United States Department of Agriculture

Natural Resources Conservation Service

11 Campus Boulevard, Suite 200 Newtown Square, PA 19073

Subject: Soil - Geophysical Assistance

Date: 15 October 2008

To: Serapio Flores Jr.
State Conservationist
USDA-NRCS,
220 East Rosser Avenue
P.O. Box 1458
Bismarck, ND 58502-1458

Purpose:
The affects of soil salinity on crop response are being studied on two fields on David Berklund's Farm in Grand Forks County. Each field was intensively surveyed with electromagnetic induction (EMI). In addition, training on the operation of the EM38 meter with the Allegro field computer and processing software was provided to David Zimmermann. A comparative study was also conducted, which evaluated the data collected with three different EMI meters. The affects of saline and sodic soil conditions on ground-penetrating radar (GPR) were also evaluated.

Participants:
Keith Anderson, MLRA Soil Survey Leader, USDA-NRCS, Fargo, ND
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Kyle Thomson, Soil Scientist, USDA-NRCS, Devils Lake, ND
Mike Ulmer, Senior MO Soil Scientists, MO7, USDA-NRCS, Bismarck, ND
David Zimmermann, Senior MLRA Soil Scientist, USDA-NRCS, Fargo, ND

Activities:
All field activities were completed during the period of 22 to 25 September 2008.

Summary:

1. High intensity EMI surveys were completed on two separate fields in Grand Forks County, which are mapped as either Bearden silty clay loam, saline, or Bearden silty clay loam. Twenty sites were identified in each field using the ESAP (version 2.35) software developed by the USDA-ARS (US Salinity Laboratory in Riverside, California). Soil samples were collected at each of these sites for laboratory analysis. These samples will be sent to the National Soil Survey Laboratory for characterization. The results of the soil analysis will be compared with collected yield data to better understand the affects of soil salinity on crop response in the Red River Valley.

2. An Excel spreadsheet with all the EMI data from the high-intensity soil survey have been forwarded to the principal participants.

3. Comparative EMI surveys were completed with three different meters (EM38, EM38DD, and EM38MK2-2 meters) in an area of Antler silty clay loam, saline. These surveys produced similar results.

4. The use of ground-penetrating radar (GPR) is severely limited in areas of saline and sodic soils. However, based on the results of GPR surveys conducted in Grand Forks County, additional testing is needed to confirm this assessment on saline and sodic soils of different soil textures.

It was my pleasure to work in North Dakota and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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Equipment:
The EM38, EM38DD, and EM38MK2-2 meters, manufactured by Geonics Limited (Mississauga, Ontario), were used in the investigations discussed in this report.[1] These meters require no ground contact and only one person to operate. These meters measured the apparent conductivity (EC_a) of soils, which is expressed in milliSiemens/meter (mS/m).

The EM38 meter weighs about 3 kg (6.6 lbs). This meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 1998).

The EM38DD meter consists of two, coupled EM38 meters. This instrument weighs about 6 kg (13.2 lbs). Operating procedures for the EM38DD meter are described by Geonics Limited (2000). When placed on the soil surface, these meters simultaneously provide nominal penetration depths of about 0.75 and 1.5 m.

The EM38-MK2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil at distances of 1.0 and 0.5 m. This configuration provides effective depth ranges of 1.5 and 0.75 m in the vertical dipole orientation and 0.75 and 0.38 m in the horizontal dipole orientation. The EM38-MK2 meter, in either orientation, provides simultaneous measurements of both the quadrature-phase (apparent conductivity) and in-phase (susceptibility) components within two depth ranges. Susceptibility is expressed parts per thousand (ppt). Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007).

Mobile EMI surveys were completed across the two sites with an EM38DD meter. An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EC_a and position data.[1] The coordinates of each EC_a

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

measurement were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2] The Trackmaker38DD software program developed by Geomar Software Inc. (Mississauga, Ontario) was used to record, store, and process EC_a and GPS data.[2]

For training and comparative testing, pedestrian surveys were conducted on a small parcel of land with the EM38, EM38DD, and EM38MK2-2 meters. The DAT38W, DAT38DDW, and DAT38-MK2W software programs developed by Geonics Limited were used to record, store, and process the collected EC_a and GPS data.[2]

To help summarize the results, the SURFER for Windows (version 8.0) software, developed by Golden Software, Inc., was used to construct the two-dimensional simulations shown in this report.[2] Grids were created using kriging methods with an octant search.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[2] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. An antenna with a center frequency of 200 MHz was used in this study. Daniels (2004) discusses the use and operation of GPR.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[2] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, and migration (see Daniels (2004) for a discussion of these techniques).

