Soil testing and nitrogen mineralization

from soil organic matter

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Mineralization is defined as "The conversion of an element from an organic form to an inorganic state as a result of microbial activity" in the *Glossary of Soil Science Terms* published by the Soil Science Society of America. For nitrogen, the first step is conversion of organic nitrogen (N) in soil organic matter (SOM) to ammonium (NH_4^+) by a process called ammonification. Often, the ammonium is rapidly converted to nitrate (NO_3^-) by the microbial process of nitrification. The amount of inorganic N (NH_4^+ and NO_3^-) originating from SOM is termed N mineralization (NM). Nitrogen mineralization is a product of the amount of organic N in the soil and the N mineralization rate (NMR).

Soil organic matter originates from crop residues, manures, and other organic amendments applied to soils. As these organic materials decompose, a portion becomes part of SOM. Trumbore (2000) showed that SOM mean age can vary from a few years to several centuries in temperate soils. As mean age increases, the less decomposable the SOM fraction and the lower the NMR. Mean ages of a few years are characteristic of SOM that originates from recent additions of crop residues, roots, manure, and other organic amendments. Longer mean ages represent more stable SOM fractions. Cropping system features that can affect NM include tillage, irrigation, fertilization, manure and other organic additions, and crop rotation. Climate determines soil temperature and moisture, which directly impact NMR.

A simplified depiction of the concepts described above is shown in Fig. 1 (next page). N Pool I in SOM originates from organic additions to soil, while N Pool II comes from organic matter in N Pool I that has aged to a point where the NMR is much lower than that in N Pool I. The figure implies that most of the ammonification occurs from N Pool I even though that N pool is only a few percent of total N (TN) in the soil.

Traditional soil-testing methods extract the plant-available form(s) of the nutrient and then correlate the amount extracted with plant response. While this approach has been applied to the N needs of specific crops over a limited geographic area, wide adaptation of a single method has not occurred. Part of the challenge has been extracting only organic N from N Pool I, which is the primary contributor to NM. In addition, an extraction method only takes a snapshot of NM, which is not a static process, but rather ongoing as microbes decompose SOM.

The latter has been addressed by research where the time course of NM has been described mathematically and the terms in the equations have been related to soil properties that can be determined in a soil-testing laboratory. The equations selected to date have assumed that NM from N Pools I and II occur simultaneously. These simultaneous models do describe the time course of NM for limited geographic areas, but just like the traditional approach, they have not been shown to have widespread use.

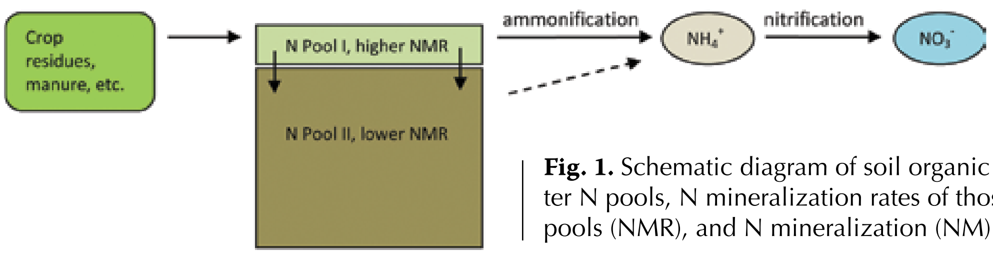

Fig. 1. Schematic diagram of soil organic matter N pools, N mineralization rates of those pools (NMR), and N mineralization (NM).

A solution

In a recent paper published in the *Soil Science Society of America Journal* (Gilmour and Mauromoustakos, 2011), the authors assumed that N Pool I and N Pool II decomposed *sequentially*; i.e., N Pool I must be completely exhausted before N Pool I undergoes NM. They evaluated long-term, laboratory N mineralization studies from the southeastern United States, Connecticut, Israel, and Australia. Soils represented differing soil depths, tillage practices, organic amendments, and cropping systems. In all, NM was calculated for 108 soils at 95°F and optimum soil moisture for 32 to 41 weeks. When they tested the simultaneous model, they found that variables in the sequential-model equations were not related to soil properties across this diverse group of soils. The key finding was that NMR varied with NM during the first week estimated from long-term data in a statistically consistent manner for the sequential model but not for the simultaneous model. Another feature of the sequential model was that NM was the product of NMR and total N, unlike the simultaneous model where NM was the product of NMR and organic N in N Pool I.

Using the sequential model, the NMR for N Pool I was related to first-week NM estimated from the long-term data. The size of N Pool I was then related to NMR for that pool. The NMR of N Pool II was related to both the size and NMR of N Pool I. There were no statistical differences among the four studies, which suggested that the sequential model has widespread application for the estimation of NM from SOM. Emphasis was placed on the NMR and size of N Pool I because NM from N Pool II is not likely in most agricultural systems.

Does all this fit into routine soil testing?

