Precision chemical analysis of soils to support precision management decisions

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Abstract

Technological advances in application of fertilizers and crop cultivars have expanded the potential for more precise management of soil. These advances can be enhanced by careful mapping and characterization of soil resources. Characterization of soil by conventional methods is tedious, expensive and provides limited information. Resin-extraction, an alternative method of characterizing soils, coupled with inductively coupled plasma (ICP) provides information about the relative activity of several elements simultaneously. Twenty-three sites of Barnes (Fine-loamy, mixed, Udic Haploborolls) and Buse (Fine-loamy, mixed, superactive Udic Calciborolls) soils were sampled over a 170,000 km^2 region. In addition, adjacent Langhei (Fine-loamy, mixed, superactive, frigid Typic Eutrochrepts) or Svea (Fine-loamy, mixed, superactive Pachic Udic Haploboroll) soils were sampled at several sites. Soil cores were withdrawn to a depth of 60-cm but only the A or Ap horizons (8- to 15-cm depths) were subjected to resin-extraction modified to include 20% ethanol in the suspension and rotated slowly during extraction at room temperature. The extracts were analyzed by ICP at the University of Minnesota Analytical Res. Lab. (St. Paul, MN). Data were statistically analyzed using SAS PROC GLM. Resin-extractable P and bicarbonate extractable P concentrations were examined for correlation. Soils in this region have developed on glacial till and are characterized by substantial calcium carbonate in the subsoil and, in the cases of Buse and Langhei soils, in the A and Ap horizons. For the Barnes and Svea soils, elements commonly present as oxyanions were extracted on the anion exchange resin. However, for the Langhei and Buse soils, as much as 90% of the readily extractable oxyanions were found on the cation exchange resins. This was attributed to the very large amounts of resin-extractable Ca obtained (mean = 27.9 µmoles g^{-1}; single extraction with Soil-CEC:resin-CEC $\cong$ 10). Bicarbonate-extractable P was weakly correlated to resin extractable P, however, each soil showed a unique relationship. The results suggest that each soil should be managed as an individual and that banded applications of fertilizer P, S, and Mg may be more beneficial than broadcast additions.

Keywords: resin-extraction, phosphorus, calcium, sulfur, magnesium trace-elements

Introduction

Technological advances in application of fertilizers and crop cultivars have expanded the potential for more precise management of soil. These advances are enhanced by careful mapping of soil resources and an evaluation of their physical and chemical attributes. Chemical characterization of soil by conventional methods is tedious, expensive and provides limited information. Resin-extraction of soils enables the simultaneous extraction of 20 or more readily exchangeable elements (Olness *et al.,* 1990; Olness and Rinke, 1994) when the resin capacity is maintained as a fraction of the soil exchange capacity and neutral salts are used as exchange ions. Through use of this technique, Olness *et al.,* (1999, 2000, 2001 a and b) were able to identify complex vanadium (V) interactions with phosphorus (P) and of magnesium (Mg) interactions with calcium (Ca) with plant genotypes of maize (*Zea mays* L.), soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.). Grain yield gains or losses of as much as 20% were associated with the specific soil exchangeable ions and either variety or hybrid. They were also able to show that soil mapping-units were distinguished easily by their suite of exchangeable ions.

Olness and Rinke (1999) were able to show distinct differences in the suite of resin-extractable elements between soils within a field. From these early observations, the question emerged as to whether or not units within a region maintained distinct profiles throughout the range of mapping units. Also, did chemical extractions obtained in one portion of a mapping region remain the same for soil mapping units in other portions of the region? If the resin-extractable characteristics associated with plant productivity remain stable throughout the region, then soil mapping can be used as an important tool in selecting soil management options for crop production. In order to address these questions, we examined the Barnes and Buse soils throughout their mapped region (170,000 km^2) in the northern Great Plains.

Materials and Methods

Twenty-three sites of Barnes (fine-loamy, mixed, superactive, frigid Calcic Hapludolls; USDA) and Buse (fine-loamy, mixed, superactive, frigid Typic Calciudolls) and Buse soils were sampled to a depth of 60 cm. Samples were also collected from eight Langhei (fine-loamy, mixed, superactive, frigid Typic Eutrudepts) and seven Svea (fine-loamy, mixed, superactive, frigid Pachic Hapludolls) soils when these soils were adjacent to either Barnes or Buse soils.

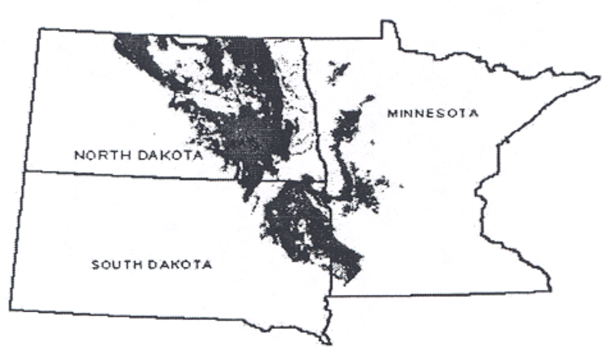

Figure 1 The distribution of the Barnes/Buse soils in the northern Great Plains (map courtesy of USDA-NRCS, Washington, DC.). The ★ symbols represent locations.

