CHEMICAL AND PHYSICAL PROPERTIES OF SELECTED SOILS IN CHARLES MIX COUNTY, SOUTH DAKOTA

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ABSTRACT

The Lake Andes-Wagner/Marty (LAW/M) proposed irrigation project (16,000 ha; 40,000 ac) area in south-central South Dakota contains soils with high electrical conductivity (EC) and selenium (Se) levels. A field study of the LAW/M project area was conducted during 1993 and 1994 to define the magnitude of EC and Se concentrations in soils derived from glacial till and collapsed drift geologic materials.

No statistical differences in Se concentrations were found between the geologic materials. Total Se concentrations increased significantly with soil profile depth, with average concentrations increasing from 929 ppb at the soil surface (0.0 to 0.5 m; 0.0 to 1.6 ft) to 1684 ppb at the 2.0- to 3.0-m (6.6- to 9.9-ft) depth. Readily available Se concentrations (has potential to move with water) also increased significantly with depth and varied from 72 ppb at the surface to 662 ppb at the lower depth, a nine-fold increase.

EC values varied significantly from 1.4 dS m^{-1} at the soil surface to 6.1 dS m^{-1} at the 1.0- to 3.0-m (6.6- to 9.9-ft) depth, with similar values for both geologic materials. However, sodium adsorption ratio (SAR) values were significantly different for the two geologic materials and changed from 1.1 and 2.4 for the top 0.5 m (1.6 ft) of the soil profile to 3.9 and 4.9 at the 2.0- to 3.0-m (3.3- to 9.9-ft) depth for the till and collapsed drift materials, respectively. Selenium concentrations were not correlated with soil EC or percentages of sand, silt, and clay. Soil bulk densities and water holding capacities were measured for four selected soils. Field measured, saturated hydraulic conductivity values had mean values of 1.1 and 3.5 cm h^{-1} (0.43 and 1.38 in h^{-1}) for the till and collapsed drift, respectively.

Keywords

Electrical conductivity (EC), hydraulic conductivity, Lake Andes-Wagner, selenium (Se), sodium adsorption ratio (SAR)

INTRODUCTION

Impacts of non-point source pollution on receiving waters are a critical issue facing irrigated agriculture. Several national organizations such as the U. S. Committee on Irrigation and Drainage (Summers and Anderson, 1986) and the National Research Council (1989) have specifically addressed irrigation water quality issues and acknowledged the establishment of a new paradigm regarding the utilization and maintenance of our natural resources.

Irrigation-induced selenium (Se) problems at the Kesterson National Wildlife Refuge in central California during the early 1980s focused the attention of the public on an interaction between irrigated agriculture and water quality in downstream terminal water bodies (Letey et al., 1986). Selenium contamination received the spotlight because of its negative impact on wildlife. Soluble Se moves with soil water and often exits an irrigated area with subsurface drainage waters. Therefore, drainage return flows can pose a Se quality problem to receiving waters.

The Lake Andes-Wagner/Marty II (LAW/M) Project (Bureau of Reclamation, 1985) is a proposed 16,000-ha (40,000-acre) irrigation project in south-central South Dakota (Figure 1). The project area is located adjacent to and east of the Missouri River where the river becomes the border between Nebraska and South Dakota. Previous drainage investigations of the Project area indicated that most of the irrigated Project lands will require subsurface (closed) drains to provide favorable soil water and salt balances for sustained irrigated conditions. In addition, Se has been detected in Project soils (Wilson et al., 1990; Doolittle

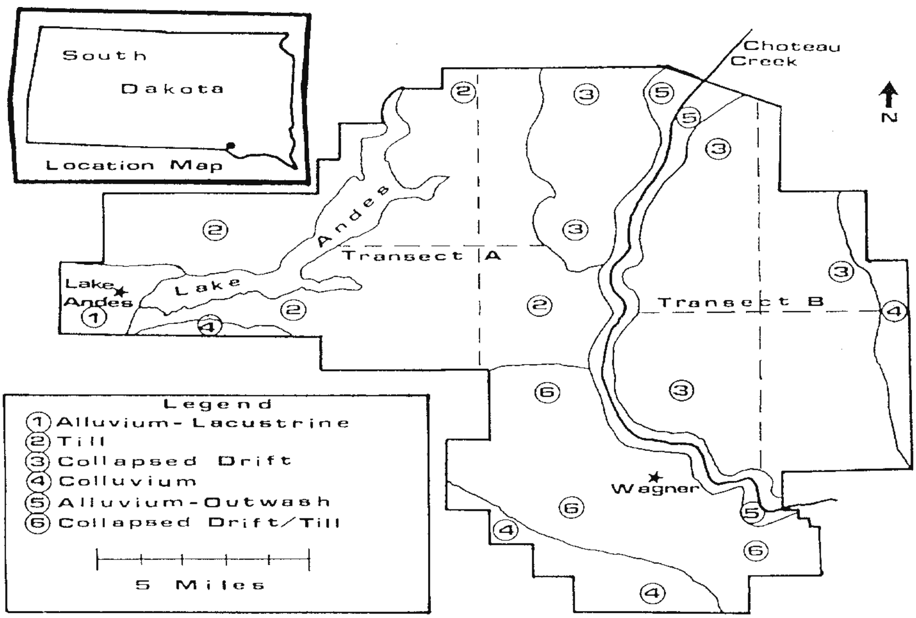

Figure 1. Location of geological materials within the boundaries of the Lake Andes-Wagner Project area and the two soil sample transects used in the field investigation.

et al., 1995). Hence, questions regarding the quality of return flows from the proposed LAW/M project area can affect the viability of the project.