The next step was to see if the results could be put in the perspective of a routine soil-testing program. Since a routine soil-testing program cannot depend on studies lasting 30 weeks or more to estimate first-week NM and one-week laboratory incubations can lead to erroneous results, the authors sought to relate first-week NM to soil analyses using data from one of four studies that included detailed soil test results (Schomberg et al., 2009). The authors of these studies evaluated total N, total C, C/N ratio, carbon dioxide evolution at three days (3d CO_2), cold KCl extract, hot KCl extract, sodium hydroxide distillation, calcium hypochlorite oxidation, and soil texture. Three analyses were found to best describe differences in first-week NM: total N, 3d CO_2, and percentage clay. The size and NMR of N Pool I were also best described using total N, 3d CO_2, and percentage clay.

A somewhat surprising finding was that the size of N Pool I and the NMR of N Pool I declined as total N increased. A possible explanation as to why this occurred can be found by considering that both N Pool I size and NMR are on a total N basis and that changes in total N among soils must be mostly in the more stable N Pool II. This underlines the concept that SOM from recent additions of organic materials (crop residues, roots, manure, etc.) is not as important in determining total N as more stable forms of SOM, the amount of which is a consequence of long-term cropping system and climate. For example, a soil that is 1% total C contains 20,000 lb of C if an acre furrow slice (6-inch depth) weighs 2 million lb. If the C/N ratio of that SOM is 12, the soil contains 1,667 lb of organic N (20,000 lb C/12 lb C/lb N). If annual organic matter additions are 5,000 lb/ac and the organic matter is 40% total C and has a C/N ratio of 40, only 50 lb of organic N (5,000 lb OM × 40 lb C/100 lb OM/40 lb C/lb N) is added to the soil each year.

N Pool I size and NMR increased as 3d CO_2 increased. Thus, as initial SOM decomposability increased, so did the size and NMR of N Pool I. This effect is most likely related to the types and amounts of SOM originating from recent organic additions to the soil. Percentage clay had a much smaller impact on N Pool I size and NMR. As percentage clay increased, both decreased, suggesting that clay increased recent SOM stability.

The results described above were obtained at 95°F and optimum soil moisture in the laboratory, conditions that do not often exist in the field. In order to extend laboratory results to the field, the NM found in the laboratory

Table 1. Examples of soil temperature/moisture correction factors (TM factors).

Temperature	TM factor at 20% WHC†	TM factor at 30% WHC
°F		
90	0.38	0.51
80	0.22	0.32
70	0.12	0.19
60	0.06	0.11
50	0.06	0.08

† WHC, water-holding capacity.

should be multiplied by a temperature–moisture factor (TM factor). Examples of the TM factors are shown in Table 1. The moisture factor is based on water-holding capacity (WHC), which is the percentage of water (dry soil basis) in an initially saturated soil after free drainage has ceased. The equation used to calculate these factors can be found in Gilmour and Mauromoustakos (2011).

Thirty-two of 38 soils reported by Schomberg et al. (2009) that represented 0- to 2-inch and 2- to 6-inch soil depths for three tillage systems were the data base for estimation of field NM. The tillage systems were conventional till (16 soils), no-till (10 soils), and no-till with non-inversion deep tillage (six soils). Laboratory NMR was corrected for field temperature and soil moisture using the TM factor. Mean TM factor was 0.26 (range was 0.21 to 0.29). In calculating the TM factor, soil moisture was assumed to be 30% WHC, and soil temperature was the mean for each soil location for the 15 weeks (t = 15 weeks) from May to August. Seasonal N mineralization was calculated per acre-inch of soil to eliminate soil depth increment differences. One acre-inch of soil was

Table 3. Estimated seasonal nitrogen mineralization (NM) for three tillage practices.

Soil depth	Seasonal NM	
inches	lb N/acre-inch	% of total N
0 to 2	17.3	3.9
2 to 6	6.2	2.9
$LSD_{0.05}$†	4.9	0.3

† LSD, least significant difference.

assumed to weigh 333,333 lb. Equation 1 below was used to make the seasonal NM calculation.

$$\text{Seasonal NM} = \%TN/100 \times 333{,}333 \times NMR/100 \times \text{TM factor} \times t \quad [1]$$

No statistically significant differences in total N, 3d CO_2, percentage clay, N Pool I size, NMR, seasonal NM in pounds of N per acre-inch, or seasonal NM in percentage of total N were found due to tillage practices (data not shown). However, there were significant differences when the two depths were compared. Table 2 presents the laboratory portion of that comparison.

Total N and 3d CO_2 were higher in the surface 2 inches than in the next 4 inches, while there was no difference due to depth for percentage clay. N Pool I size and NMR were larger for the 0- to 2-inch depth than the 2- to 6-inch soil depth.

Seasonal estimates of NM in the field using Equation 2 are presented in Table 3. Seasonal NM in the 0- to 2-inch depth was 2.8 times that in the 2- to 6-inch depth. As a percentage of total N, seasonal NM was 1.3 times larger in the 0- to 2-inch depth as compared with the 2- to 6-inch soil depth. On a total depth increment basis, the 0- to 2-inch depth contributed 34.6 lb N/acre, while the 2- to 6-inch depth contributed 24.8 lb N/acre, giving a to-

Table 2. Mean laboratory data for two depths. N Pool I size and N mineralization rate (NMR) were determined at 95°F and optimum soil moisture (55% water-holding capacity).

