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Understanding the role of mineralization in supply of plant available nitrogen

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UNDERSTANDING THE ROLE OF MINERALIZATION IN SUPPLY OF PLANT AVAILABLE NITROGEN

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1. Introduction

In non-leguminous crops, there are three major sources that contribute available nitrogen (N) to plants over a growing season: 1) residual inorganic nitrogen in the form of ammonium and nitrate present at the start of the growing season; 2) conversion of organically bound nitrogen to plant available inorganic forms (mineralization); and 3) added synthetic fertilizer N products. Of the three sources, the mineralization input is probably the most difficult to measure and account for, since nitrogen mineralization is a biological process, carried out by soil microorganisms whose activity is highly influenced by environmental factors. A further complication is the need to distinguish between the effects of decomposition of recent crop residues and the mineralization of soil organic matter (humus) nitrogen accumulated in the soil over long time periods. In some soils of the world, humus nitrogen levels are so low that the contribution from mineralization of soil organic matter is negligible and the mineralization contribution mainly reflects the effects of decomposition of the most recent crop residue. However, in most Western Canadian soils the contribution from mineralization of native soil organic matter is significant and variable, depending on such factors as the soil climatic zone, management history, and landscape position, as these factors affect the quantity and quality of soil organic matter available for microbial decomposition. More recently, as Western Canadian producers have moved to extended cropping systems with a greater variety of crops in the rotation, including legumes, the effects on available nitrogen related to decomposition of the previous year's crop residue have become a more important consideration. Good predictions of the contribution of mineralization, both from native soil organic matter and past crop residue, are required for accurate nitrogen fertilizer recommendations. This paper examines the factors affecting the contribution of N mineralization to plant available N over a growing season and its significance in N fertility management.

2. Factors Affecting Mineralization Rates of Organic Nitrogen

The rate at which nitrogen in organic matter is released into the plant available ammonium and nitrate forms by soil microorganisms is dependent on a host of factors. The major factors controlling mineralization rates are the amount of organic nitrogen and associated organic carbon available (substrate quantity), the ease with which it may be decomposed (substrate quality), and the activity of the decomposing microorganisms as affected by population size and type and most importantly, environmental conditions. The environmental parameters having the most profound effect on microbial activity and mineralization rates are temperature, moisture and aeration. Clearly, the introduction of cropping systems and management practices which alter organic matter amounts, composition, and environmental conditions will affect mineralization rates, and these changes should be taken into consideration in fertilization decisions.

Organic Matter Quantity and Quality

Moving across Saskatchewan, the total quantity of soil organic matter tends to change systematically as reflected in the various soil - climatic zones that exist across the province. As expected, the organic nitrogen content closely follows the trends in the organic matter content, with soils of the Black soil zone having the highest organic nitrogen contents. Incubations of soils from the different soil zones under controlled conditions has generally shown that mineralization rates in the laboratory follow the expected pattern across the soil zones in relation to organic nitrogen content, with highest mineralization potentials measured in soils from the zones with the highest organic matter content (Fig. 1). However, measured mineralization rates in the Black soil zone are not as high as would be expected based on organic N levels alone, due to an apparent greater resistance of the organic N to mineralization (Roberts, 1985). These principles have been used successfully to adjust fertilizer nitrogen recommendations in accordance with expected mineralization rates in farm fields from different soil zones across Saskatchewan (Henry, 1991). Estimates of the typical growing season contribution of mineralization in the top 15 cm to plant available N across the soil zones ranges from about 15 to 50 kg N / ha.

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Figure 1. Average mineralization potential (NO) of N in the soil zones (adapted from Roberts, 1985).

Within any one soil - climatic zone, soil organic matter content is not homogeneous but instead tends to vary, sometimes considerably, from field to field in response to local soil conditions, cropping history and management. The potential for such variations in response to management is perhaps best demonstrated in the range of organic nitrogen levels reported in long-term tillage / rotation plots at the Agriculture Canada research stations in Western Canada. The benefits of extended cropping and legumes in rotation on organic nitrogen levels are well established (Campbell et al., 1991; 1990). A recent study of N mineralization rates in soils from these rotations using different short and long term laboratory incubation techniques has shown consistently higher N release rates in soils from treatments with reduced fallow and addition of N and P fertilizers (Table 10, and with legumes in rotation. Clearly, the ability of such management practices to build long term N mineralization power needs to be taken into consideration in future fertilizer recommendation systems.

Table 1. Influence of crop rotation and fertilization history on nitrogen release potential measured in samples from the old rotations at Swift Current Agriculture Canada Research Station (Jalil, Campbell and Schoenau, 1995 unpublished data).

