SOIL RESPIRATION TESTS AS PREDICTORS OF NITROGEN MINERALIZATION POTENTIAL

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ABSTRACT

Estimation of seasonal N availability via a soil test has proved difficult. This information gap has lead to fertilizer recommendations based upon soil inorganic N levels found before planting and or preside dress. Complicating matters, as famers adopt new irrigation technologies, the results from older fertilizer rate trails may also be less applicable. In general, most when not all recommendations do not account for the contribution of soil N mineralization during the growing season, which has been shown to contribute up to 50% of total plant N uptake.

A variety of soil tests, both lab-based and in situ, have been used to estimate growing season N mineralization. Biologically based tests allow for an estimation of available soil N by incubating soil samples at temperatures and moisture contents that facilitate N mineralization, providing a proxy to estimate N mineralization potential. However, these incubations are lengthy and not well suited for routine analysis in a soil test lab setting.

The close coupling of the C and N cycles theoretically should allow for biologically based estimation of long-term N mineralization using short-term cumulative CO_2 evolution, as shown in some previous studies. This has been demonstrated in dairy-amended soils, which showed a correlation between 24-hour CO_2 production and 28-day N mineralization. Other studies have shown a correlation between 72-hour CO_2 and 28-day N mineralization in unamended soils. Generally, better correlations can be made in soils with higher organic matter content or consistent additions of organic based fertilizers. Overall, regardless of soil management, soil respiration based tests to estimate growing season soil N mineralization are variable and their use requires more testing to develop relationships to accurately predict in season soil N mineralization.

INTRODUCTION

Crops require sufficient nitrogen (N) to attain maximum yield potential. The unpredictable nature of soils to supply N cause it to be the most limiting nutrient for crop production (Foth and Ellis, 1997). Although many productive mineral soils contain several thousand kilograms of N per hectare, greater than 90% of soil N is unavailable in the form of organic matter, with the remainder existing mostly as fixed ammonium (NH_4^+) in clays. Only a small fraction of the N in soils, generally less than 0.1%, exists in plant-available mineral forms, such as nitrate (NO_3^-) and exchangeable NH_4^+, at any one time, and no more than 1-2% of the total soil N will be available to plants during a growing season (Stevenson and Cole, 1999). However, the large size of the soil N pool can be significant source of plant available N during the growing season and therefore should be accounted from an N management perspective.

Estimating growing season soil N availability using a soil test remains problematic with few proven solutions. As a result, fertilizer recommendations are often made without an accurate assessment of the amount of N that can be potentially made available through soil N mineralization (Figure 1). Current available tests are based primarily on soil N levels, e.g. the pre-plant nitrate test, side dress soil nitrate, total soil N and or previous crop recommendations. These tests are often not suited or poor predictors of available soil N in low organic matter and/or irrigated soils. The lack of a suitable test to estimate potentially mineralizable N has troubled the soil test industry for decades and can lead to over application of N. After years of research on the soil N cycle and soil N tests to predict soil N mineralization, we still have no adequate testing procedures the soil testing industry can rely on to account for soil N mineralization and its contribution for crop N uptake. Though studies have shown that soil tests, such as hot KCl, permanganate digestion, phosphate-borate extractions and total soil N, are fairly accurate under controlled research conditions (field plots) these tests have not worked well in practice. The failure of these tests is due, in part, to the variability associated with soil mineralogy, soil texture, soil management, crop planting dates, etc.