Study Sites:
Sites for the two high-intensity EMI surveys were located in recently harvested, cultivated fields. Study site 1 is located in the southern ½, NE ¼ of Section 16, T. 151 N., R. 51 W. Soils are mapped as Bearden silty clay loam, saline (270). Study site 2 is located in the SE ¼ of Section 25, T. 151 N., R. 51 W. Soils are mapped as Bearden silty clay loam (126). The very deep, somewhat poorly drained Bearden soils formed in calcareous silt loam and silty clay loam lacustrine sediments. The Bearden series is a member of the fine-silty, mixed, superactive, frigid Aeric Calciaquolls taxonomic family.

Survey Procedures:
A mobile EMI survey was completed on the two field sites in Grand Forks County. Mobile EMI survey provides more comprehensive site coverage, in a shorter period of time, and with less effort than pedestrian surveys. For these surveys, an EM38DD meter was towed behind a Polaris Ranger in a plastic sled at speeds of 2 to 4 m/sec. The EMI survey was completed by driving the Polaris Ranger at a uniform speed in a back and forth manner across each field.

The EC_a data discussed in this report were not temperature corrected to a standard temperature. At the time of this investigation, the temperature of the soil at a depth of about 50 cm was 59 ^{o} F.

All data were entered into an Excel spreadsheet and processed thru the ESAP (version 2.35) software program developed by USDA-ARS, US Salinity Laboratory in Riverside, California. The Response Surface Sampling Design (RSSD) program of ESAP was used to generate an optimal sampling design within each field based on the EC_a data. Based on the response surface sampling design, twenty optimal sampling locations were selected within each field. For each high-intensity survey, plots of EC_a data were prepared using the SURFER for Windows program.

Plots of EC_a data showing the locations of the 20 optimal sampling points were compiled and copies used by soil scientists involved in soil sampling.

Results:
Table 1 provides the basic statistics for the two high-intensity EMI surveys. The field mapped as Bearden silty clay loam, saline (Site 1) displays higher and more variable EC_a than the field mapped as Bearden silty clay loam (Site 2). As higher EC_a is inferred to reflect higher levels of soil salinity, the results of the EMI surveys provide some confirmation of the order-two soil mapping, which was completed in the later 1970s. In both fields, EC_a increased with increasing soil depth (measurements obtained in the shallower-sensing horizontal dipole orientation were less than those obtained in the deeper-sensing vertical

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[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

dipole orientation). This reflects a *normal salt profile*. *Normal salt profiles* have increasing levels of soluble salts with increasing soil depth.

Table 1. Basic statistics for the two sampled fields in Grand Forks County.
(With the exception of Number, all values are measures of EC_a expressed in mS/m.)

Site	***Dipole***	***Number***	***Mean***	***Std. Dev***	***Minimum***	***25%tile***	***75%tile***	***Maximum***
Site 1	VDO	7080	164.5	51.4	67.5	122.0	201.0	345.1
Site 1	HDO	7080	107.5	40.0	32.1	73.8	135.0	283.1
Site 2	VDO	2804	101.5	31.7	39.4	79.0	118.6	205.0
Site 2	HDO	2804	74.1	25.2	25.8	55.0	87.9	173.5

Spatial EC_a patterns across sites 1 and 2 are shown in Figures 1 and 2, respectively. For display purposes, the same color scale and intervals have been used in each plot. In each of the accompanying figures, separate plots show the spatial distribution of EC_a in both the shallower-sensing (0 to 75 cm) horizontal or deeper-sensing (0 to 150 cm) vertical dipole orientations. The locations of the optimal sampling sites and their identifier (observation #) are also shown in these plots. Levels of EC_a are not uniform across sites, but form characteristic pock-mark patterns with areas of higher EC_a alternating with areas of lower EC_a. Areas of higher EC_a appear to form discontinuous, irregular patterns across each field.