A field study was initiated in 1993 to assess selected chemical and physical characteristics of LAW/M Project area soils. Specific objectives of the study were to:

1. Measure selected chemical characteristics (available, conditionally available, and total Se, electrical conductivity (EC), sodium adsorption ratios (SAR), and pH) of Lake Andes-Wagner/Marty Project area soils, and

2. Measure selected physical characteristics (bulk density, soil water holding capacity, and hydraulic conductivity) of selected Lake Andes-Wagner/Marty Project soils.

METHODS

Soil samples were collected along two orthogonal transects as illustrated in Figure 1. Each orthogonal transect consisted of east-west and north-south components. Transect A was positioned in the till area west of Choteau Creek and Transect B was located east of Choteau Creek in collapsed drift geologic material. Soil samples were collected at sites about every 0.2 km (1/8 mile) along the transects. Transect A contained a total of 131 sample sites with 72 sites (14.3 km, 8 7/8 miles) in the north-south direction and 59 sites (11.8 km, 7 1/4 miles) in the east-west direction, while Transect B had a total of 133 sample sites with 83 sites (16.7 km, 10 3/8 miles) in the north-south direction and 50 sites (9.9 km, 6 1/8 miles) in the east-west direction.

Four soil sample depths were used in the investigation: 0.0 to 0.5 m, 0.5 to 1.0 m, 1.0 to 2.0 m, and 2.0 to 3.0 m (0.0 to 1.6 ft, 1.6 to 3.3 ft, 3.3 to 6.6 ft, and 6.6 to 9.9 ft). Soil samples were collected with a Giddings hydraulic soil coring probe and a 76-mm (3-in) diameter core tube to a depth of 1.0 m (3.3 ft). A 51-mm (2-in) diameter core tube was used for the 1.0- to 2.0-m depth (3.3- to 6.6-ft) and a 41-mm (1.6-in) diameter core tube was used for the 2.0- to 3.0-m (6.6- to 9.9-ft) depth.

Selenium (Se) analyses were grouped into three operationally defined fractions (available, conditionally available, and unavailable Se) (Chao and Sanzolene, 1989). Available Se and conditionally available Se were extracted from the same soil sample. Available Se was defined as 0.1 $\underline{M}$ KH_2PO_4 extractable and includes the H_2O-soluble and nonspecifically adsorbed selenate and the exchangeable, specifically adsorbed selenite. Conditionally available Se was defined as 4$\underline{M}$ HCL-extractable, which is the Se associated with oxide minerals (Fe, Mn, and Al), amorphous minerals, carbonates, acid-volatile sulfides, and acid-hydrolyzable organic matter. The Se in this fraction is not readily available; however, it has the potential to become available with changes in pH or redox potential. Total Se was determined from a separate sample using a mixed acid digestion (Briggs and Crock, 1986). Unavailable Se was calculated as the difference between total Se and the sum of the available and conditionally available Se.

Electrical conductivity (EC) values were determined by a method presented by Rhoades (1982). Likewise, sodium adsorption ratio (SAR) values were determined by standard laboratory methods given by Rhoades (1982).

Soil water retention data were collected from two sample sites of a Highmore silt loam (Fine-silty, mixed, superactive, mesic Typic Argiustolls), one site of an Ethan loam (Fine-loamy, mixed, superactive, mesic Typic Calciustolls), and one site of an Eakin silt loam (Fine-silty, mixed, superactive, mesic Typic Argiustolls) that were located in the collapsed drift material east of Choteau Creek. Soil classification details were provided by the Natural Resources Conservation Service (Soil Survey Staff, 2004). Undisturbed soil cores 39-mm (1.5-in) in diameter and 14-mm (0.55-in) high, except those below the 2.0-m (6.6-ft) depth, which were 29-mm (1.1-in) in diameter and 16-mm (0.63-in) high, were used in the study. Soil textures were determined by using the USDA soil texture classification system and the hydrometer method to define the clay fraction (Gee and Bauder, 1986). Bulk density was determined by the core method using the Giddings hydraulic probe soil samples (Blake and Hartge, 1986). An Eijkelkamp tension table was used to determine soil water contents for matric potentials equal to or greater than -0.01 MPa (-0.1 bar) and a pressure plate apparatus was used for matrix potential values from -0.02 to -1.5 MPa (-0.2 to -15.0 bars) (Klute, 1986). Field measurements of saturated soil hydraulic conductivities were made by Bureau of Reclamation engineers using pump-in, pump-out and piezometer test procedures (Bureau of Reclamation, 1978) and were reported as weighted values (Bureau of Reclamation, 1985). The till and collapsed drift data sets contained 77 and 65 values, respectively.