	Treatments		
N Release Index*	Continuous Wheat		Fallow-Wheat
	N+P	P	N+P
NO_3-N flux to buried resin strip $\mu g/10cm^2$/ 2weeks	757 (±88)	703 (±77)	621 (±43)
Potentially mineralizable nitrogen (NO) ppm	146 (±20)	150 (±7)	138 (±15)
Canola N uptake in growth chamber mg/pot at flowering	15.5 (±1.2)	14.5 (±2.0)	12.3 (±0.4)
Organic N (%)	**0.218** (±0.011)	0.203 (±0.002)	0.188 (±.009)

* Values are means from three replicate plots of each treatment with standard deviation in bracken

Often, the total amount of soil organic nitrogen is not a good indicator of nitrogen mineralization rate and two soils with the same total organic nitrogen level may release nitrogen at very different rates due to qualitative differences in organic matter (Campbell et al., 1984; Campbell, 1978). Such qualitative differences can be induced by management practices. In soil samples taken from a long term (15 yr) continuously cropped direct - seeded field in the Black soil zone, Greer and Schoenau (1992) found that the proportion of total organic nitrogen mineralized to nitrate over a 12 week incubation was approximately double (6% of organic N mineralized) compared to an adjacent cereal - fallow mechanically tilled field (3% of organic N mineralized). The pool of potentially mineralizable nitrogen is thus a variable component of the soil organic matter and it is unlikely that reliable estimates of mineralization input can be obtained simply from the measurement of soil organic matter content alone. Such qualitative differences in soil organic matter, particularly in the content of the "active" fraction, make assessments or predictions of mineralization rate rather difficult and time consuming, since one of the best estimates of potentially minerahzable N involves incubation and leaching of soil samples over several weeks. Promising new approaches which may provide a more rapid index of N mineralization potential include short term soil incubations with ion exchange resin strips (Qian et al. 1994; Qian and Schoenau, 1995) and extraction of soil with hot KC1 (Jalil and Campbell, 1995 unpublished data).

Most fields in Saskatchewan are not level but instead have some type of variable topography or landscape. The redistribution of water and topsoil from knolls to depressions gives rise to significant variations in soil properties in undulating fields. Of particular note are the spatial variations in soil organic matter content and available water at different slope positions. Knolls tend to be drier and have lower organic nutrient contents than the depressional areas in which water and topsoil accumulates from upper regions of the landscape (Roberts et al., 1989). The variations in soil organic matter and available water content create large differences in N mineralization rates in different topographic regions of farm fields. Roberts (1985) showed landscape position to be a significant factor influencing N mineralization in laboratory incubations, with lowest mineralization rates found in upper slope positions. Similar trends were found in a study of in - field mineralization rates in variable landscapes in the Dark Brown soil zone (Qian et al., 1994). The nitrate accumulated over two weeks on buried ion exchange resin strips was found to be significantly higher in lower footslopes than in upslope shoulder positions (Fig. 2). Greater substrate availability in the form of higher organic nitrogen content and greater moisture availability can explain the higher mineralization rates observed in the footslope positions. Landscape variations in mineralization rate such as these should be taken into account in landscape - based variable rate fertilizer applications.

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Figure 2. Nitrate accumulated on anion exchange resin strips buried for two weeks in the field in July,1992 at two slope positions in two fallow fields with undulating topography at Perdue, Saskatchewan (Qian et al., 1994).

While the level of native soil organic matter is a good general indicator of the ability of the soil to release plant available N by mineralization and supply crop N demands over the long term, understanding short -term N availability also requires consideration of mineralization and immobilization reactions related to the previous crop residue. In this case, the amount of residue, its nitrogen content and overall decomposition rate impact greatly on N availability. Residues of low N content such as cereal straws typically induce an initial net reduction (immobilization) of plant available N upon decomposition, which is related to the residue having a large amount of carbon relative to nitrogen (wide C:N ratio) such that there is not enough nitrogen in the residue relative to carbon to meet the microbial demand (Parr and Papendick, 1978). Extra N is thus temporarily removed from the plant available pool. On the other hand, high nitrogen residues (low

C:N ratio) as from many legumes, can contribute plant available N almost immediately upon decomposition. However, the contribution of legume residues to plant available N can vary greatly. For example, Bremer and van Kessel(1992) found only about 5% recovery of residue N added as lentil straw (C:N 3 1: 1) in a subsequent wheat crop. The C:N ratio of the residue is a good predictor of whether there will be a net tie-up or release of plant available N upon initial decomposition of the residue. Residues with C:N ratio greater than 20 to 30 typically result in immobilization while residues of lower C:N result in net mineralization (Ocio et al., 1991). Environmental factors which hamper microbial activity will slow the mineralization - immobilization of N contained in crop residues. Cold temperatures and low moisture content will generally reduce the decomposition rate. Above ground residue decomposition rates tend to be lower than when residue is incorporated, owing to greater temperature and moisture fluctuations and reduced nutrient availability for microbial activity (Schomberg et al., 1994).