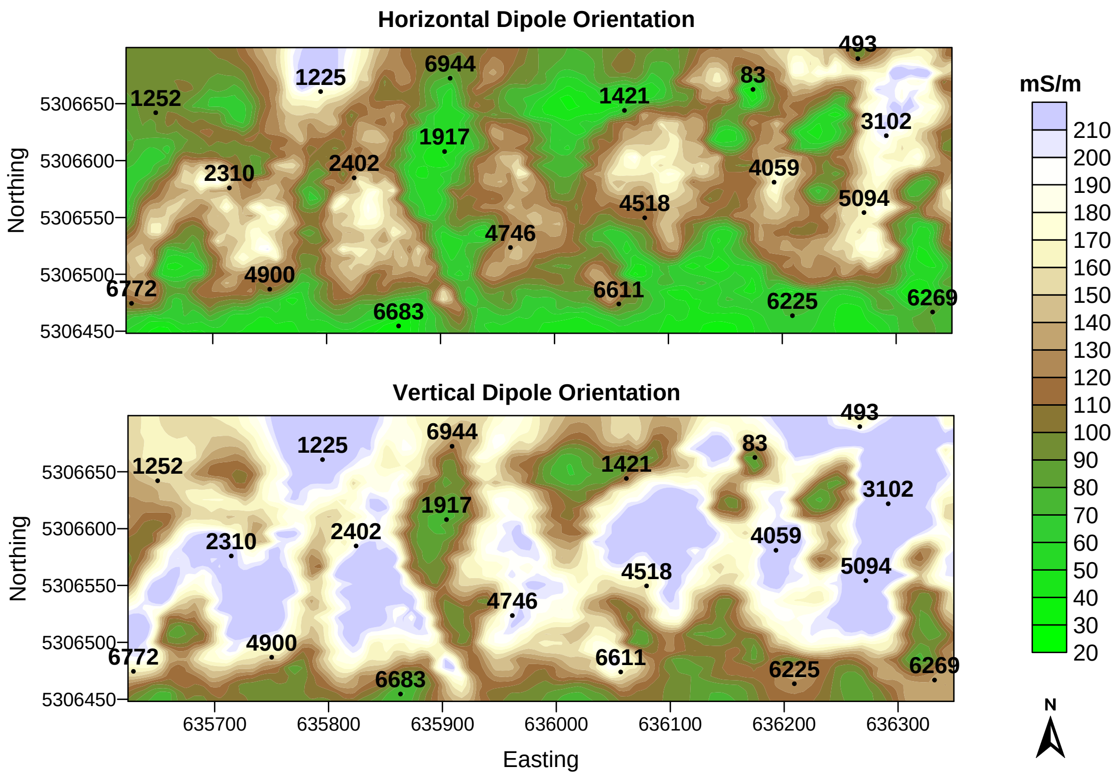

Figure 1. Plots of spatial EC_a patterns across a field (Site 1) mapped as Bearden silty clay loam, saline, in Grand Forks County, North Dakota. The numbers identify the locations of the soil sampling sites as determined by the ESAP program.

Tables 2 and 3 provide listings of the optimal sample sites as determined by the ESAP program for each field. In each table, the observation number, location (in UTM), and EC_a measurement obtained with the EM38DD meter (both in the vertical dipole (VDO) and horizontal dipole (HDO) orientations) are presented.