All statistical analyses were conducted using a SAS Institute (1999) computer program and a statistical significance of $P \leq 0.05$.

RESULTS AND DISCUSSION

Chemical Properties

Selenium. A summary of Se concentration values for both the till and collapsed drift materials is presented in Table 1. An analysis of the Se data sets disclosed that "outlier" data values in all of the data sets were responsible for the large standard deviation values. For example, the removal of five data values (about 2 % of the 264 total data set values) reduced the overall Se mean value of the readily available data set from 72 to 54 ppb and the standard deviation from 134 to 29 ppb. Maximum values of 974 and 1766 ppb Se (about 13 and 25 times the mean Se value) in the till and drift data sets, respectively, greatly impacted the statistics of the data sets. These large or "outlier" data values were removed from the data sets used in a companion paper (DeBoer, 2005), but all data values were kept in the data sets used in this reported paper. Thus, most of the mean and standard deviation values are different from each other in the two papers.

An ANOVA showed that all till material means were not statistically different from all collapsed drift means because of relatively large standard deviations associated with the data sets. However, total Se concentrations significantly increased with depth in the profile, as shown in Table 2. Total Se concentration values ranged from 929 ppb for the top sample depth to 1684 ppb at the deepest

Table 1. Statistical summary of selenium (Se) concentrations (ppb) for the till and collapsed drift geologic materials.

	Readily Available		Conditionally Available		Unavailable		Total	
	Mean (Standard Dev)		Mean (Standard Dev)		Mean (Standard Dev)		Mean (Standard Dev)	
Depth (m)	Till	Collapsed Drift	Till	Collapsed Drift	Till	Collapsed Drift	Till	Collapsed Drift
0.0 - 0.5	73	71	224	260	666	562	963	894
	(110)	(153)	(154)	(101)	(306)	(257)	(427)	(336)
0.5 - 1.0	306	211	408	440	318	314	1033	965
	(673)	(417)	(359)	(272)	(236)	(237)	(971)	(631)
1.0 - 2.0	693	501	572	567	217	278	1482	1346
	(1132)	(740)	(370)	(410)	(294)	(604)	(1414)	(1228)
2.0 - 3.0	689	634	742	735	263	305	1694	1674
	(965)	(1073)	(494)	(525)	(254)	(305)	(1330)	(1410)
0.0 - 3.0	524	425	544	550	324	340	1391	1316
	(727)	(615)	(300)	(290)	(151)	(247)	(977)	(900)

Each till and collapsed drift value represents 131 and 133 data values, respectively.

Table 2. ANOVA results for the selenium (Se) data sets.

	Readily available Se		Conditionally available Se		Unavailable Se		Total Se	
Depth (m)	Mean (ppb)	Significance-Group[a]	Mean (ppb)	Significance-Group[a]	Mean (ppb)	Significance-Group[a]	Mean (ppb)	Significance-Group[a]
0.0 - 0.5	72	A	242	A	614	A	929	A
0.5 - 1.0	259	B	424	B	316	B	999	A
1.0 - 2.0	597	C	570	C	248	C	1414	B
2.0 - 3.0	662	C	739	D	284	B C	1684	C
0.0 - 3.0	475		547		332		1354	

[a] Means (each derived from 264 data values) with the same letters are not different from each other.

depth, a two-fold increase. No significant difference was detected between means of the top two depths but means of the top two depths were different from means of the lower two depths.

Readily available Se concentrations also increased significantly with depth for both geologic materials with mean readily available concentrations increasing from 72 to 662 ppb, a nine-fold increase (Table 2). The 72 ppb mean for the 0.0-0.5 m (0.0-1.6 ft) depth was significantly different from the other three depths and the 259 ppb mean for the 0.5-1.0 m (1.6-3.3 ft) depth was also significantly different from the other three depths, but there was no difference between the 597 and 662 ppb values for the two lower depths.

Conditionally available Se concentrations also increased significantly with depth where the mean concentrations varied from 242 ppb for the 0.0- to 0.5-m (0.0- to 1.6-ft) depth to 739 ppb for the 2.0- to 3.0-m (6.6- to 9.9-ft) depth, a three-fold increase (Table 2). All four depths had significantly different mean values. It appears that readily and conditionally available Se fractions have eluviated from the upper one meter of the soil profile to lower depths over time. Table 2 also shows the decrease in unavailable Se concentrations with depth. Unavailable Se concentrations averaged 614 ppb at the upper depth to 284 ppb at the deepest depth. For practical purposes, one can consider unavailable Se concentrations for the 0.0- to 0.5-m (0.0- to 1.6-ft) depth to be different from values for the 0.5- to 2.0-m (1.6- to 6.6-ft) depth.

