Four Northern Great Plains Soils: Their Unique Chemical Signatures

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Abstract:

Most soils in the Northern Great Plains are managed as if little variation occurred within the landscape. The current study was undertaken to determine the chemical nature of four soils in Western Minnesota, Eastern South Dakota, and Central and Eastern North Dakota. A Resin extraction technique was applied to samples of four adjacent soils (Barnes, Buse, Langhei, and Svea) collected on 23 sites. Extracts were analyzed for 20 elements by inductively coupled plasma. Samples were also subjected to conventional analyses for available P, K, total and inorganic C, total N and pH. Conventional soil analyses showed little differences between soils; they were generally rich in available P, and K. The Barnes, Buse and Svea soils were relatively rich in organic C and N. The pH values followed the order Svea = Barnes < Buse < Langhei. Resin extractions provided some unexpected results. As a consequence of complexes with exceptionally large amounts of Ca and Mg in the Langhei soil, more than 90 % of the resin extractable anions such as S and B were extracted with cationic resins. Bicarbonate extractable P was often correlated with resin extractable P with the exception of the Langhei soil for which no relationship was observed. The characteristics of these soils that were revealed by resin

extraction point to management options for each soil such as fertilizer placement and composition.

Introduction:

Conservation of soil has long concentrated on preserving the physical properties and maintaining the soil in its place of origin. However, soils also have unique chemical and biological characteristics that are often ignored. Some insights to their chemical character are described in the National Soil Survey http://soils.usda.gov/classification/main.htm.

In spite of the fact that inventories have been developed and differences in soils have been identified, most land managers apply a uniform set of practices (tillage, fertilizer forms and rates, etc.) to the land in support of crop production. Partly as a consequence, the original uniqueness of some soils has been compromised through excessive erosion or fertilization, particularly with livestock manures.

Most previous evaluations of soils have focused on gross chemical characteristics such as total organic carbon, cation exchange capacity, pH, and one or two elemental determinations. However, the subtle nature of soil chemistry lies in the range and variety of elements that are relatively easily displaced. The factors that most directly affect plant growth are the forms and concentrations of elements that are easily displaced. These easily displaced elements are most accurately assessed using an ion-exchange type of extraction which allows a fraction of the soil elements to be exchanged for an element from a homogeneously saturated exchange resin.

The subtlety of the chemical character of soils is shown here in the data obtained from a study of four Northern Great Plains soils.

Approach:

Four soils were selected for sampling and evaluation; Barnes (fine-loamy, mixed, superactive, frigid Calcic Hapludolls), Buse (fine-loamy, mixed, superactive, frigid Typic Calciudolls), Langhei (fine-loamy, mixed, superactive, frigid Typic Eutrudepts) or Svea (fine-loamy, mixed, superactive, frigid Pachic Hapludolls; Soil Survey Division, 2001). Langhei soils are located on convex slopes of 2 to 55 % (14 % typical) whereas and Svea soils often occupy concave slope (< 2% typical) positions. Barnes soils are located at the crest of the knolls and Buse soils are often in close association with the Barnes soils. Twenty three sites were selected in North Dakota, South Dakota and Minnesota (Fig. 1). Typical profiles of each soil are shown in Fig. 2. Soil samples were taken manually with a 2.54 cm diameter Hoffer tube.
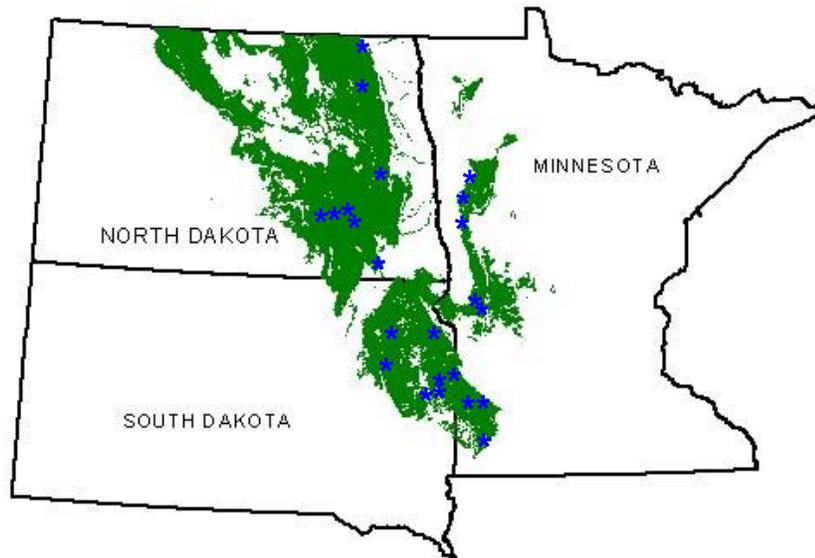
Fig. 1. The location of the Barnes-Buse and associated soils in the Northern Great Plains. The stars are sites at which soil samples were obtained for resin-extraction of readily available ions.