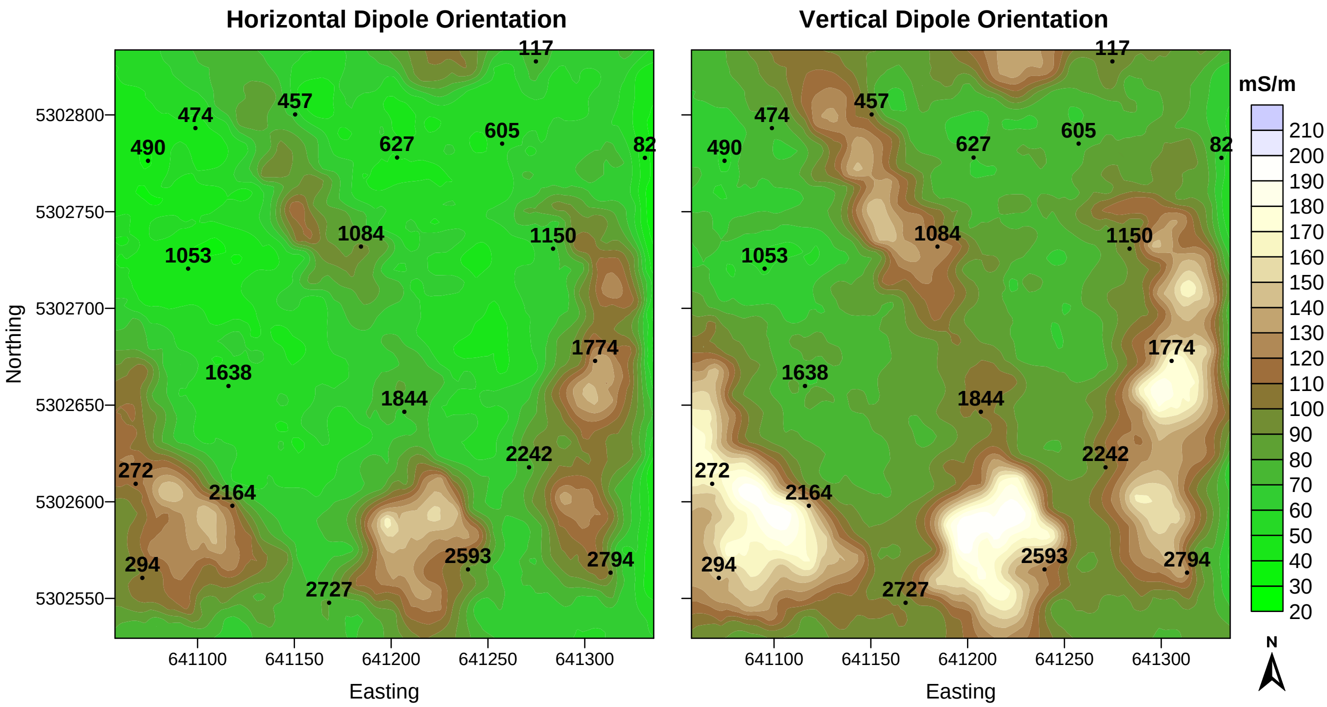

Figure 2. Plots of spatial EC_a patterns across a field (Site 2) mapped as Bearden silty clay loam, in Grand Forks County, North Dakota. The numbers identify the locations of the soil sampling sites as determined by the ESAP program.

Table 2. Optimal Soil Sampling Point Data for Site 1.
Bearden silty clay loam, saline

OBS	EASTING	NORTHING	VDO	HDO
83	636174.32	5306662.53	95.50	45.50
493	636266.41	5306689.62	171.63	91.50
1225	635794.66	5306660.66	229.50	157.00
1252	635649.90	5306642.08	153.75	99.13
1421	636061.46	5306644.08	100.63	58.13
1917	635903.52	5306607.95	74.63	51.13
2310	635714.54	5306575.98	214.75	139.13
2402	635824.13	5306584.78	204.75	144.75
3102	636291.39	5306621.86	294.38	208.38
4059	636192.83	5306580.96	240.25	179.13
4518	636079.23	5306549.65	160.00	113.75
4746	635961.34	5306523.59	202.88	137.00
4900	635750.02	5306486.95	150.63	117.00
5094	636271.79	5306554.29	260.25	167.13
6225	636208.96	5306463.68	123.63	69.13
6269	636332.06	5306466.92	125.88	77.38
6611	636056.49	5306474.02	168.75	100.88
6683	635863.12	5306454.64	69.63	33.63
6772	635628.61	5306474.54	161.25	106.63
6944	635908.42	5306672.37	115.38	75.88

Table 3. Optimal Soil Sampling Point Data for Site 3.
Bearden silty clay loam

OBS	EASTING	NORTHING	EM38V	EM38H
82	641331.09	5302777.82	61.9	42.6
New	641316.30	5302775.70	92.0	70.0
117	641274.78	5302827.69	98.6	77.3
272	641068.07	5302609.28	165.6	116.5
294	641071.49	5302560.63	142.6	106.1
457	641150.42	5302800.27	106.5	67.1
474	641098.91	5302793.20	67.4	41.1
490	641074.44	5302776.29	39.4	25.8
605	641257.35	5302785.16	78.0	55.5
627	641203.07	5302777.97	70.8	53.8
1053	641095.15	5302720.53	56.9	44.5
1084	641184.43	5302731.93	131.0	93.4
1150	641283.65	5302730.85	94.0	68.0
1638	641115.98	5302659.86	76.1	50.1
1774	641305.38	5302672.84	178.9	134.8
1844	641206.83	5302646.52	104.4	70.8
2164	641117.99	5302597.93	148.0	118.8
2242	641271.24	5302617.81	98.6	72.0
2593	641239.72	5302565.03	123.3	91.4
2727	641167.97	5302547.77	95.0	79.9
2794	641313.35	5302563.33	127.1	98.6