Selenium concentration values for a composite (depth weighted) soil profile are also illustrated in Table 2. A representative 3-m soil profile has mean concentrations of 475 ppb (35 %) readily available Se, 547 ppb (40 %) conditionally available Se, 332 ppb (25 %) unavailable Se, and 1354 ppb total Se concentrations.

Further analysis of the Se data sets (Table 2) shows that 8 % of the total Se in the top one-half meter (1.6 ft) of the soil profile is in the readily available form and increases to about 40 % of the total Se concentration for the bottom meter (3.3 ft). Average total Se values of 26 and 42 % would be representative for the 0.5-1.0 m (1.6-3.3 ft) and 1.0-2.0 m (3.3-6.6 ft) depths, respectively. Twelve percent of the readily available Se, 20 % of conditionally available Se, and 47 % of unavailable Se were found in the top one meter (3.3 ft) of the 3-m (9.9-ft) soil profile.

A relationship between readily available Se and total Se concentrations in 3-m (9.9-ft) composite profiles for the combined till and collapsed drift material data sets is illustrated in Figure 2. A quadratic equation ($Y = 0.189X + 9.2*10^{-5}X^2$) with an R^2 value of 0.84 was developed to approximate the relationship. Since the relationship is concaved upward, it is an indication that an increasing percentage of total Se concentration is in the readily available form as total concentrations increase in value. For example, the quadratic relationship indicates a readily available Se value of 281 ppb (28 % of the total) at the 1000 ppb total Se concentration value and a corresponding readily available Se value of 1395 ppb (47 % of the total) for a total Se concentration value of 3000 ppb. A line with a 0.75 slope through the origin can be used to approximate the upper bound for the data set, which means that a maximum of 75 % of the total Se in a 3-m (9.9-ft) soil profile could be in the readily available form.

Spatial variability of total and readily available Se concentrations appear to exhibit random patterns as shown in Figures 3 and 4 for the north to south portion of the transect in the glacial drift material. All Se fraction data sets at all depths had similar spatial patterns. Comparable spatial variability was also found for the drift data sets. Doolittle et al. (1995) found Se spatial dependence varied from 0.9 to 7.5 km (0.56 to 4.67 mi) for the Se data set parameters based on the results of a geostatistical analysis.

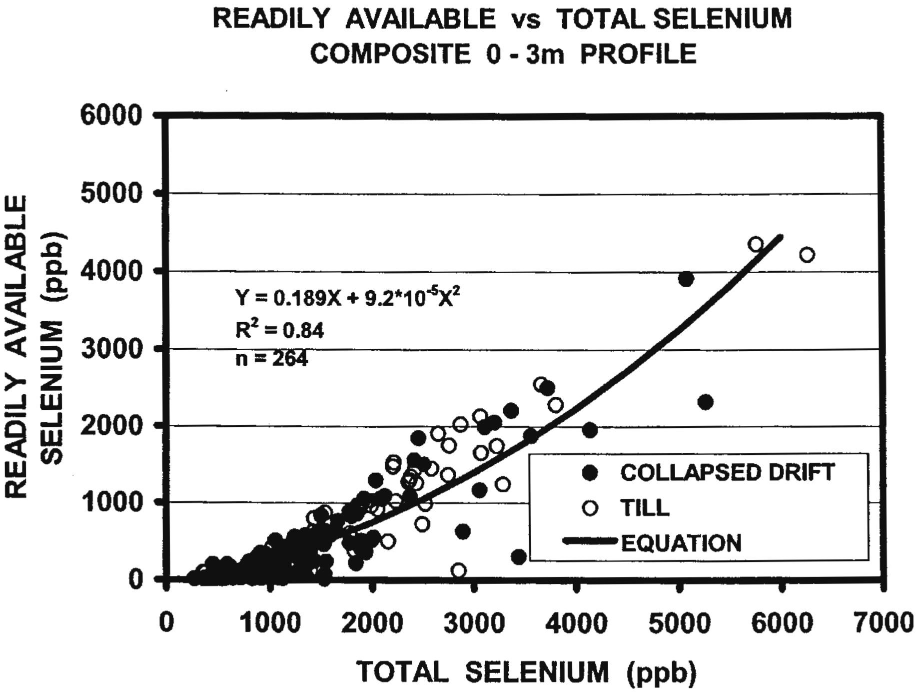

Figure 2. Relationship between readily available and total selenium concentrations for a 3-m composite soil profile and the combined till and collapsed drift glacial material data sets.

