in the NM bags, they were equivalent to those in the root zone or to any N left in the plant roots. Leaching losses may also have been offset by any N left in the plant roots. No roots grew into any bags during a single season unless the bag was torn during installation.

Concentrations of O_2 within the NM bags under the potato plants in 1977 were usually greater than 16%; only one gas sample, taken immediately after an irrigation, was as low as 12% O_2. Concentrations of CO_2 were generally less than 1.5%. The O_2 concentrations in the soil atmosphere in the plant root zone outside the NM bags and within the NM bags were similar, whereas the CO_2 concentrations outside the bags were about 50% less than those in the NM bags. This indicated that O_2 diffusion through the polyethylene bags was not being restricted while CO_2 diffusion tended to be restricted. These conditions would probably not lead to denitrification in the NM bags since denitrification did not occur in a soil when its atmosphere contained O_2 and CO_2 concentrations of 13.4 and 4%, respectively (9). The O_2 and CO_2 diffusion rates through polyethylene films are relatively high (12).

DISCUSSION AND CONCLUSIONS

A loss or gain of soil water in the NM bags was not detected during this study. There was a tendency for soil water in NM bags buried in fallow sites to move from warmer soil near the surface to cooler soil at lower depths. The net effect of this soil water movement is not known; however, less N would probably be mineralized in the drier soil. This amount may be partially compensated for if more N is mineralized in the wetter soil and if dentrification does not become a factor in the wetter soil at lower depths. Soil temperature differences with depth would probably moderate mineralization changes due to the water movement. This redistribution of soil water in the NM bags with time was not observed under a crop cover when the maximum soil surface temperatures were lower. The N mineralized in the NM bags would need to be corrected for the soil water changes in the plant root zone between irrigations and rainfall, since the soil water content in the bags is constant.

Using buried polyethylene bags does not completely solve the problem of predicting the amount of N that will be released during a cropping season. Several rapid laboratory techniques may be correlated with the N-supplying capability of a soil (8, 14, 20) and which may allow that prediction are being evaluated.

Data presented here and by others (13) indicates that this technique provides an alternative method for estimating mineralizable soil N under field conditions. This estimate can be used to help assess soil N availability for the next crop or for several future crops if cropping practices do not change significantly. This study demonstrates that this technique can be used to estimate the N uptake by corn and potatoes during the growing season if the NO_3-N in the root zone is also evaluated. Monitoring the N-mineralization process during the cropping season can provide a basis for changing or updating N fertilizer application. This ability plus the incorporation of other management and plant factors should increase N fertilizer efficiencies.

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