Comparative EMI Study:
Three EMI meters developed by Geonics Limited are being used by USDA-NRCS soil scientists: the EM38, EM38DD, and EM38MK2 meters. The EM38 is the most widely used of these meters. While the EM38DD meter has been used for the salinity appraisals in the Red River Valley by the National Soil Survey Center, this is the only unit available within USDA-NRCS. The newly developed EM38MK2 meter will replace the EM38 meter, which, while supported, will no longer be marketed by Geonics Limited. For soil and salinity appraisals, measurements obtained with these three meters need to be closely similar. To evaluate the measurements obtained with these three meters in an area of medium-textured, saline soils, a study was conducted near the Berklund homestead in the SE ¼ Section 32, T. 151. N., R 51 W. The study site is located in an area of Antler silty clay loam, saline (65). The very deep, somewhat poorly drained Antler soils formed in silty lacustrine sediments over loam or clay loam glacial till on glacial lake plains and interbeach areas. The Antler series is a member of the fine-loamy, mixed, superactive, frigid Aeric Calciaquolls taxonomic family.

Table 4. Comparative measurements obtained with an EM38, EM38DD, and EM38MK2-2 meters over the same area of Antler silty clay loam, saline, in Grand Forks County. The EM38 and EM38MK2-2 meters were only operated in the vertical dipole orientation (VDO).

	EM38MK2-2	EM38MK2-2	EM38DD	EM38DD	EM38
	100 cm	*50 cm*	*VDO*	*HDO*	*VDO*
Number	384	384	475	475	663
Minimum	114.9	95.7	110.9	83.9	117.2
25%-tile	152.5	124.7	148.0	116.2	147.9
75%-tile	190.0	232.8	188.5	154.9	190.5
Maximum	260.4	232.8	250.6	220.6	254.8
Mean	173.9	147.2	171.8	137.2	173.2
Std. Dev.	8.1	8.1	8.1	8.1	7.9

A 20 by 25 meter grid was established across the study site. Survey flags were spaced at 2 m intervals along two parallel, east-west trending lines, which were spaced 25 m apart. Survey were completed with each meter by walking in a back and forth pattern between similarly numbered flags on the opposing sides of the grid. Each meter was operated in the continuous mode. Though guided by the similarly-numbered flags on opposing grid lines, the coordinates of each EC_a measurement were recorded with a Trimble AgGPS114 L-band DGPS antenna. An Allegro CX field computer was used to record and store both EC_a and position data. The DAT38W, DAT38DDW, and DAT38-MK2W software programs developed by Geonics Limited were used to record, store, and process the collected EC_a and GPS data.[3]