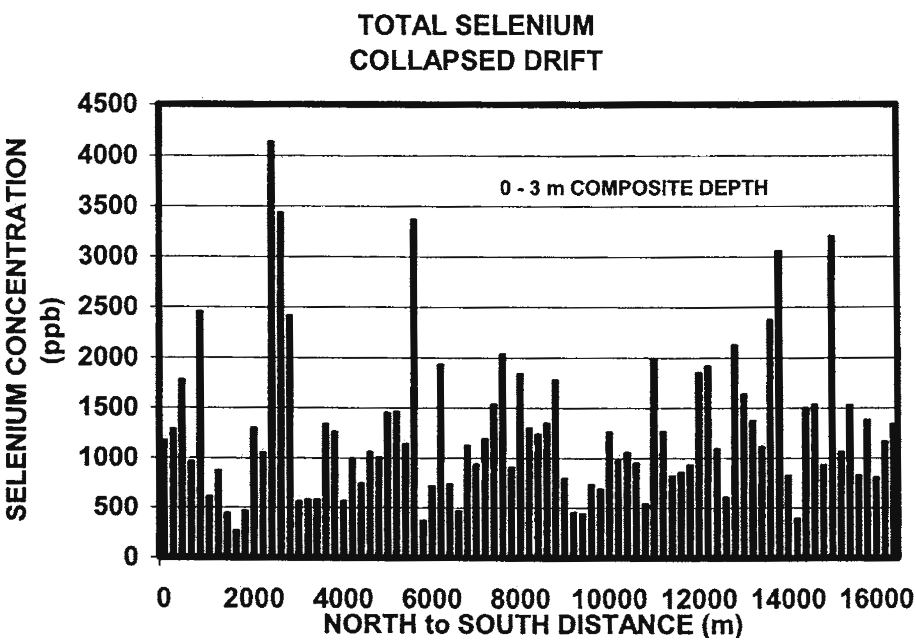

Figure 3. Total selenium concentrations for 3-m composite soil profiles along the north to south leg of the transect in the collapsed drift material.

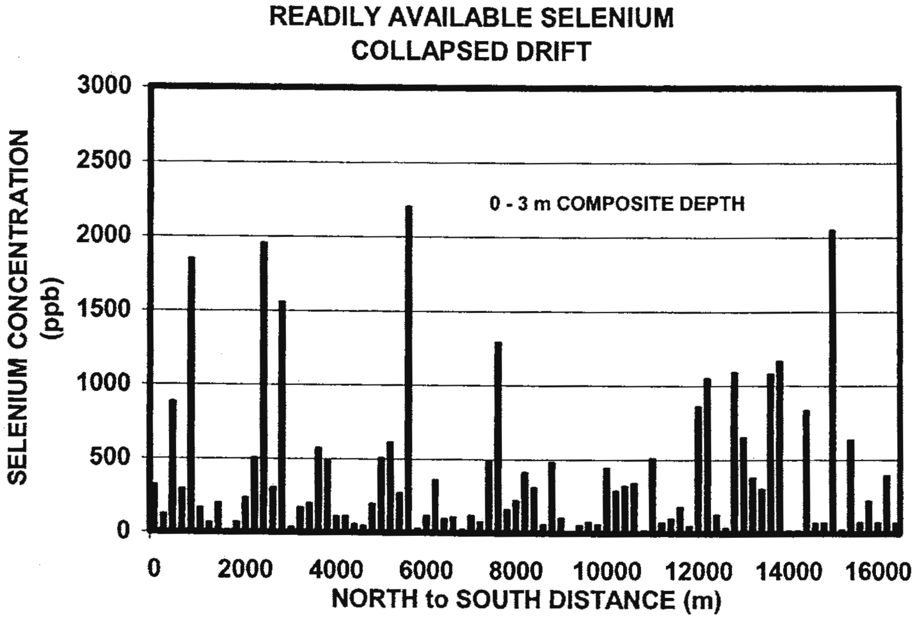

Figure 4. Readily available selenium concentrations for 3-m composite soil profiles along the north to south leg of the transect in the collapsed drift material.

Electrical conductivity. No soil electrical conductivity differences were found between the two geologic materials, with an overall depth-weighted mean value of 5.0 dS m^{-1} for the soil profiles. Soil salinity significantly increased with depth as evidenced by the results of an ANOVA (Table 3) with electrical conductivity values varying from 1.4 dS m^{-1} for the upper soil layer to 6.1 dS m^{-1} for the bottom two meters of the soil profile. Removal of "outlier" data values (DeBoer, 2004) reduced electrical conductivity values for the top soil layer to 1.2 dS m^{-1} but had no influence on the other conductivity values.

Table 3. ANOVA results for electrical conductivity (EC), sodium adsorption ratio (SAR), and pH data sets.

	Electrical conductivity (EC)		Sodium adsorption ratio (SAR)		pH	
Depth (m)	Mean (dS/m)	Significance Group[a]	Mean	Significance Group[a]	Mean	Significance Group[a]
0.0 - 0.5	1.4	A	1.8	A	7.90	A
0.5 - 1.0	4.0	B	2.7	B	7.83	A
1.0 - 2.0	6.1	C	4.2	C	7.68	B
2.0 - 3.0	6.1	C	4.4	C	7.68	B
0.0 - 3.0	5.0		3.6		7.74	

[a] Means (each derived from 264 data values) with the same letters are not different from each other.

