

ASSESSING CHEMICAL METHODS FOR ESTIMATING MINERALIZABLE NITROGEN IN SASKATCHEWAN SOILS

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Abstract

An experiment was conducted to correlate the potentially mineralizable nitrogen (NO) in Saskatchewan soils with chemical extractant. An array of soils (129) representing all soil zones, soil textures and crop management practices and varying in soil organic C from 1.0 to 6.3% and pH from 5.1 to 7.8 were used in this study. The two chemical solutions used to extract ammonium (NH₄) in soil were, hot 2 M KCl and phosphate-borate buffer at pH 11.2. The NH₄ extracted with the hot KCl method provided a better index of available N in soil than the phosphate-borate buffer method. The KCl method was highly correlated with net N mineralized over 24 weeks under aerobic conditions at 35°C. Although, the KCl method was significantly ($P < 0.001$) correlated with NO ($r^2 = 0.53^{**}$) it was better correlated with the product of N₀ and the rate constant (k) (initial potential rate of N mineralization) ($r^2 = 0.80^{***}$). The KCl method may not be a good indicator of NO for some soils in the Black soil zones and soils recently fertilized with farmyard manure. Because several studies have shown that N₀k is a very good index of the N-supplying power of soils and is closely related to grain yields, we believe that the KCl method may have great potential for use in soil testing labs to make more precise N fertilizer recommendations to producers. This is particularly true for more humid environments where the NO₃ test is not appropriate.

Introduction

Plants obtain nitrogen (N) primarily from residual N present in the soil at seeding, N mineralized from organic matter during the growing season, N added as fertilizers, manures and, if legumes are present, N₂ fixed from air (Campbell, 1978). The residual N is measured as nitrate (NO₃) in the fall, or just prior to seeding in the spring. In humid climates where NO₃ is readily leached, there are no suitable tests for available N at present (Wells and Thompson, 1992); in semiarid climates the NO₃ test is commonly used. However, there is an urgent need to develop accurate methods for quantifying the rate at which soils will mineralize N during the growing the season. A solution to this problem would allow better management of fertilizer N applications, which means improvement in crop quality (e.g., grain protein) maximization of net returns and reduction of environmental pollution.

The concept of potentially mineralizable N (the capacity of the soil to mineralize N) can be used effectively to quantify the amount of N that a soil can mineralize during a growing season. The factors required to make this estimate are not easy to determine. The most difficult to obtain is

potentially mineralizable $N(N_0)$ because it differs for each soil (Stanford and Smith, 1972; Campbell *et al.*, 1984) and its determination requires long term aerobic incubation (24 weeks or more at 35°C). The latter makes this technique impractical for use in soil testing laboratories. Estimating a rate constant of N mineralization (k) is also difficult, but this can be approximated by using literature data (e.g., Stanford and Smith, 1982) and assuming a Q_{10} of 2 (rate of reaction doubles for every 10°C increase in temperature).

To make this approach usable by soil testing laboratories, a quick, effective routine method of estimating NO is required. Gianello and Bremner (1986) used chemical methods to assess potentially available organic N in soil. In one method ammonia-N produced with phosphate-borate buffer solution of pH 11.2 was determined. In another method, ammonium produced by heating soil with 2M KCl for four hours was determined. The N extracted in both these methods correlated well with N-mineralized during the first 2 weeks of aerobic incubation at 35°C ($r^2 = 0.86$). Stanford and Smith (1972) and Campbell *et al.* (1984) have shown excellent correlation ($r^2 = 0.83-0.85$) between N_0 and N mineralized in the first two weeks of aerobic incubation at 35°C (Campbell *et al.*, 1994). Gregorich *et al.* (1994) have also observed a correlation between N mineralized in three weeks and cumulative N mineralized in 22 weeks in nine Ontario soils.

We therefore, hypothesize that there should be a close correlation between potentially mineralizable N (NO) in soil and chemically (KCl or buffer) extracted ammonium. This study was initiated to determine if either KCl or phosphate-borate buffer methods could be used to estimate the potentially mineralizable N.

Materials and Methods

The soils used were taken from all soil zones throughout Saskatchewan, Canada. Most of the samples were taken from 0- 15 cm depth, but some that were taken from long-term crop rotation studies were sampled from the 0-7.5 cm and 7.5-15 cm depths. Samples were taken in May, 1994 before seeding of the crop. In the samples, organic carbon varied from 0.98 to 6.3%, total nitrogen from 0.113 to 0.559%, pH (CaCl₂) ranged from 5.1 to 7.8 and soil texture varied from light to heavy. There were various management regimes, including the presence of legumes, farmyard manure and various cultural practices in long-term rotations of Agriculture Canada, at Swift Current, Indian Head and Melfort.

Chemical Methods:

Hot KCl: A soil sample was treated with 2 M KCl in a Tecator digestion tube for 4 hr at 100°C . Ammonium present in the sample was determined by distillation. Modifications we made to the Gianello and Bremner (1986) procedure were: (a) Amount of distillate collected in the beaker was 40 ml instead of 30 ml, and (b) Ammonium N in the distillate was determined by automatic titrator (Compact Mettler DL20) with 0.005N H_2SO_4 to final pH of 5.2.

Phosphate-Borate Buffer: Soil was steam distilled with phosphate-borate buffer at pH 11.2 for 7 minutes. Rest of the procedure was same as described under KCl.