The A (surface) or Ap (surface mixed due to tillage) horizons were extracted using the method of Olness and Rinke (1994) modified to include 20 % ethanol in the extraction solution (Olness et al., 1999). Extracts were analyzed by inductively coupled plasma-atomic emission spectroscopy at the analytical research laboratory of the University of Minnesota at St. Paul. Data were logarithmically transformed to obtain normal distributions and then analyzed using SAS PROC GLM and ANOVA procedures (SAS Insitute, 1989).
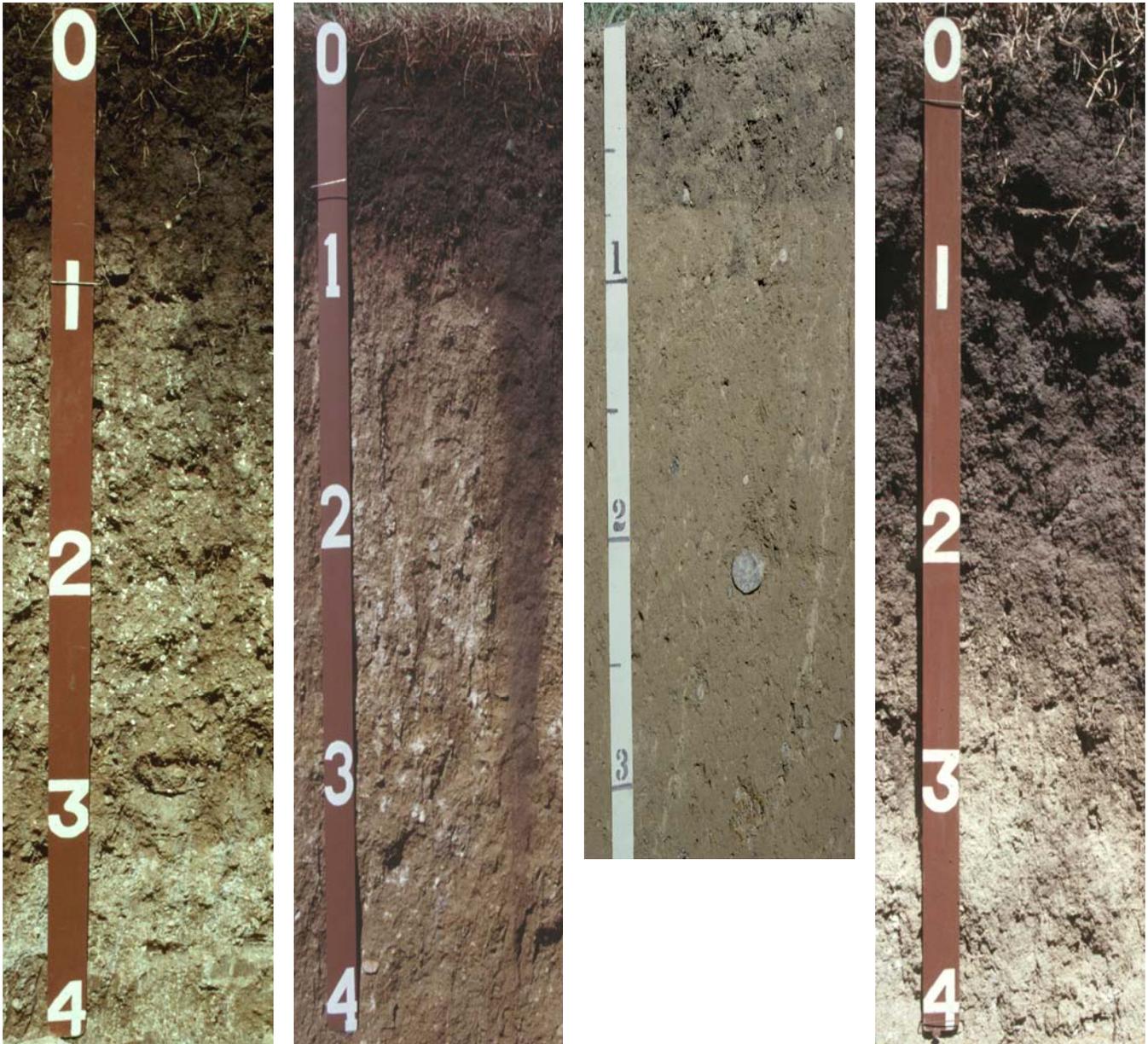
Fig. 2. Typical profiles of the Barnes (far left), Buse (second from the left), Langhei (second from the right) and Svea (far right) loam soils.

Particle size analyses were conducted using the Bouyoucos hydrometer sedimentation method (Gee and Bauder, 1996) without peroxide oxidation. Extractable P was determined with the bicarbonate method (Kuo, 1996) and extractable K was determined using the ammonium acetate method (Helmke and Sparks, 1996). Total carbon was determined through ignition and infrared detection using a LECO CN2000 furnace (LECO, 1994 a and b). Inorganic carbon was determined using the modified pressure calcimeter method of Wagner et al. (1998). Soil pH values were determined on a 2:1 soil water paste (Thomas, 1996).