Sodium adsorption ratio. Likewise, the sodium adsorption ratio (SAR) also increased with depth for both geologic materials in a manner similar to the electrical conductivity data set (Table 3, Figure 5). However, there was a statistical difference between the data set mean values of 2.7 and 3.9 for the till and collapsed drift materials, respectively. Till SAR values varied from 1.1 for the top depth to 3.9 for the 2.0 to 3.0-m (6.6 to 9.9-ft) depth while collapsed drift values ranged from 2.4 for the 0.0 to 0.5-m (0.0 to 1.6-ft) depth to 4.9 for the lower two depths. A representative 3-m (9.9-ft) soil profile would have depth-weighted mean SAR values of 3.0 and 4.2 for the till and collapsed drift materials, respectively (Figure 5).

pH. The ANOVA of the pH data set showed statistical significance for soil depth, geologic materials, and an interaction between depth and material. Data set mean pH values of 7.81 and 7.72 for till and collapsed drift materials, respectively, were different from each other. Mean values for the top two soil depths were similar to each other as were the bottom two soil depths, but the top two depth values were different from the bottom two depth values (Table 3). The significant interaction was produced by equal values for the top depth but consistently different values for the other three depths. Even though statistically significant differences were found within the pH data set, differences among depths and geologic materials are numerically small.

Readily available Se and EC. An analysis of the correlation between readily available Se and EC for composite (0 to 3-m, 0 to 9.9-ft) or depth-weighted

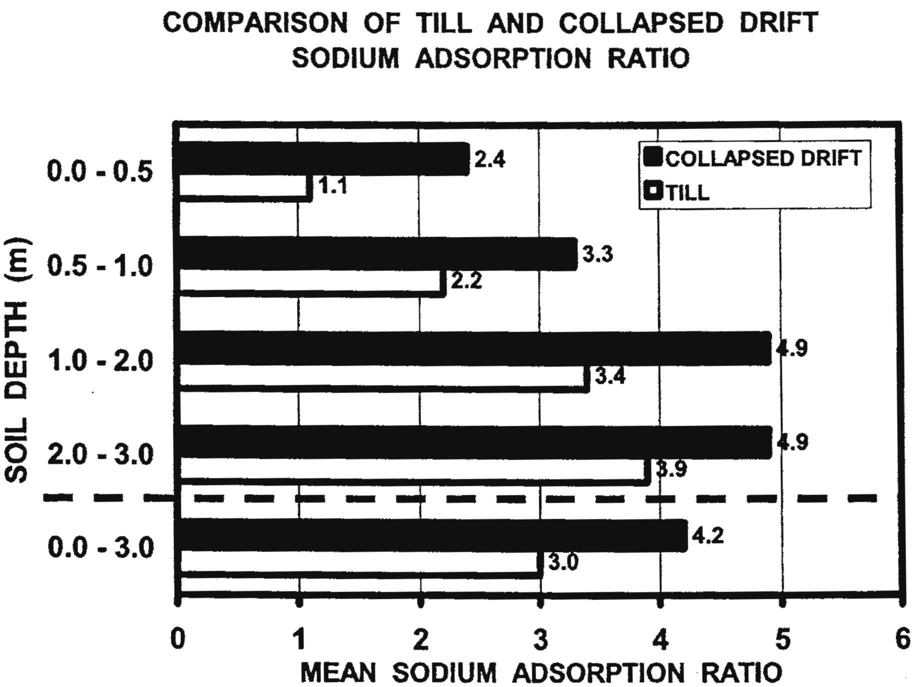

Figure 5. Distribution of sodium adsorption ratio (SAR) values with soil depth and a composite 3-m soil profile for the collapsed drift and till glacial material data sets.

profiles produced a correlation index (R^2) value of 0.37 between the two data sets (Figure 6). Both geologic materials had similar correlation index values of 0.35 and 0.39 for the till and collapsed drift, respectively. A regression analysis produced a relationship ($Y = 17.1X^2$) with an R^2 value of 0.40 for the data set. Readily available Se concentrations tend to be small, less than 250 ppb, when EC values are less than 4 dS m^{-1} for both materials. However, one can expect a wide range of readily available Se concentrations for soils where electrical conductivity values are more than 4 dS m^{-1}. These same trends were evident for the individual soil layers (not shown) as well, except that all Se concentrations were small, mostly less than 250 ppb for the top 0.5-m (1.6-ft) data sets.