Soil/land management ranged from cultivated cropland to virgin prairie/grazed grasslands. Svea soils are on concave positions on till plains and usually have slopes of from 0 to 6% and are usually found at elevations below those of Barnes-Buse soils. Barnes soils occupy level to hilly till plains and moraines with typical slopes of 0 to 25%. Buse soils have strongly convex slopes and gradients of 3 to 50%. Langhei soils have slightly to strongly convex positions on undulating to hilly slopes ranging from 2 to 55%. At each site, 5 soil cores were obtained to a depth of 60 cm using a 2.5 cm Hoffer soil corer; each core was segmented by soil horizon. The horizon segments were then composited for each soil at each site to provide a single sample. Soil samples were returned to the laboratory, dried, and ground to pass a 20 mm mesh. Samples were evaluated for pH (Thomas, 1996), organic and total C (LECO Corp., 1994 a and b), inorganic C (Wagner *et al.,* 1998), bicarbonate extractable P (Kuo, 1996) and extractable K (Helmke and Sparks, 1996).

Samples of the surface horizon were subjected to resin-extraction modified to include 20% ethanol in the suspension (Olness and Rinke, 1994 and Olness *et al.,* 2000) and rotated slowly during extraction at room temperature. Eluted extracts were analyzed using inductively coupled plasma at the University of Minnesota Analytical Research Laboratory (St. Paul, MN).

Data were statistically analyzed using SAS PROC GLM (SAS Ins., 1989). Analytical chemical data obtained from the resin-extractions were log10 transformed before statistical analyses to obtain near normal distributions of the data; transformed means and standard deviations were converted to decimal values. Resin-extractable P and bicarbonate extractable P concentrations were examined for correlation.

Results and Discussion

Conventional methods of soil analyses show few distinctions between the soil mapping units over the region (Table 1). These soils are very fertile and generally calcareous. All are fine textured loams and generally rich in organic carbon except for the Langhei soil. All are very rich in potassium (K) and, with the exception of the Langhei, all have ample amounts of bicarbonate extractable P. Even in the Langhei soil, the average bicarbonate extractable P is regarded as being 'medium' to 'rich' and additions of P would generally not be recommended. While the variances in K were large, few of the samples had less than 100 µg extractable K per g of soil. With the exception of pH, none of the conventional tests suggest any special management requirements or predict serious nutrient deficiencies.

Table 1 Selected soil characteristics.

Soil	Clay	Silt	pH	Carbon		P	K
				Organic	Total		
	---------%---------			----------%---------		-------µg g-1------	
Svea	19.3	36.0	6.8 c	3.5 a	3.6	25 a	248
Barnes	21.8	29.9	7.3 b	2.8 a	2.9	22 ab	275
Buse	21.9	29.4	7.8 a	2.5 a	3.4	19 bc	284
Langhei	24.3	27.0	8.0 a	1.1 b	3.3	14 c	192

† Within columns, values followed by different letters are measurably different ($p > 0.05$).

By maintaining the ratio of cation exchange capacity of soil to that of the resin at about 10, we obtained a suite of extractable ions from each soil. Because of differences in climate across the northern Great Plains, the soil changes gradually and this change should be reflected in the amounts of resin-extractable ions and in the suite of resin-extractable ions. This characteristic is exemplified by the resin-extractable K^+. The amount of resin-extractable K^+ tended to increase with distance from the southern limit of the mapped region to the northern limit in all soils ($p < 0.10$; Figure 2) and from the eastern limit to the western limit ($p < 0.05$; Figure 3). The rate of change ranged from about 36 to 93 ng K^+ g^{-1} km^{-1} in the south-north transect and from 96 to 314 ng K^+ g^{-1} km^{-1} in the east-west transect for the Barnes and Buse soils. The direction of greatest rate of change is from south-west to north-east and this reflects both the relative intensity of rainfall that the region receives annually and the predominant glaciation direction during the last ice age. Part of the variance in the results is undoubtedly due to addition of K through commercial fertilizers and livestock manure over the last 50 y. However, within the region, the soil mapping units remain rather stable.