Soil depth	Number of soils	Total N percentage	3d CO_2	Clay percentage	N Pool I size	NMR
inches	no.	%	ppm	%	% of total N	% of total N/week
0 to 2	16	0.129	175	7	12.7	1.07
2 to 6	16	0.067	65	8	8.3	0.64
$LSD_{0.05}$†	—	0.027	62	ns	2.4	0.24

† LSD, least significant difference.

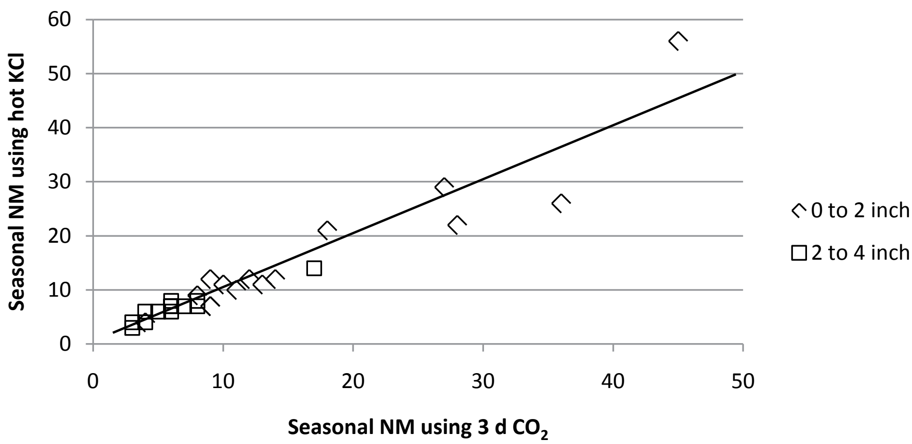

Fig. 2. Seasonal N mineralization (NM) calculated using hot KCl vs. seasonal NM calculated using 3 d CO_2. Line is the 1:1 line.

tal for the 0- to 6-inch soil depth of 59.4 lb N/acre. When the seasonal NM as a percentage of total N was compared with the size of N Pool I, 31% of N Pool I organic N was mineralized for the 0- to 2-inch depth, while 35% of N Pool I organic N was mineralized for the 2- to 6-inch soil depth.

What does the future hold?

One of the challenges of moving this technology from the research laboratory to routine soil testing is finding simple, rapid, and repeatable methods. In many soil test laboratories, TN is a common soil analysis. If it is not, SOM is commonly determined and TN can be estimated from SOM. For example, assume that SOM is 50% organic C and that the typical C/N ratio is 12. A soil with 2% SOM would contain 1% organic C and 0.0833% organic N. If an acre furrow slice was assumed to weigh 2 million lb, TN would be 1,667 lbs (2,000,000 lb × 0.0833% TN/100). Percentage clay can be estimated from soil texture and, as discussed above, has a minor impact on the size of N Pool I and NMR, so percentage clay estimates do not have to be exact. The stumbling block for many soil test laboratories will be 3d CO_2 due to the set up required and the three-day delay in obtaining results. One promising replacement for 3d CO_2 is a hot 2 *M* KCl extract of the soil (see Schomberg et al., 2009). This method requires incubating the soil KCl mixture in a 212°F water bath for four hours, cooling the mixture, and filtering and analyzing it for ammonium N.

Seasonal NM estimated using hot KCl is compared with seasonal NM using 3d CO_2 in Fig. 2 above for the 32 soils from Tables 2 and 3. A statistically significant relationship (R^2 = 0.91) was found where the slope was 0.99 and the intercept (0.05) was not significantly different from zero. These results support the use of the hot KCl extract in place of 3d CO_2.

It should be emphasized that the NM values obtained for a given field should be put in the perspective of NM values for soils used in determining N fertilization programs. The latter serve as a benchmark against which NM for specific soils can be compared. This approach can be used to identify situations where crop response to N fertilizer can be expected and where a response is less likely. Each soil-testing laboratory will have to set and adjust these benchmarks based on available data.

Soils should be sampled prior to preplant spring additions of organic amendments such as manures and biosolids. Prior-year manure or biosolid additions are part of TN, N Pool I size, and NMR. The amount of N mineralization from organic amendments for the current year should be estimated independently and added to NM from SOM to give total plant-available N. If the hot KCl extract is used, soils should be sampled before preplant inorganic N fertilizer additions as the extract will include fertilizer N.

And finally, how often should the seasonal NM be determined? Until more experience is gained with this method, the frequency should be similar to that for other soil tests. When a management practice is changed that might impact seasonal NM, that would be a good time to see if the management change has affected seasonal NM.

Adapted from the Soil Science Society of America Journal *article, "Nitrogen Mineralization from Soil Organic Matter: A Sequential Model," by J.T. Gilmour and A. Mauromoustakos. Soil Sci. Soc. Am. J. 75:317–323.*

References

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