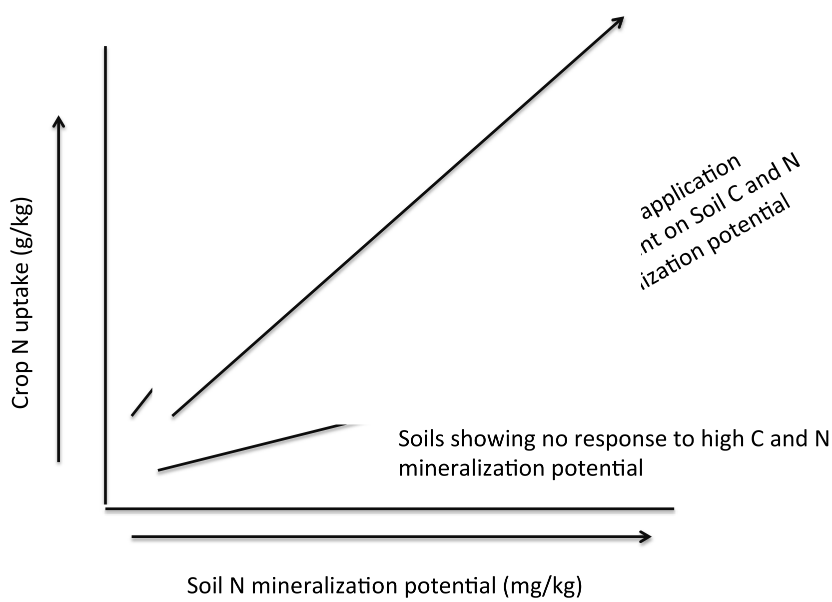

Figure 1. Conceptual diagram depicting the relationship between soil N mineralization and crop N demand. As soil N mineralization increases the amount of fertilizer N application can be decreased. The extent of decrease depends on the amount of soil N mineralized and the certainty of the N mineralization results of specific soils and cropping systems. For example, the ranges depicted by A, B and C represent decreasing need for fertilizer N inputs.

Biological based tests, i.e. incubations, have been shown to predict soil N availability better than chemical tests. The soil microbial biomass plays a critical role in controlling the supply of N to crops by mineralizing soil organic N. Biological tests are often based on lab incubations of field soils and rely on the soil microbial community to mineralize soil N from various soil organic matter fractions, ranging from easily decomposable fresh litter to resistant mineral fractions. The mineralization of soil N often accounts for more than 50% of total crop N uptake, as indicated by studies using isotopically labeled N fertilizers (Kramer et al 2002; Doane et al 2009). However, from a soil testing perspective, incubations are time consuming, space demanding and labor intensive, and, therefore, not suited for high output and turnover requirements of soil test labs. Recent studies have shown the flush of CO_2 following drying and rewetting of soil to mimic natural processes and characteristics of long-term incubations, correlate with N-supply potential in soils with a wide range of organic mater contents (Franzluebbers et al., 2000; Haney et al., 2008). In some studies, this short-term flush of soil CO_2 explained 97% of the variability in N mineralization among different soils over several weeks. However, the short pulse of soil respiration has not been tested rigorously enough to adopt as a standardized test. The goal of this research is to provide data to test the relationship in low organic matter irrigated soils of the western US.

METHODS

Soil samples from three of California's major cropping systems, corn, tomato, and cotton, were gathered from across California's Central Valley, giving a diversity of textures, chemistry, parent materials, and climatic regimes. Soil samples were sieved to pass through a 4mm sieve and stored air dried. The soil samples were analyzed for various soil properties including inorganic N, dissolved organic carbon (DOC), dissolved organic nitrogen (DON), water holding capacity (WHC), and Total C/N. Soil texture and taxonomy were retrieved using SoilWeb (http://casoilresource.lawr.ucdavis.edu/soilweb/).

To validate the "24-Hour CO_2 Respiration Test" soils were incubated in airtight chambers and CO_2 flux measurements taken at days 1, 3, 7, 14, 28, 56, and 105. Additionally, cumulative CO_2 evolution was done on soils at field capacity at 6, 24, and 72 hour intervals.

To validate the "24-Hour CO_2 Respiration Test" for field results, fields from where the soil samples were collected contained a full N and zero N plots. Periodically, soil samples were gathered from each treatment and analyzed for DOC, NO_3^- and NH_4^+. Plant biomass samples were gathered at key stages of plant growth and analyzed for N uptake. Soil and plant samples will be gathered at harvest and analyzed for N content (some data not presented).