Environmental Parameters

Soil temperature and moisture have a profound influence on microbial activity and the rate at which soil organic matter and crop residues are decomposed and associated nutrients released to the plant available inorganic form. Laboratory incubations of soil samples exposed to different temperature and moisture regimes have shown that mineralization rate is directly related to temperature, with increasing mineralization rates up to about 35°C, which is considered optimal for N mineralization (Campbell et al., 1984; Ellert, 1990). Similarly, mineralization rates are closely related to moisture content, increasing from lowest values at permanent wilting point to highest rates at field capacity (Ellert, 1990). Increases in moisture content above field capacity slow mineralization rate, as anaerobic conditions set in which slow decomposition rate and encourage loss of nitrate by denitrification.

Fluctuation in temperature and moisture over a growing season can have large effects on mineralization and the subsequent size of the plant available nitrogen pool. In a 1994 study of nitrate dynamics over a fallow period from May to October in a landscape in the Brown soil zone, nitrate was found to accumulate most rapidly over a period starting at the end of June and proceeding through to mid August, coinciding with the period of greatest soil warming (Fig. 3). Accumulation rates slowed in the fall period, associated with decreasing surface soil temperatures. An 18mm downpour on August 27 may account for the reduction in nitrate concentration observed between August 24 and September 6. Adjustments of mineralization rates to account for expected temperature and moisture conditions should lead to better estimates of required fertilizer N, although it is quite difficult to predict whether the next growing season will be colder or warmer, or wetter or drier than normal.

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Figure 3. KC1 extractable nitrate concentrations (0-15cm) determined every two weeks at three landscape positions (ten replicates of each position) in a no-till fallow field (Ardill association) in southwestern Saskatchewan (Jowkin and Schoenau, 1995).

3. Conclusions

Mineralization of organic N makes a substantial contribution to plant available N in Western Canadian soils and should be accounted for when assessing fertilizer N requirements. Differences in soil organic matter quantity and quality induced by long term climatic conditions during soil formation, soil-crop management system, and landscape position give rise to variability in mineralization rates among regions, fields, and locations within fields, which may require adjustment of fertilizer N rate. The impact of previous crop residue on N mineralization - immobilization must also be considered. Temperature and moisture greatly influence mineralization rates over a growing season but are difficult to account for in recommendation systems. Improved methods are needed to account for the contribution of mineralization in fertilizer recommendations, including better predictive models and methods to quickly assess mineralization potential in soil samples and directly in the field.

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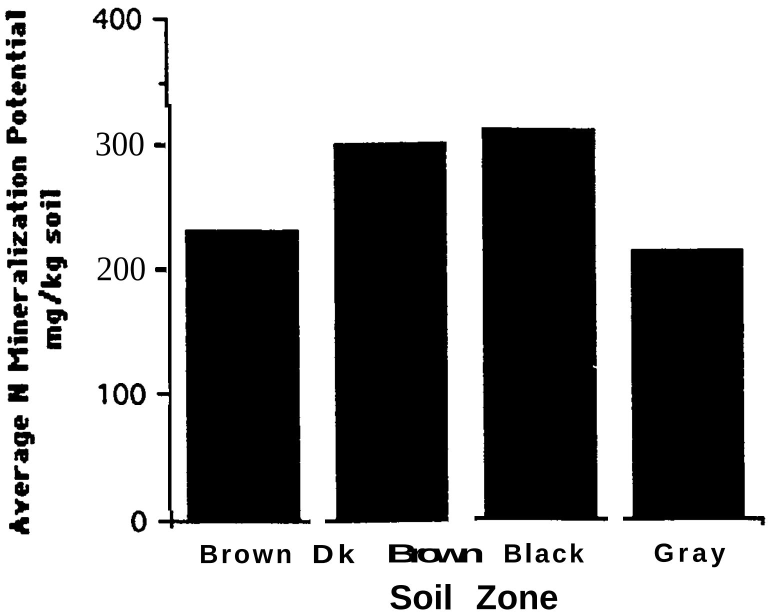