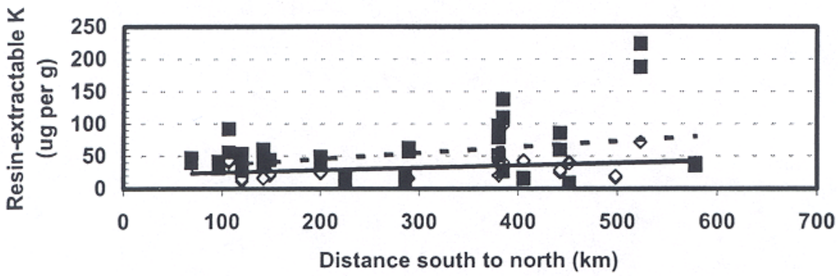

Figure 2 The rate of change in resin-extractable K in Barnes (—■—) and Buse (--- ---) soils with distance from the southern border to the northern border of the mapped area.

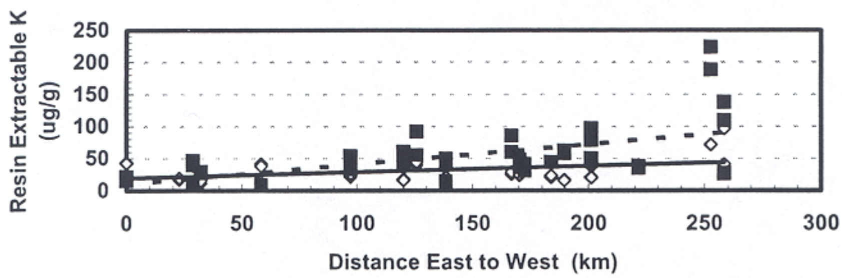

Figure 3 The rate of change in resin-extractable K in Barnes (—■—) and Buse (------) soils with distance from the southern border to the northern border of the mapped area.

Each soil within the region could be distinguished from each of the other soils on the basis of the extracted suite of ions. The differences in suites of resin-extractable ions was probably best represented by sulfur (S), phosphorus (P), magnesium (Mg), and calcium (Ca). Each of the epipedons were relatively rich in magnesium (Figure 4) and calcium (Figure 5). Even the Svea soil had 108 nmoles of extractable Mg g^{-1} and 148 nmoles of extractable Ca g^{-1} but it is dwarfed by the exceptionally large amounts of extractable Ca in the Langhei soil. The Barnes, Buse, and either the Langhei or Svea soils lie adjacent to each other in the landscape. Thus, the extractable cation complements represent rather large changes in soil character over very short distances (often <30 m).

These large differences in extractability of traditional cations has an equally large effect on extractability of traditional anions. The effect is best shown by resin extraction of S. For the Svea soil, all resin-extractable S is found on the anion exchange resin and this result is typical for the extraction of sulfate-S from many soils (Figure 6).

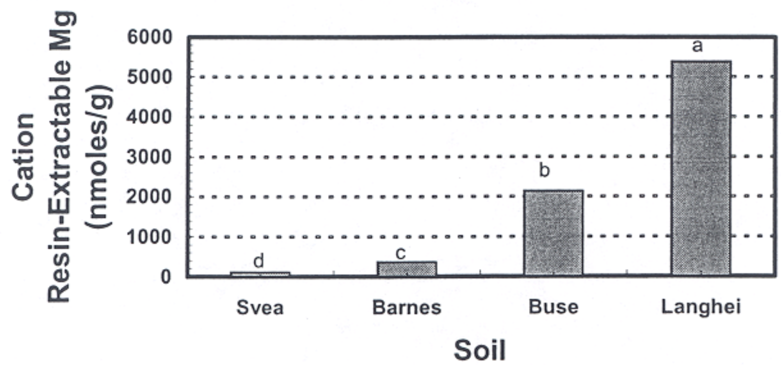

Figure 4 Resin-extractable Mg obtained on cation exchange resins for four soils in the northern Great Plains of north America. Columns with different letters at the top indicate measurably different amounts of ions (p = 0.05).

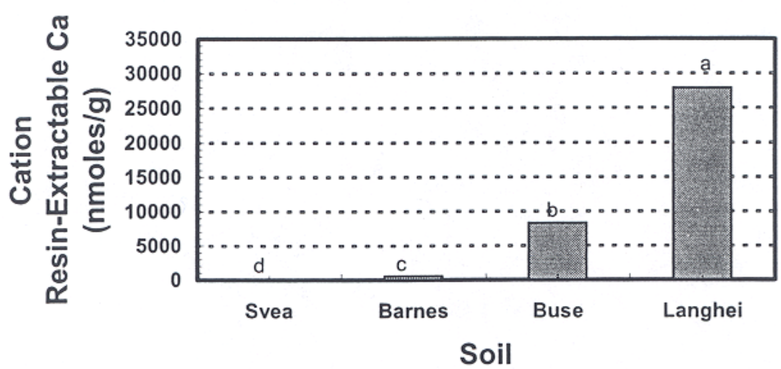

Figure 5 Resin-extractable Ca obtained on cation exchange resins for four soils in the northern Great Plains of north America. Columns with different letters at the top indicate measurably different amounts of ions (p = 0.05).