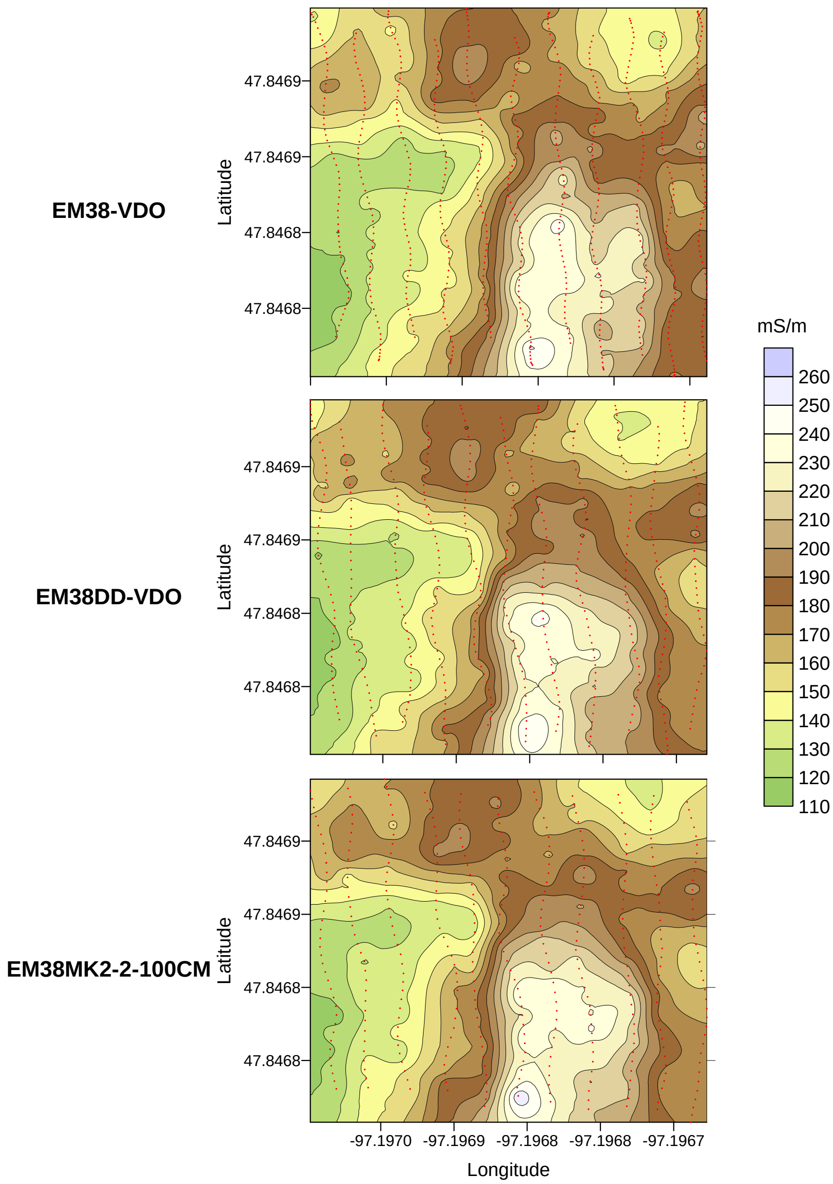

Figure 3. Plots of spatial EC_a patterns measured with three EMI meters operated in the vertical dipole orientation across the same test site located in an area of Antler silty clay loam, saline, in Grand Forks County, North Dakota.

[3] Manufacturer's names are provided for specific information; use does not constitute endorsement.

For each meter, the depth of penetration and measured EC_a are influenced by the instrument's coil orientation, coil separation, and frequency, as well as the conductivity of the profiled material(s). For the EM38, EM38DD, and EM38MK2-2l meters, the orientation (either vertical or horizontal) of the transmitter and receiver coil axis with respect to the ground surface affects the response from materials at different depths. For the EM38MK2-2 meter, the spacing of the two receiver coils (either 50 or 100 cm) to the transmitter coil will affect the depth of penetration as well. For these three meters, when operated in either the vertical dipole (VDO) or horizontal dipole (HDO) orientations, similar responses should be obtained for the same intercoil spacings (100 cm). In Table 4, data contained in columns 2, 4, and 6 should be closely similar as all were collected in the vertical dipole orientation and with a 100 cm intercoil spacing. The data sets are very closely similar.

Data contained in columns 3 and 5 represent data collected over identical nominal depths, but in different dipole orientations with different depth-weighting response functions. Although the EM38DD meter operated in the horizontal dipole orientation, should provide a similar penetration depth (75 cm) as the EM38MK2-2 meter's 50 cm coil separation, the depth weighting function and maximum sensitivity depth will vary slightly. As evident in Table 4, measurements are closely similar, but not identical. Differences in these measurements can be attributed to differences in the depth response functions (HDO versus VDO) and the volume of soil measured with the EM38DD and EM38MK2-2 meters. Differences in the depth of penetration, volume of soil material measured, and resolution of each tool affect EC_a measurements.