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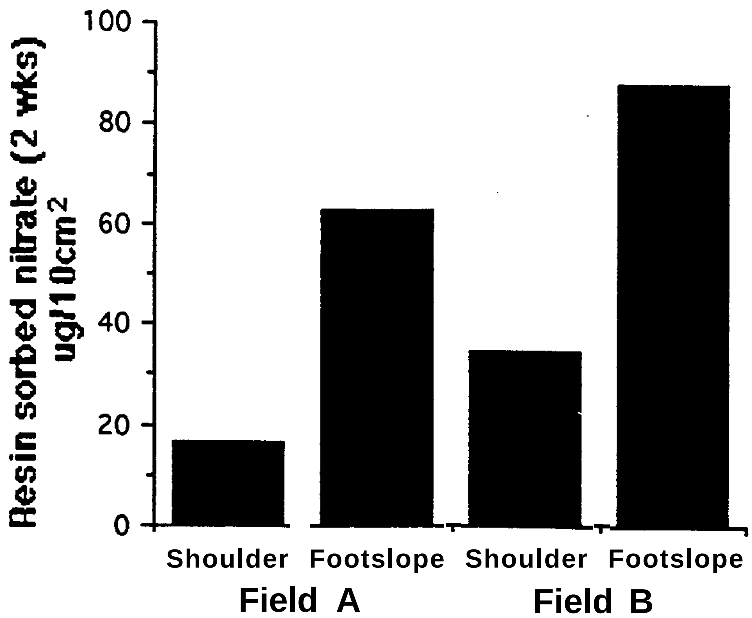

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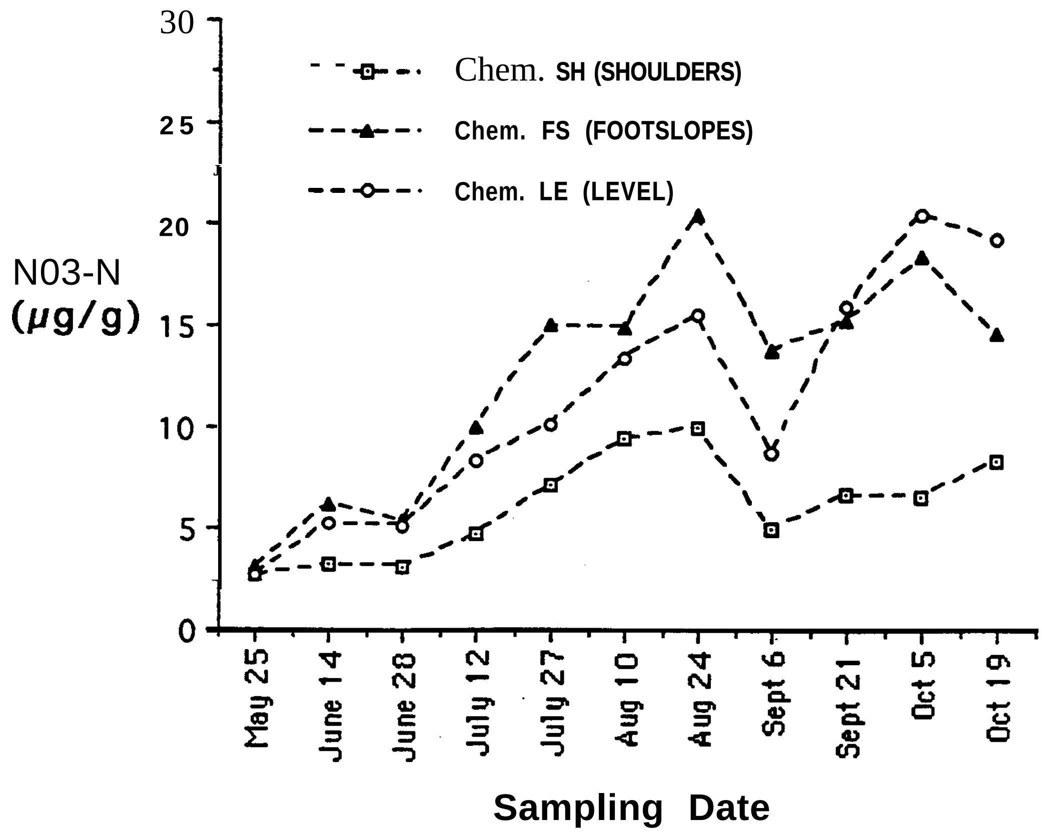

Figure 3. KCI extractable nitrate concentrations (0-15cm) determined every two weeks at three landscape positions (ten replicates of each position) in a no-till fallow field (Ardill association) in southwestern Saskatchewan (Jowkin and Schoenau, 1995).