Assessing Soil N Availability Indices - Is Inorganic N Enough?

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Abstract

Assessing soil N availability is complicated enormously by the complexity of the N-cycle. Over the years, several methods of estimating potentially available N have been suggested. In an ongoing study, we have been assessing the suitability of a number of these methods for predicting potential crop response to fertilizer N. In particular, we correlated amino-sugar N levels to wheat yield across a variable landscape. This relatively new soil N test appears to be sensitive to changes in organic matter quality as related to landscape position and holds some promise for assessing potentially available N. The results presented here are preliminary.

Introduction

Nitrogen often is the most limiting nutrient for plant growth and there has been considerable interest over the years in estimating plant available soil N to predict fertilizer N requirements for crop production with the goal of improving nitrogen use efficiency (Bremner, 1965; Keeney, 1982). In recent years, environmental concerns regarding potential groundwater contamination have provided a further impetus for improving N fertilizer use efficiency in crop production (Mulvaney et al., 2001). Our ability to accurately predict fertilizer N requirements is predicated on sound knowledge of crop N requirements and accurate estimates of the N supplying power of the soil.

Most agricultural soils contain several thousand kilograms of N per ha in organic forms; however, a large proportion of the total soil N remains physically and chemically protected from microbial degradation in the form of stable soil organic matter (SOM), and thus is unavailable for plant uptake (Jenkinson et al., 1987). Because N exists in the soil in many different organic and inorganic N forms, all of which can differ in terms of plant availability, it is useful to think of soil N as existing in different soil N pools. These pools are connected and some N may be free to flow between the different pools, but the direction of flow, and the size of the pools, is likely to differ from field to field and from year to year. For example, on the Prairies, soil zones reflect different level of soil organic matter and thus soils in different zones are likely to have different sized pools of organic N. Inorganic N can flow out of the organic pool if the conditions favour N mineralization. It is estimated that 1 to 3% of the soil organic N mineralizes and becomes available for plant uptake each year (Keeney, 1982), and these labile fractions of the SOM remain an important source of N (Jenkinson and Parry, 1989). Variations in the estimates of soil N release (i.e., from 1 to 3%) reflect not only the impact of different climatic and soil conditions that influence annual N release, but also the nature (i.e., quality) of the organic N pool itself.

Most soil testing labs in western Canada and the Great Plains region of the USA historically have based fertilizer recommendations on a single pre-plant soil nitrate test (i.e., an inorganic N pool) to account for the carryover and contribution of mineral N from previous cropping (Henry, 1991). Moreover, labs often either ignore or estimate the N contribution from the organic N pool. More recently, some of the soil testing labs have either introduced, or are in the process of adapting, measures of potentially available N for routine soil testing purposes. Ideally, a soil test for N should provide both a measure of available inorganic N pool together with a measurable estimate of the potential supply or flow of N from the organic N pool that is likely to occur during critical crop growth stages. The challenge is to identify a specific soil N pool that mineralizes rapidly and predictably and is directly related to crop responses to fertilizer N additions (Mulvaney et al., 2001)

Over the years, numerous soil N availability indices, based on either biological or chemical principles (Bremner, 1965; Keeney, 1982), have been proposed. Because many of the methods used to estimate N availability measure, in part, the release of N from some component of the SOM pool, various indices have been found to be closely related to total SOM and total organic N (Keeney, 1982; Wang et al., 2001). Stanford and Smith (1972) developed a biologically based, long-term incubation method whereby potentially mineralizable N (N_o) can be estimated using one-pool (Stanford and Smith, 1972), two-pool (Molina et al., 1983) or incremental models (Ellert and Bettany, 1988). Incubation methods are time-consuming by nature, and thus more recent research has focused on the development of more rapid chemical extraction methods, such as the hot KCl (e.g., Gianello and Bremner, 1986; Smith and Li, 1993; Jalil et al., 1996; Curtin and Wen, 1999) and phosphate-borate buffer (Gianello and Bremner (1986) methods for estimating potentially available N. Anion exchange membranes (AEM) also have been used to estimate soil N availability (Qian and Schoenau, 1995; Ziadi et al., 1999) and this technology has been commercially developed. Very recently, Mulvaney and Khan (2001) described a diffusion method to determine different forms of N in soil hydrolysates, one of which (i.e., amino sugar N) was highly correlated both with check yield and fertilizer N response (Mulvaney et al., 2001). All of these methods share a common characteristic in that they measure the 'potential' for N release and do not provide an absolute measure of N release. The latter is dependant on microbial activity that, in turn, is subject to the vagaries of weather – most importantly precipitation and temperature – and thus is expected to be highly variable.