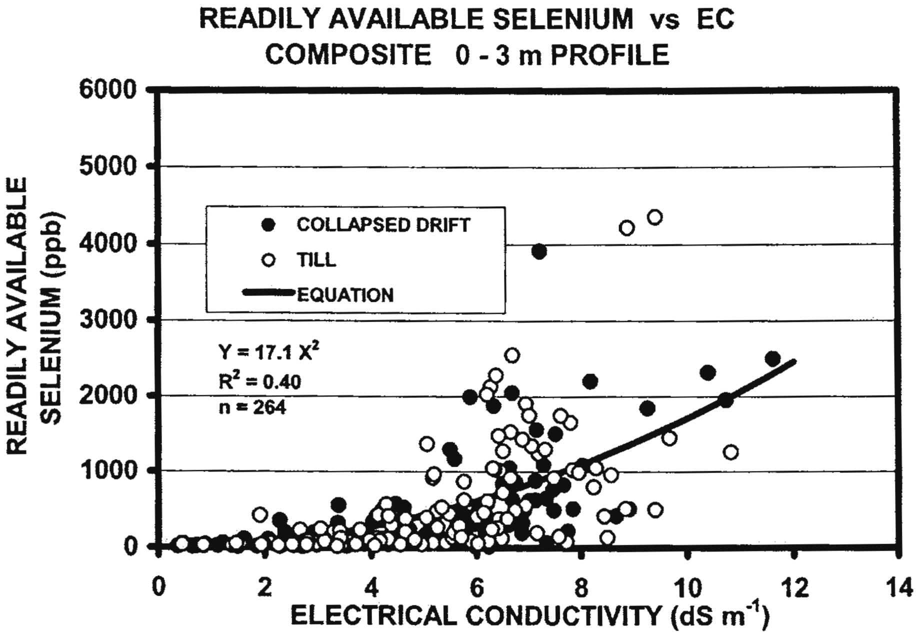

Figure 6. Readily available selenium versus electrical conductivity for a 3-m composite soil profile and the combined till and collapsed drift glacial material data sets.

Physical Properties

Soil texture and Se. One previous study of Se in glacial till in South Dakota (Searight and Moxon, 1945) implied that the silt fraction could represent that portion of the soil particle spectrum that would contain the largest percentage of Se. A textural analysis was completed for soil samples taken from the 2.0- to 3.0-m (6.6- to 9.9-ft) depth in the collapsed drift region. This sample depth was below any vertical clay illuviation associated with normal soil genesis and was assumed to be representative of soil parent material.

Correlations between total Se concentrations and percent sand, silt, and clay were investigated (Table 4). No useful correlations, with R^2 values ranging from -0.04 for sand to 0.02 for clay, were found for the total Se data set. An analysis of the read-

Table 4. Correlation index (R^2) values between total and readily available selenium and sand, silt, and clay percentages.

	Sand %	Silt %	Clay %
Total selenium	-0.04 (n = 57)	0.02 (n = 59)	0.02 (n = 59)
Readily available selenium	-0.04 (n = 56)	0.02 (n = 59)	0.01 (n = 59)

ily available Se data set produced similar results for the relationship between readily available Se concentrations and sand, silt, and clay percentages (Table 4).

Bulk density. Bulk density values for four soil sites were representative of a normal agricultural soil (Figure 7). Line discontinuities represent soil samples that were used for other components of the physical properties analysis. The Highmore silt loams exhibit an increase in bulk density between the 60- and 100-cm (24- and 40- in) depths while the Eakin silt loam displays a similar increase between the 30- and 90-cm (12- and 36- in) depths. The Ethan loam site did not exhibit this characteristic. Bulk density values varied from about 1.4 to 1.6 g cm^{-3} for depths ranging from 50 to 290 cm (20 to 115 in).

Soil water retention. Soil water retention data were collected from two different Highmore silt loam sites, one Ethan loam site, and one Eakin silt loam site in the collapsed drift material. A maximum of seven replicates was collected at each site. If available soil water can be defined as that portion between -0.02 and -1.5 MPa, available soil water in the top 90 cm (3 ft) of the profile averaged 9 and 13 % for the Highmore sites, 16 % for the Ethan site, and 17 % for the Eakin site (Table 5). For till of such texture, expected available soil water contents would be between 15 and 19 %. The Ethan and Eakin values are reasonable but the Highmore values appear to be low and should be checked under field conditions.

Saturated hydraulic conductivity. There was a significant difference be-

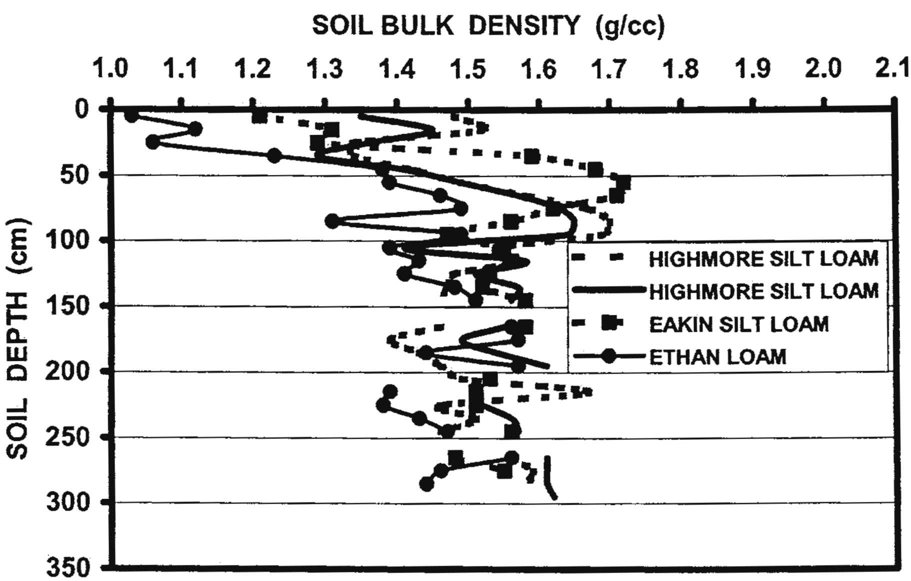

Figure 7. Soil bulk density versus soil depth for four selected soils.