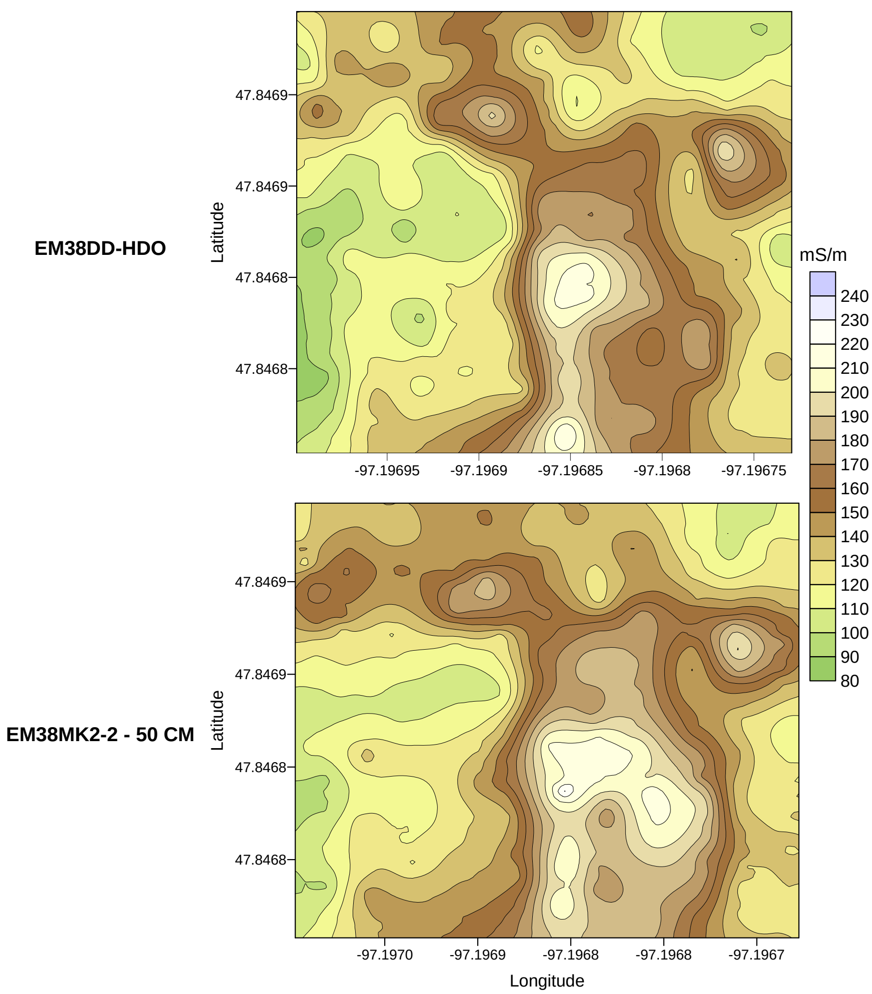

Figure 4. Plots of spatial EC_a patterns measured with the EM38DD operated in the horizontal dipole orientation and the 50 cm intercoil spacing of the EM38MK2-2 operated in the vertical dipole orientation across the same test site located in an area of Antler silty clay loam, saline, in Grand Forks County, North Dakota.

In this study, EC_a measurements were obtained with three different meters. As evident in Figures 3 and 4, spatial patterns of apparent conductivity produced by the three meters are closely similar and all appear to produce reasonable results. For each instrument, different dipole orientations produce different responses and sounding depths. In Figures 3, the locations of each measurement point is indicated by a red dot. Slight spatial differences in the locations of the coordinates recorded with the GPS are evident in these plots. These differences will result in slightly different graphic interpolations in SURFER for Windows.

Ground-penetrating radar (GPR) Tests:
Because of their high electrical conductivity, saline (saturated extract electrical conductivity ≥ 4 mmhos cm^{-1}) and sodic (sodium absorption ratio ≥13) soils are considered unsuited to ground-penetrating radar (Doolittle et al., 2003). In saline and sodic soils, penetration depths are generally assumed to be less than 25 cm (Daniels, 2004). To verify these interpretations, radar traverses were conducted across areas of saline and sodium-affected soils in Grand Forks County. The saline site is located in an area of Bearden silty clay loam saline (270). This site is located in the SW ¼ Sec 21 T. 151 N., R. 51 W. The site was in corn with noticeable barren spots. Along the GPR traverse line, EC_a ranged from 210 to 280 mS/m.