We examined the relationship between amino-sugar N (Mulvaney and Khan, 2001) and wheat yields along a 100-point sampling transect in the Black soil zone. Soils used in this evaluation were collected as a component of a previous study (Yates, 2001), and were re-analyzed for the purposes of the current investigation.

Materials and Methods

The experimental design and sampling protocol used in this study were previously described (Walley et al., 2002). Briefly, the study site is located in the Thin Black soil zone near Hepburn, Saskatchewan, Canada (106^{o}41'W, 52^{o}25'N) on a ridged hummocky morainal surface with average slope gradients ranging from 6 to 9%. The parent materials are medium to moderately fine-textured moderately to strongly calcareous, unsorted glacial till. The field had been cropped with wheat for the previous two years using zero tillage management.

A single 300-m north-south transect, consisting of 100 sampling points at 3-m intervals, was selected. The sampling points and surrounding area were surveyed using a total station laser theodolite (Model Set 5, Sokkisha Co. Ltd., Japan). Soil samples were collected on 4-5 May 1998. Soil cores, 6.5 cm in diameter, were taken to a depth of 60 cm in three increments (0 - 15 cm, 15 - 30 cm, and 30 - 60 cm). Samples were stored at 4^oC until analyzed for all but amino-sugar N. Amino sugar N samples were dried, ground and stored at room temperature until they were analyzed in 2002. Data relating to the 0-15 cm soil depths are presented here.

Hard red spring wheat (*Triticum aestivum* var. AC Barrie) was seeded on May 15th at a rate of 90 kg ha^{-1} and fertilized with monoammonium phosphate, supplying P_2O_5 at a rate of 27.5 kg ha^{-1} and N at a rate of 5.5 kg ha^{-1}. No additional fertilizer-N was applied. A second strip of wheat fertilized with an additional 70 kg N ha^{-1} was seeded immediately adjacent to the non-N strip. At crop maturity on 3 September 1998 a 1-m^2 yield sample was hand harvested at each sampling point, dried to constant weight at 60^oC, weighed, and threshed. Grain and straw yield, and N uptake were determined.

Soil Nitrogen Availability Indicators

In the original study, several soil N availability indicators were examined including: (i) cumulative N released during a two-week aerobic incubation (N_{MIN}); (ii) potentially mineralizable N estimated using a sixteen-week aerobic incubation (N_0); (iii) NO_3 sorbed on anion exchange membranes (NO_{3AEM}); (iv) N extracted with hot 2 M KCl (N_{KCl}); and (v) N hydrolyzed with hot 2 M KCl (N_{HYDR}). The aerobic incubation (i.e., N_{MIN} and N_0) was carried out using the methodology and leaching apparatus as described by Campbell et al. (1993). Nitrate sorbed on anion exchange membranes (NO_{3AEM}) (PRS^{TM}, Western Ag Innovation, Saskatoon, Canada) were used to estimate N availability for the three depths in the laboratory, according to Qian and Schoenau (1995). Because NO_{3AEM} is a function of time (2 wks) and the surface area of the AEM (10 cm^2), the units of this measurement are expressed as a supply rate of µg NO_3 x 10cm^{-2} x 2 wks. Inorganic-N extracted with hot 2 *M* KCl (N_{KCl}) was determined using a modification of the method described by Gianello and Bremner (1986). Nitrogen hydrolyzed using hot 2 *M* KCl (N_{HYDR}) was calculated by subtracting the quantity of inorganic N extracted with 2 *M* KCl at room temperature from the amount in the heated extract (Wang et al., 2001). Results relating to these soil N availability indices were previously reported (Walley et al., 2002).

