United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI -- Geophysical Assistance

Date: 8 November 2006

To: Stephen K. Chick
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Purpose:
Field training was provided to soil scientists on the operation of a newly acquired EM38 meter, DAS70 Data Acquisition System, and supporting software. For each field site, plots were developed and trainees interpreted spatial apparent conductivity (EC_a) patterns. Patterns were related to differences in soils and soil properties. The EMI training was conducted contemporaneously with scheduled soil sampling in Scotts Bluff County.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Neil Dominy, Soil Scientist, USDA-NRCS, Grand Island, NE
Jose Idrach, Soil Scientist, USDA-NRCS, Grand Island, NE
Cameron Loerch, State Soil Scientist, USDA-NRCS, Lincoln, NE
Chad Remley, Soil Data Quality Specialist, USDA-NRCS, Salinas, KS
Steve Scheinost, Soil Scientist, USDA-NRCS, Lincoln, NE
David Vyian, Soil Scientist, USDA-NRCS, Scottsbluff, NE

Activities:
All field activities were completed during the period of 24 to 26 October 2006.

Summary of Results:

1. The requirements of modern soil surveys necessitate the use of new technologies. Methodological and economical constraints make the use of traditional soil augering techniques impractical for updating soil surveys over large resource areas. The soil staff in Nebraska is commended for its foresight and willingness to explore the potentials of using electromagnetic induction (EMI) to help improve the documentation of soils and soil properties in soil survey updates and resource assessments.

2. Instructions on the operation of the EM38 meter, field exercises, and interpretations of the results of EMI surveys were provided to Neil Dominy and Jose Idrach. These two soil scientists are commended for their attention to instructions and enthusiasm in tackling this technology. The display and use of EMI data will depend on their ability to integrate EMI data into GIS.

3. The beneficial use of EMI as a precursory tool to select representative sites for soil sampling was demonstrated during the course of this assignment.

4. Results contained in this trip report are interpretative and based on the methods and procedures used. As only a limited number of ground-truth verifications were carried out during the EMI surveys, interpretations are constrained.

It was my pleasure to work in Nebraska 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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Background:
Soil surveys are expensive, time-consuming, and labor-intensive endeavors. In order to reduce resource expenditures, alternative methods are being explored to ease and expedite fieldwork, provide more information, and improve the assessment of soils and soil properties. Electromagnetic induction (EMI) has demonstrated potential for identifying differences in soils and soil properties and inclusions in soil delineations (Fenton and Lauterbach, 1999). Because of its speed and ease of use, EMI has immense advantages over traditional soil survey techniques. Because of the larger number of measurements, maps prepared from EMI data provide higher levels of resolution than soil maps prepared with conventional tools or survey methods (Jaynes, 1995).

Electromagnetic induction measures the apparent conductivity (EC_a) of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in EC_a are produced by differences in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The EC_a of soils increases with increases in soluble salt, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Apparent conductivity provides an additional layer of soil information and a relational reference frame to infer and map variations in soils and soil properties. Maps of EC_a appear to be reasonable facsimiles of soil maps. In many areas, spatial EC_a patterns corresponded well with the soil patterns shown on soil survey maps (Jaynes, 1995). Stafford (2000) observed that EC_a is often a good substitute for spatially varying soil properties that are not easily sensed or mapped such as clay or moisture contents. However, a weakness of this interpretative process is *equivalence*: soil properties are spatiotemporally variable and simultaneous variations in more than one property may result in equivalent EMI responses. In many landscapes, variations in more than one of soil properties create interpretational ambiguities and challenges in relating EC_a to a specific soil property. Because of equivalence, a functional analysis of each soil-landscape or management units is often required to decipher the exact site-specific causes of EMI variability (Sommer et al., 2003).