Biological Method: Leaching procedure and leaching apparatus used in this study were the same as described by Campbell *et al.* (1993). The process involves leaching and discarding the initial mineral N then incubating soil at approximately field capacity for 24 weeks with periodic leaching and repeated (every two weeks for 8 weeks and every four weeks thereafter) extraction of mineral N using 0.01M CaCl₂ followed by an N-minus nutrient solution. The cumulated N_{\min} and time

were used to calculate NO and k by means of a non-linear regression iteration program (Ralston, 1988; Campbell et al., 1993).

Results and Discussion

Both hot KCl and phosphate-borate buffer methods were assessed on soils taken from all the soil zones of Saskatchewan. The KCl method produced better correlation with potentially mineralizable nitrogen (NO) in soil than the phosphate-borate buffer method (Table 1). Thus, only the KCl method will be discussed in this paper.

Table 1. Quantitative relationship between a chemical extractant and various indices of available N (based on 129 Saskatchewan soil samples).

Dependent variable+	Independent variable	Intercept	Slope	r^2 *** (n = 129)
N_0	Cum. N_{min}	9.4	1.2	0.87
N_0	KCl - NH_4	59	5.5	0.53
N_0^+	KCl - NH_4	24	8.4	0.72
N_0	Phos-Borate- NH_4	69	2.1	0.39
N_0k	Cum. N_{min}	1.1	0.1	0.81
N_0k	KCl - NH_4	0.68	0.61	0.80
KCl - NH_4	Cum. N_{min}	0.77	0.14	0.70

+ Units for all variables are $mg\ kg^{-1}$ except N_0k where units are $mg\ kg^{-1}wk^{-1}$.

*** Significant at $P < 0.001$.

F.Y.M. and Melfort long-term rotation excluded (n = 106).

Cumulative N_{min} (Net N mineralized in 24 week under aerobic conditions) is a valid test of biological activity. We found ammonium extracted with hot KCl to be closely related to it ($r^2=0.70$ ***) (Table 1).

Ammonium-N extracted with hot 2M KCl was correlated significantly with NO ($r^2=0.53$ ***) but the coefficient of determination was not as high as we had hoped. However, if we exclude samples from the Melfort long-term crop rotation study and three samples in which fresh farmyard manure had recently been applied, the r^2 values improved to 0.72***. We are not sure of the underlying cause of this effect; however, this suggests that we may have to include some pedo-transfer function in the equation to improve the relationship.

Campbell et al. (1991) have shown that N_0k is a superior index to NO for estimating potential N_{min} . For example, by using this concept they were able to distinguish both the quantitative and qualitative changes in soil organic N due to various cultural and management practices in the Indian Head long-term crop rotation experiment. Recently, they used soils collected from these plots and, under controlled conditions in the growth room applied various rates of N and P fertilizers and

showed that grain yield was highly correlated to N_0k ($r^2=0.96^{***}$). We found excellent correlation between hot KC1 extracted NH_4 and N_0k ($r^2=0.80^{***}$). Schoenau et al. (personal communication) using the same soils that we have used have also observed a close relationship between N-uptake by plants grown in the growth room and hot KC1 extractable NH_4 . We therefore suggest that this chemical extractant has great promise for use in conjunction with the NO_3 test to assess N fertilizer requirements in semiarid soils. Because it is easy and fairly rapid to run, and can be automated, it could be used in soil testing laboratories.

This test may be particularly useful for use in humid climates, where NO_3 is readily lost by leaching and denitrification and where the nitrate test is not effective for making N-fertilizer recommendations to producers (Wells and Thompson, 1992). Under dryland conditions, if this method was combined with the soil test NO_3 method (residual available N in soil) it should provide an estimate of the latent ability of the soil to supply N to the crop during the growing season, and should therefore enhance the accuracy of N-fertilizer recommendations to producers.

Nonetheless, although the relationship with N_0k identifies this KC1 extractant as a useful semi-quantitative procedure, it is the relationship with NO_3 that will allow us to use this procedure quantitatively in a soil test laboratory. We therefore still need to determine, what characteristics of the Melfort long-term rotation and the manure-treated systems cause them to behave unpredictably. We are working on this aspect.

To use N_0 quantitatively, we must also have an estimate of the rate constant (k). We found the average k value (wk^{-1}) for 25 of 27 sites sampled throughout the various soil zones of Saskatchewan to be 0.060 ± 0.014 (standard dev.). Two of the soils receiving fresh manure had values of 0.174 and 0.111. The k values for the various crop rotations were: Indian Head (8 rotations) 0.056; Swift Current (3 rotations) 0.069; and for Melfort (9 rotations) 0.105. Except for Melfort and two of the systems where fresh manure was applied, the average k value was no different from k reported by Stanford and Smith (1972) for an array of 39 North American soils (0.054 ± 0.009). This suggests that, in most cases where k is unknown, it might be possible to assume that k at $35^\circ C$ is about 0.055 and we could then use a Q_{10} value of 2 to estimate k at other temperatures. Thus, we could use the relationships developed relating N_0 to KC1 extracted NH_4 , the k value relationships cited above, the historical precipitation records for a site (to estimate soil moisture), and historical temperatures, together with N_{min} models such as that developed by Campbell et al. (1994), to estimate probable N that will be mineralized by a soil during a growing season.

Conclusions

Using soil samples taken from many soils throughout Saskatchewan we have shown that a chemical extractant, hot KC1 can be used to estimate the N supplying power of the soil. We propose that the KC1 method can be used in soil testing labs to estimate the N mineralization potential of soils during the growing season. The KC1 method need to be refined so that it is applicable to all the soils in Black soil zones and to soils where farmyard manure has been freshly applied.

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