More recently (2002), we re-analyzed the stored soils collected in 1998 for amino-sugar N using the method described by Khan et al. (2001). Briefly, I g of air-dried soil was treated with 10 mL of 2 N NaOH in a wide-mouth Mason jar, and the sample was heated for 5-h at 50^oC on a hot plate. Liberated NH_3 (NH_4 + amino-sugar N) was collected in H_3BO_3 and subsequently determined by titration.

Soil inorganic N (NO_3 and NH_4) was determined using standard procedures (Keeney and Nelson, 1982). Gravimetric soil moisture content for each soil depth was determined in the spring prior to seeding. Soil samples (30 g,) were oven dried for 24 h at 105^oC and the moisture content determined. Total N in the straw and grain, and total soil N and C were determined by dry combustion using a LECO CNS-2000 analyzer (LECO Instruments, Ltd., Mississauga). Total organic soil C was determined using a LECO Carbon Determinator CR-12 (LECO Instruments, Ltd., Mississauga).

Results and Discussion

Relative elevation along the transect across the ridged hummocky morainal surface varied within a range of 1.5 m with average slope gradients ranging from 6 to 9%. Thus, although topography was variable along the transect, the site was not characterized by extreme topographic variation. Interestingly, even these relatively moderate topographic variations strongly influenced a number of soil and plant growth characteristics. For example, a negative relationship existed between relative elevation and spring soil available moisture (Fig. 1). In contrast, no significant correlation existed between relative elevations and spring inorganic N (r=0.19 n.s.) or total organic C (r=-0.114 n.s.) (data not shown).

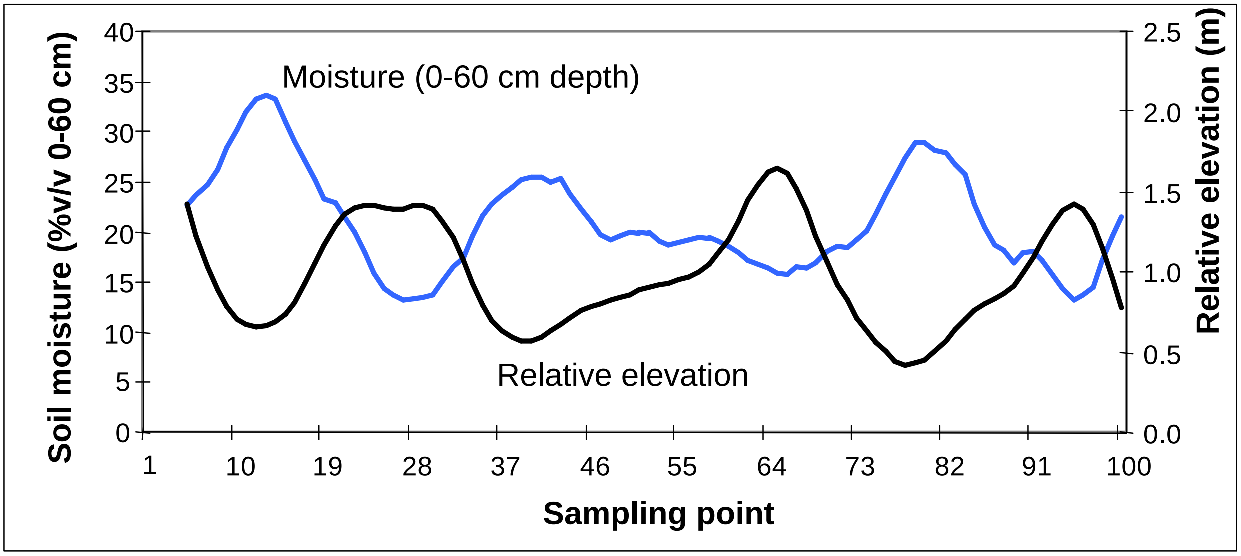

Figure 1. Relationship between relative elevation and spring soil moisture at Hepburn, Saskatchewan, 1998.