The sodium-affected soil site is located in an area of Cresbard-Cavour loams, 0 to 3 percent slopes (G124A). This site is located in the SW ¼ Sec 14, T. 152 N., R. 56 W. The site was in hay land. Along the GPR traverse line, EC_a ranged from 115 to 130 mS/m. The very deep, moderately well and well drained Cresbard and Cavour soils formed in glacial till on uplands. Cresbard and Cavour series are members of the fine, smectitic, frigid Glossic Natrudolls and the fine, smectitic, frigid Calcic Natrudolls taxonomic families, respectively. Along the GPR traverse line, soils were identified as sodium-affected Aastad (fine-loamy, mixed, superactive, frigid Pachic Argiudolls) and unfortunately are not representative of either Cresbard or Cavour soils.

A both site, 5 survey flags were placed in the soil at 1 m intervals. This created a 4 m traverse line. At the middle flag, a 25 cm diameter metal plate was buried at a depth of 50 cm. A 200 MHz was pulled along the traverse line.

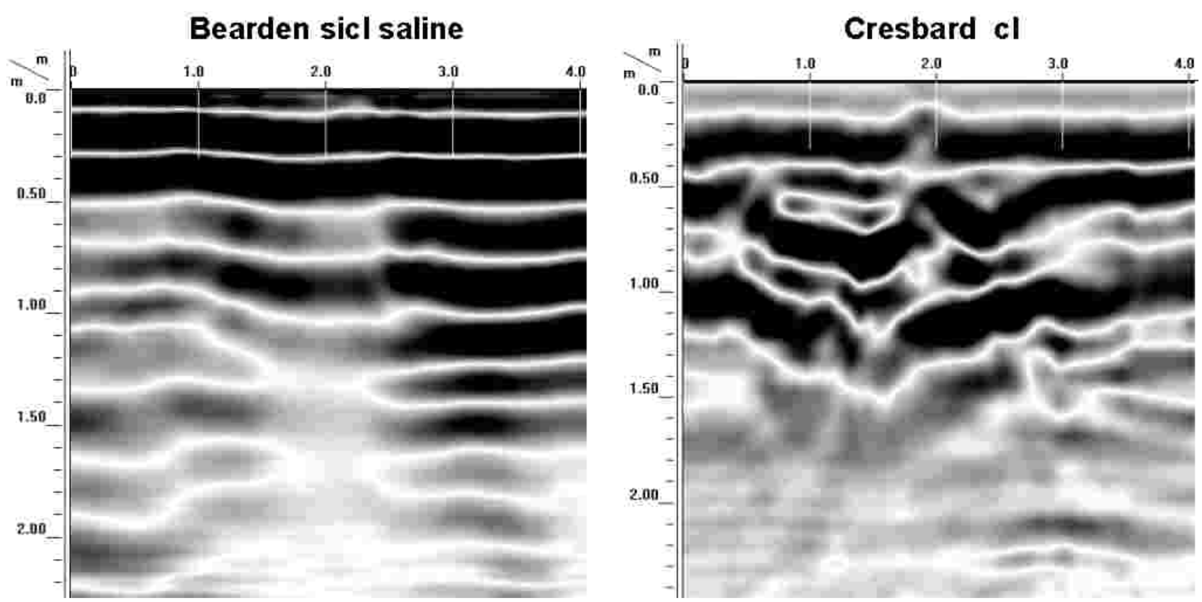

Figure 5. These radar records were obtained with a 200 MHz antenna in areas of Bearden silty clay loam saline (left), and Cresbard-Cavour loams, 0 to 3 percent slopes (right).

The radar records from the two sites are shown in Figure 5. In both plots, depth and distance measurements are expressed in meters. On each radar record, the metal plate should appear at a depth of 50 cm beneath the 2-m distance mark. On both radar records, soil disturbance and the less dense materials used to backfill the hole for the buried plate appear as low-amplitude reflections. On the Bearden silty clay loam, saline, radar record (left), the radar signal has been significantly attenuated and the metal plate can not be detected. No subsurface reflectors are apparent on this radar record; the horizontal bands represent low-frequency background noise. On the Cresbard clay loam radar record (right), the upper boundary of the Bt horizon is apparent at depths of 40 to 60 cm. This interface appears to partially obscures the hyperbolic (^) reflection from the metal plate.

The results of these brief traverses satisfy the general suitability interpretations made for GPR on saline and sodic soils. However, I would personally like to journey around North Dakota and extend this survey onto more saline and sodic soils that belong to different textural classes.

References:

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