Table Table 5. Available water holding capacities as a function of soil depth for four single soil sites.

	Highmore silt loam #1	Highmore silt loam #2	Ethan loam	Eakin silt loam
Depth (cm)	**Percent by volume**	**Percent by volume**	**Percent by volume**	**Percent by volume**
5 - 15	10.6	9.9	13.8	19.5
20 - 30	14.2	10.5	12.1	18.7
50 - 60	13.9	7.6	19.7	14.3
80 - 90	12.7	8.1	19.0	17.2
150 - 160	13.1	6.6	14.0	13.4
250 - 260	16.4	16.5		17.3

tween the conductivities of the till and collapsed drift materials with mean values of 1.1 and 3.5 cm h^{-1} for the till and collapsed drift, geologic materials, respectively. There also was a greater range of conductivity values for the collapsed drift which had a maximum value of about 10 cm h^{-1} in contrast to a maximum value of about 5.0 cm h^{-1} for the till material. Standard deviations of the hydraulic conductivity data sets were 3.5 cm h^{-1} for the collapsed drift material and 1.1 cm h^{-1} for the till material. A companion paper (DeBoer, 2005) contains parameter values for log-normal probability density functions that can be used to describe the magnitude and frequency of hydraulic conductivity values.

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LITERATURE CITED

Blake, G.R. and K.H. Hartge. 1986. Bulk density. p 363-375. In: A. Klute (ed.) Methods of soil analyses, Part 1. Physical and mineralogical methods. Agronomy Monograph No. 9. Am. Soc. of Agronomy, Madison, WI.

Briggs, P.H. and J.G. Crock. 1986. Automated determination of total selenium in rocks, soils and plants. US Geological Survey Open-File Report 86-40. Washington, DC.

Chao, T.T. and R.F. Sanzolene. 1989. Fractionation of soil selenium by sequential partial dissolution. Soil Sci. Soc. Am. J. 53:385-392.

Bureau of Reclamation. 1978. Drainage Manual. U.S. Department of the Interior. US Govt. Printing Office, Washington, DC.

Bureau of Reclamation. 1985. Lake Andes-Wagner Unit planning report/draft environmental statement: Appendix G - Drainage. U.S. Department of the Interior, Upper Missouri Region, Billings, MT.

DeBoer, D.W. 2005. Probability functions for some South Dakota soil properties. Proc. of SD Academy of Sci.

Doolittle, J.J., X. Huang and A.G. Bly. 1995. The spatial variability of selenium in selected soils of Charles Mix County, South Dakota. Proc. of SD Academy of Sci. 74:113-122.

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. p 383-411. In: A. Klute (ed.) Methods of soil analyses, Part 1. Physical and mineralogical methods. Agronomy Monograph No. 9. Am. Soc. of Agronomy, Madison, WI.

Klute, A. 1986. Water retention: laboratory methods. p 635-662. In: A. Klute (ed.) Methods of soil analyses, Part 1. Physical and mineralogical methods. Agronomy Monograph No. 9. Am. Soc. of Agronomy, Madison, WI.

Letey, J., C. Roberts, M. Penberth and C. Vasek. 1986. An agricultural dilemma: drainage water and toxics disposal in the San Joaquin Valley. Calif. Agr. Expt. Sta. Spec. Pub. 3319. Univ. of Calif., Riverside, CA.

National Research Council. 1989. Irrigation-induced water quality problems. National Academy Press. Washington, D. C.

Rhoades, J.D. 1982. Soluble salts. p 167-179. In: A.L. Page et al. (ed.) Methods of soil analysis, Part 2. Chemical and microbial properties. Agronomy Monograph No. 9. Am. Soc. of Agronomy, Madison, WI.

SAS Institute. 1999. The SAS System for Windows, Version 8. SAS Institute, Inc. Cary, NC

Searight, W.V. and A.L. Moxon. 1945. Selenium in glacial and associated deposits. Agr. Expt. Sta. SD State College, Brookings, SD. Tech. Bul. 5. 33p

Soil Survey Staff. 2004. Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available URL: *http://soils.usda.gov/soils/technical /classification/osd/index.html.*

Summers, J. B. and S. S. Anderson (ed). 1986. Toxic substances in agricultural water supply and drainage. US Comm. Irrig. and Drain., Denver, CO.

Wilson, S. A., R. C. Severson, K. R. Kennedy, A. R. Shinneman and S. A. Kinney. 1990. Total and extractable selenium in soils from the Lake Andes-Wagner irrigation area, South Dakota. Open File Report 90-52. USDI, Geological Survey, Washington, DC.