Statistical analyses were done to correlate C and N mineralization. All values shown reflect the mean of three (3) field replicate soil samples. For both cumulative CO_2 flush and other C and N mineralization incubations, these replicates were split into three blocks due to space constraints, with one replicate from each field being represented per block. A simple ANOVA was run on each data point calculated, with no significant difference found between blocks (P<0.05). All sampling dates indicate days after rewetting of air-dried (AD) soil.

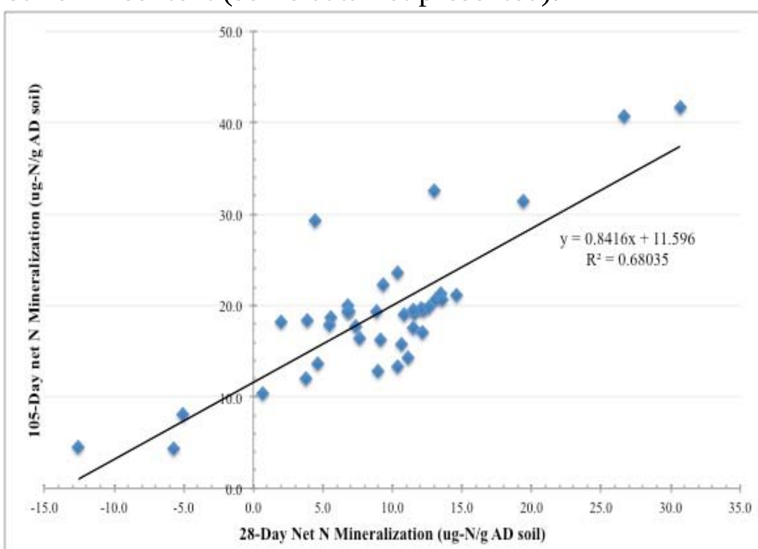

Figure 2. The relationship between net N mineralization at day 28 and day 105.

RESULTS AND DISCUSSION

A wide range of initial soil inorganic N values (6.05-97.01ug-N/g AD soil) and C:N ratios (6.22-22.96 by weight) allowed for a broad sample set (data not shown). The difference between initial soil inorganic N (NO_3^- + NH_4^+) and soil inorganic N at a sampling date was calculated as the net N mineralization (NMIN). Total C, measured on a % weight basis, ranged from 0.54-3.46%, with most values falling below 1.5%. These values are typical for most California agricultural soils.

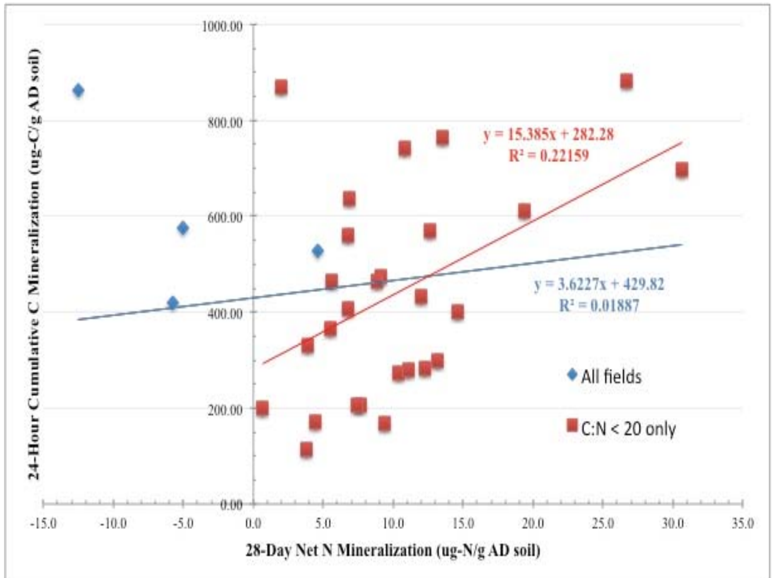

Figure 3. The relationship between cumulative 24-Hour CO_2 flush and net N mineralization at 28 days after rewetting, one series including immobilizing soils and one excluding.