Observations:

Conventional methods of soil examination suggest that the soils selected for this study are rather uniform. For example, the pH values vary from about 6.76 to about 8.03 (Table 1). Total bicarbonate extractable phosphorus ranged from about 14.1µg g^{-1} in the Langhei soil to about 24.9 µg g^{-1} in the Svea soil; these values are considered adequate for most crop production in the region (Dahnke et al., 1992; Gelderman and Gerwing et al., 1998). Ammonium acetate extractable potassium levels, 192 to 248 µg g^{-1}, exceeded the levels at which fertilizer additions would be recommended. Organic carbon contents in the Svea, Barnes, and Buse soils were not measurably different and ranged from about 2.49 to 3.51 %; organic carbon contents in the Langhei soil are measurably less than in the other three soils at 1.06 %.

Table 1. Selected chemical characteristics of A/Ap horizons of Barnes, Buse, Langhei and Svea soils[†].

Soil	pH	Extractable		Carbon		
		P	K	Total	Inorganic	Organic
		-------- μg g^{-1} --------		-------------------- % -------------------		
Svea	6.76 c	24.9 a	248	3.51	0.05	3.51 a
Barnes	7.33 b	22.3 ab	275	2.90	0.13	2.77 a
Buse	7.75 a	19.2 bc	284	3.36	0.86	2.49 a
Langhei	8.03 a	14.1 c	192	3.30	2.23	1.06 b

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

Under most conditions, we might expect that elements existing as anions such as sulfate and borate would be found only on anion exchange resins and cations such as potassium, calcium, magnesium and lithium would be found exclusively on cation exchange resins. Such a situation holds true for the Svea soils where all sulfate and borate is extracted on the anion exchange resin (Table 2). However, as the soil pH increases, larger and larger amounts of sulfur and boron are extracted with the cation exchange resins. In fact, nearly 99 % of the total readily extractable sulfur and 85 % of the boron in the Langhei soil is extracted on the cation exchange resin. Further, the Buse soils contained little readily extractable sulfur and 60 % of this amount was found on the cation exchange resins.

Table 2. Anions extractable with resins from A/Ap horizons of Svea, Barnes, Buse, and Langhei soils.

Soil	Boron		Sulfur		Phosphorus	
resin =	anion	cation	anion	cation	anion	cation
	--- nmol g^{-1} ---					
Svea	0.184 b	0.000 d	24 a	0.00 c	57 a	0.40 a
Barnes	0.287 a	0.131 c	15 a	0.38 c	77 a	0.42 a
Buse	0.391 a	0.455 b	1.0 b	1.6 b	32 b	0.94 a
Langhei	0.469 a	2.349 a	0.23 c	33 a	11 c	4.3 a

[†] Within columns, values followed by the same letter are not measurably different ($p < 0.05$).

The explanation for the large amounts of 'traditional' anions appearing on cation exchange resins becomes apparent when we examine the amounts of cations extracted. The Svea soil has the least amounts of extractable cations and > 99 % are extracted on the cation exchange resins (Table 3). The amounts of easily extractable calcium and magnesium in the Langhei soil exceeds the amounts of economically important anions by more than 1000 to 1; apparently, these cations are forming positively charged complexes with the anions and carrying them to the cation exchange resins.

Table 3. Cations extractable with resins from A/Ap horizons of Svea, Barnes, Buse, and Langhei soils.

Soil	Potassium			Magnesium			Calcium		
resin =	anion	cation		anion	cation		anion	cation	
	--- nmol g^{-1} -------------------------------------								
Svea	0.106 b	421 c		1.11 b	108 d		0.059 c	148 d	
Barnes	0.211 ab	702 b		1.36 b	361 c		1.62 b	592 c	
Buse	0.320 ab	1030 a		2.04 ab	2130 b		2.56 b	8,320 b	
Langhei	3.30 a	459 c		14.0 a	5380 a		165 a	27,900 a	

[†] Within columns, values followed by the same letter are not measurably different ($p < 0.05$).

As a general rule, crop producers manage heterogeneous landscapes to maximize returns from the land resource without regard to subtle features of the soil. This often results in soils with adequate amounts of fertilizers receiving more nutrient than is needed to meet crop needs and soils with inadequate levels of fertility receiving less nutrient than is needed to meet potential demand.

In this region, most soils have rather high levels of phosphorus and adequate amounts of sulfur and boron. Still, both the Buse and Langhei soils would be candidates for examination of sulfur adequacy. While conventional techniques might identify a sulfur deficiency in the Buse soil they would certainly miss the complexation that is apparent. It is unclear whether complex formation of sulfur actually inhibits plant accumulation. If complex formation inhibited plant uptake of sulfur and the total resin extractable amounts were correlated with conventional methods of assessment, then

conventional methods would be unable to identify a sulfur deficiency. The extent to which complex formation affects nutrient availability is unclear at this point. What is clear is that conventional methods of soil evaluation are unable to identify these complex interactions and they only marginally adequate for suggesting a management strategy to mitigate the effects of complex formation on nutrient availability to plants.

Summary:

Soils lying immediately adjacent to each other in the landscape of the Northern Great Plains have large but subtle differences in the amounts of extractable elements that can be obtained with resin extraction techniques. Resin extraction permits the identification of complex interactions that impact fertilization management practices such as method of application and composition of the fertilizer itself.

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