Although no significant correlation existed between elevation and soil organic C, it is interesting that a significant negative correlation existed between relative elevation and amino sugar-N (Fig. 2). This observation suggests that the controls related to topography influenced the 'quality' of soil organic matter although a correlation between the quantity of soil organic matter within the 0-15 cm depth and elevation was not detected. Clearly elevation itself is not directly influencing soil organic matter quality; rather, it is an indirect effect of elevation on some factor or factors that ultimately control organic matter quality. It seems likely that the influence of topography on soil moisture redistribution within the landscape is subsequently influencing organic matter inputs and cycling within the landscape, and thus is influencing levels of amino sugar-N.

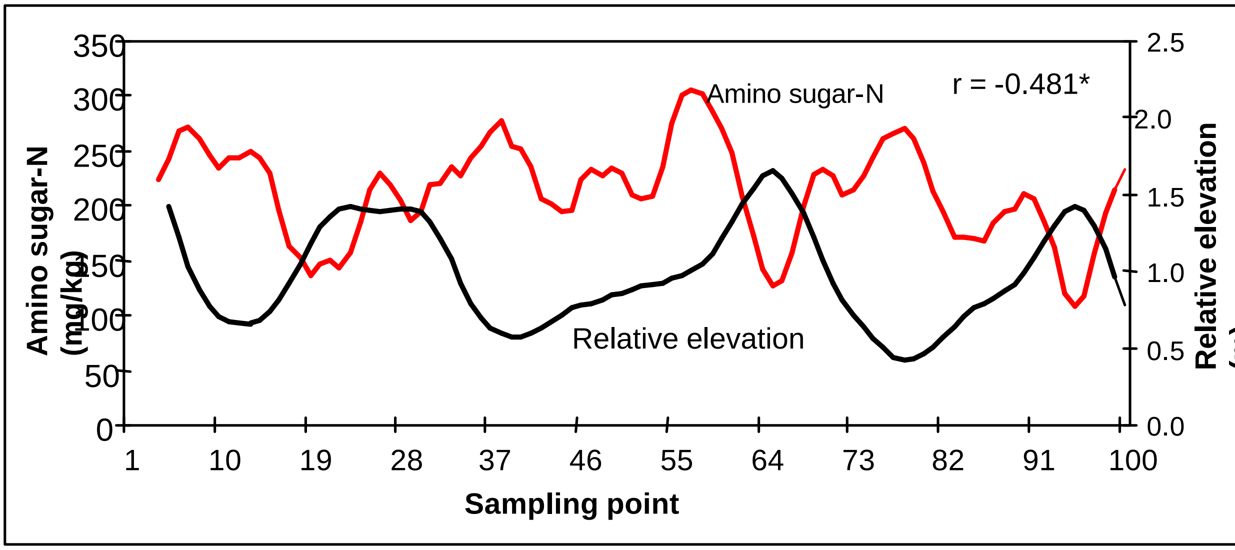

Figure 2. Relationship between relative elevation and amino sugar-N at Hepburn, Saskatchewan, 1998.

Amino sugar N was found to be positively correlated with the unfertilized (N) yield of spring wheat (Fig. 3). Although the correlation was not strong (r=0.566) it was significant (p=0.05). Moreover, this correlation was higher than correlation between unfertilized yield and any of the other N availability indices, as reported previously (Walley et al., 2002). These preliminary results suggest that the amino sugar N test may have potential applications for describing N availability for Saskatchewan soils.