Net N mineralization varied widely at 28 days after rewetting, with a range of -12.5 (immobilization) to 30.0 ug-N/g AD soil. There was a strong relationship between the NMIN28 (28 day N mineralization) and NMIN105 (105 day N mineralization). NMIN105 had less variability than NMIN28, with a range of 4 to 42 ug-N/g AD soil (Figure 2). Most fields had low to moderate N mineralization, while some fields showed significantly negative NMIN28, indicating immobilization. Those fields, which had negative NMIN28 also had total C values 2-3 times that of the average field (total C >3%). When these fields with a C:N ratio >20 were not considered, the relationship improved (Figure 2; R^2=0.22). These are Tulare Lake bottom soils showing N immobilization and may not be representative of typical agricultural soils in California.

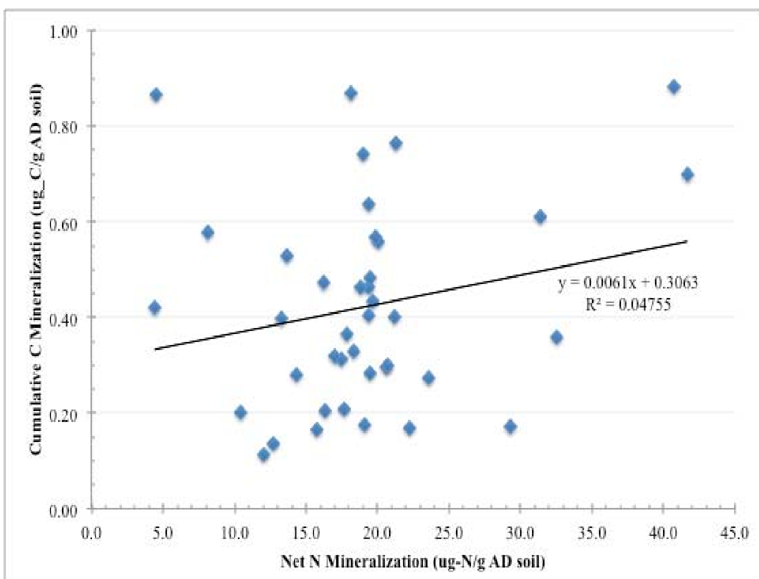

Figure 4. The relationship between cumulative 24-Hour CO_2 flush and net N mineralization at 105 days after rewetting.

The 24-hour CO_2 flush following rewetting showed little to no correlation with NMIN28 (Figure 3) and NMIN105 (Figure 4). There was a correlation between 24-hour and 72-hour C mineralization (R^2=0.69) (data not shown).

CONCLUSIONS

The development of suitable soil tests to estimate growing season soil N mineralization for crop uptake has not seen much success despite decades of research on this topic. This study also shows the problem in developing a soil respiration based test. This is particularly disturbing in light of the fact that many when not all enzymatic processes involved in the N cycle are known. Despite knowing the enzymology associated with N cycling processes, we have failed to use this understanding to predict available soil N. The failure to predict soil N mineralization has resulted in a guessing game based on perceived crop N needs likely estimated from fertilizer rate trials or long-term yield studies or observations. The result is that fertilizer recommendations are made without an accurate assessment of the amount of N that can become available from soil N mineralization during the crop growing season. Previous studies have shown this to be an important source of crop N (mentioned above). As a result, based on a mix of economic decisions and determination to achieve maximum productivity, N application rates may be above crop need. Evidence of over- applications of fertilizer N has been documented in recent reports from the Water Resources Center and Agricultural Sustainability Institute California N Assessment at the University of California's (Viers et al. 2012; http://asi.ucdavis.edu/research/nitrogen). For this reason, there is an immediate need to develop a soil test that will predict soil N availability during the growing season. Once a soil's growing season N mineralization potential is known, fertilizer N application rates can be reassessed accordingly. The data shown above are not particular convincing, but do show potential in developing a correlation among soil biology factors and in season soil N mineralization.

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