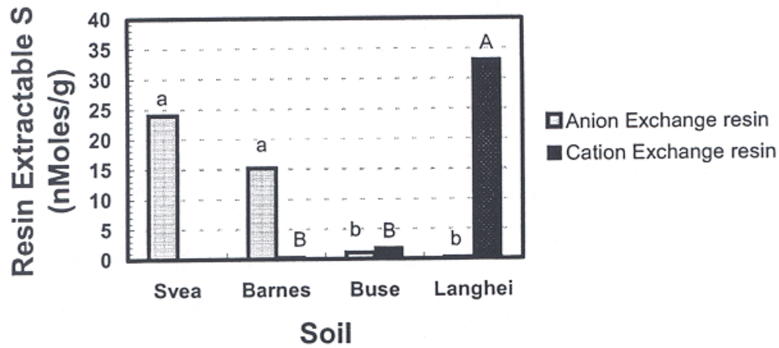

Figure 6 Resin-extractable S obtained on cation and anion exchange resins for four soils in the northern Great Plains of north America. Columns within an ionic form with different letters at the top indicate measurably different amounts of ions ($p = 0.05$). Note: No S was obtained on the cation exchange resin of the Svea soil.

However, as the soil becomes more calcareous and the amount of extractable Ca increases, S is found in larger amounts on the cation exchange resin. For the Langhei soil, over 99% of the S is found on cation exchange resin of the Langhei soil. If anion uptake through plant roots requires that the anions be independent of associated cations, then plants grown on the Buse and Langhei soils may experience a S deficiency. Calcium sulfate is rather insoluble, and the total supply of S to roots of plants grown in soils rich in exchangeable Ca may show evidence of S insufficiency even in the presence of rather large amounts of easily extractable S. Bly *et al.* (2001) have observed apparent S deficiency symptoms and responses to S fertilizer in this region. The Buse soil contains the least total resin-extractable S and about 60% was extracted on the cation exchange resin.

Among the oxyanions, P showed the least amounts of adsorption by the cation exchange resins. Generally, P was weakly correlated with bicarbonate extractable P ($p < 0.05$). However, for the Barnes soil, two distinct populations of samples were apparent (Figure 7). Resin extractable P from the Langhei soil showed almost no correlation with bicarbonate extractable P and showed a relationship much like the Barnes soils (Figure 7, solid symbols). The Svea was rather rich in resin extractable P (data not shown). The Buse soils showed responses similar to the Barnes soils (Figure 7 open symbols; data not shown). Thus, application of P may be economically beneficial in several soils even when conventional soil tests suggest that this element is present in adequate amounts. In the presence of very large amounts of resin-extractable Ca, band applications of fertilizer P (and other elements) may effect more efficient use of nutrients than broadcast applications.

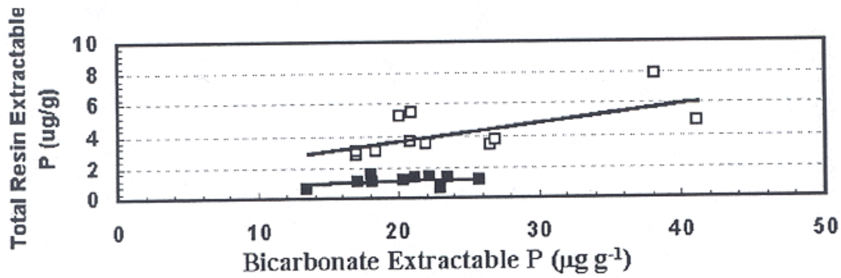

Figure 7 Resin-extractable P correlation with bicarbonate extractable P for the Barnes soil in the Barnes-Buse mapping region. The open symbols show a strong relationship between resin-extractable P and bicarbonate extractable P; the closed symbols show almost no relationship between the two types of extractions. Two points with > 10 µg resin-extractable P g^{-1} of soil were omitted; they had recently received manure applications.

Conclusions

Resin-extraction of the surface horizons of four soils in the north central Great Plains of the US revealed unique chemical characteristics of the suite of ions easily removed from the soil. Conventional analyses of soil fail to reveal subtle features that undoubtedly affect crop yield. Some soils have rather modest amounts of resin-extractable nutrient anions. In other soils, nutrient anions may be present in large amounts but they are complexed with overwhelming amounts of readily extractable cations. In both cases, fertilization with nutrient anions may effect economic yield increases. Also, concentrated band applications of nutrients may effect more efficient use of fertilizers in these soils.

Extractable suites of ions remained rather constant relative to their respective mapping units throughout the region and this suggests that current soil maps will have value in identifying potential management strategies and genotype selection. Concentrations of resin-extractable elements increased from an east to west and south to north distance. These changes are consistent with general climatic and much earlier patterns of glaciation.

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