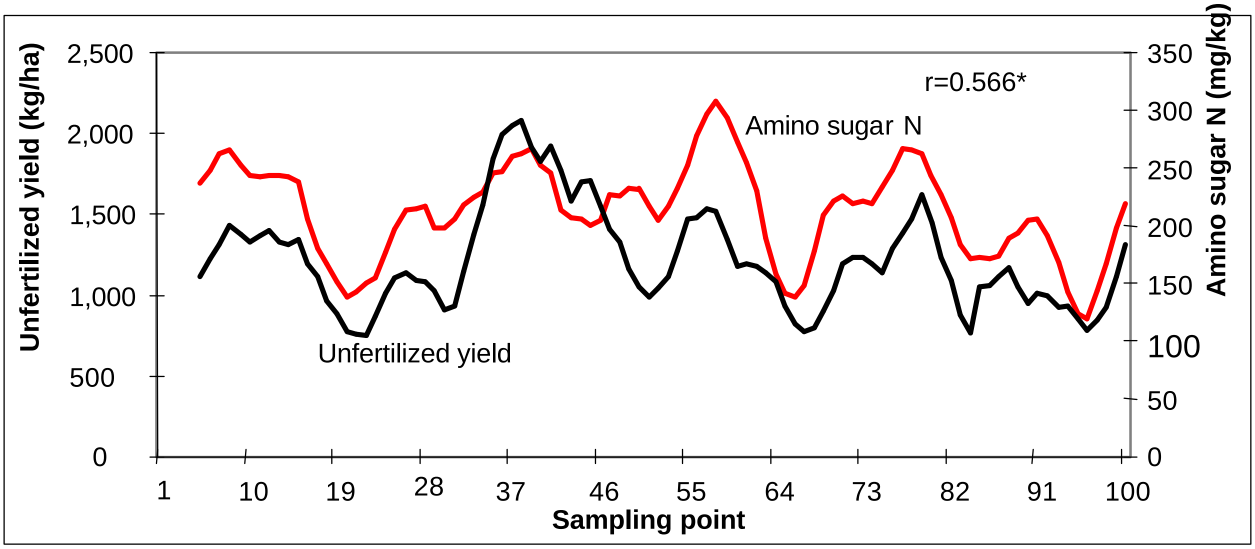

Figure 3. Relationship between unfertilized (N) wheat yield and amino sugar-N at Hepburn, Saskatchewan, 1998.

Conclusions

Nitrogen cycling is a highly dynamic process that is dependent on microbial activities. Soil microorganisms are, in turn, controlled by a multitude of factors including climate and variable soil conditions. As a further complication, no single climatic or soil factor solely controls N-cycling – rather these factors act in concert. Thus, even if we can measure the size of the 'potentially available' soil N pool (and current research suggests that the amino-sugar N test has the potential to provide a good estimate of potentially available N), the realization of this N potential remains dependent on a host of interacting factors, which can vary from year-to-year and field-to-field. According to Khan et al. (2001) "estimation of plant available N is complicated enormously by the dynamic nature of soil N, owing largely to the effects of temperature and moisture supply on N-cycle processes". Indeed, it is not enough for us to be able to estimate the size of the potentially available N pool – we also need to understand the impact that the multitude of environmental and soil factors have on N-cycling processes and, consequently, soil N supply.

Ultimately, there will always be a level of uncertainty regarding N fertilizer requirements, even if we expand our soil testing efforts to include measures of both the inorganic N pool (i.e., nitrate-N) and the organic N pool (i.e., potentially available N). However, this level of uncertainty does not negate the value of soil N testing, nor should we abandon soil testing for predicting N fertilizer requirements. Soil testing clearly measures pools of N that are, or will be, available for plant use and this information is of great value when planning fertilizer N applications. However, we need to be realistic about our expectations regarding soil N testing for predicting fertilizer N requirements and understand that any estimate of fertilizer N requirements is subject to the vagaries of weather.

Results reported here regarding the amino-sugar N test are preliminary and further investigation is required. However, correlations between measured amino-sugar N levels and unfertilized yield suggest that this relatively new soil N test may be useful for assessing potentially available N in Saskatchewan soils. It is important to note that application of any new soil N test will require the development of appropriate production response curves and subsequent field validation.

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