Interpretations of EMI data are based on the identification of spatial patterns within data sets. Though seldom diagnostic in themselves, lateral and vertical variations in EC_a have been used to infer changes in soils and soil properties (Kravchenko et al., 2002; Doolittle et al., 1996 and 1994; Sudduth et al., 1995; Jaynes et al., 1993). Electromagnetic induction has been used to assess depths to claypans (Sudduth et al., 1995; Doolittle et al., 1994; Stroh et al., 1993; Sudduth and Kitchen, 1993), soil drainage classes (Kravchenko et al., 2002) and soil salinity (Rhoades and Corwin, 1981). It has been used to measure soil water content (Sheets and Hendrickx, 1995; Kachanoski et al., 1988), clay content (Sommer et al., 2003; William and Hoey, 1987), cation exchange capacity and exchangeable Ca and Mg (McBride et al., 1990), soil organic carbon (Jaynes, 1996), field-scale leaching rates of solutes (Slavich and Yang, 1990), and herbicide partition coefficients (Jaynes et al., 1994). EMI has also been used as a soil-mapping tool to assist precision agriculture or site-specific management (Jaynes, 1995; Jaynes et al., 1995; Sudduth et al., 1995) and to evaluate soil properties that affect yields (Johnson et al., 2001). In these studies, EC_a was either directly related to the soil property under investigation or the soil property (e.g., soil organic carbon) was associated with changes in a property (e.g., moisture contents) that is measured with EMI.

Electromagnetic induction surveys are commonly conducted with a field computer, which simultaneously records EC_a, GPS position, and elevation data. The speed and ease at which these data are recorded greatly reduces survey time and makes practical the surveying of large areas. Kitchen et al. (2005 and 2003) discuss the integration of these data to improve soil interpretations. The collection of EC_a, position, and elevation data is seen as a practical method for improving soil surveys. A routine and convenient method of interpreting geo-referenced EC_a and elevation data is with graphic displays. Geographical information systems (GIS) are considered the most effective tool to organize, manipulate, and display both soil and EC_a data (Corwin and Lesch, 2005). However, the integration of EC_a data into GIS is presently not well documented nor frequently undertaken. The purpose of this field trip was to provide training and to introduce the potential of using EC_a data as an additional layer of soil information which can improve the efficacy of soil surveys and the quality and quantity of soil data collection.

Equipment:
An EM38 meter, manufactured by Geonics limited (Mississauga, Ontario) was used in this study. [1] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 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).

Figure 1. Soil Scientists Neil Dominy and Jose Idrach learning to operate the EM38 meter with the DAS70 Data Acquisition System

The Geonics DAS70 Data Acquisition System was used with the EM38 meter to record and store both EC_a and position data (see Figure 1).[1] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS). [1] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered.

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0, developed by Golden Software, Inc. (Golden, CO), was used to construct the graphic simulations shown in this report.[1] Grids of EC_a data were created using kriging methods with an octant search.

Study Areas:
All study sites were located in western Scotts Bluff County, south of Lyman, and near the Wyoming State Line. Site 1 is located in the SW ¼ of Section 28, T. 22 N., R.58 W. The approximate location of my vehicle at the time

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

of the survey was 41.84352º N. Lat., and 104.05262º W. Long. The site is in a portion of a cultivated field that was mapped as Mitchell and Buffington soils, alkali, 0 to 5 % slopes (MU 2MBB) (websoilsurvey.nrcs.usda.gov). A pedon of Buffington was sampled at this site.

Site 2 is located in the NW ¼ of Section 4, T. 21 N., R.58 W. The approximate location of my vehicle at the time of the survey was 41.82505º N. Lat., and 104.04904º W. Long. The site is in a portion of a cultivated field that was mapped as Anselmo fine sandy loam, 3 to 5 % slopes (MU AnB), Anselmo fine sandy loam, 5 to 9 % slopes (MU AnC), Mitchell fine sandy loam, 0 to 3 % slopes (MU MzA), and Otero-Bayard fine sandy loams, 0 to 3 percent slopes (MU OBA) (websoilsurvey.nrcs.usda.gov). A pedon of Jayem soil was sampled at this site.

Site 3 is also located in the NW ¼ of Section 4, T. 21 N., R.58 W. The approximate location of my vehicle at the time of the survey was 41.82368º N. Lat., and 104.04962º W. Long. The site is in a portion of a cultivated field that was mapped as Anselmo fine sandy loam, 5 to 9 % slopes (MU AnC), and Satanta fine sandy loam, 1 to 3 % slopes (MU Sa). A pedon of Dwyer soil was sampled at this site.

Site 4 is located in the NW ¼ of Section 7, T. 21 N., R.57 W. The approximate location of the vehicle at my time of the survey was 41.81284º N. Lat., and 103.98061º W. Long. The site is in a portion of a cultivated field that was mapped as Keith loam, 0 to 1 % slopes (MU Ke), and Keith loam, 1 to 3 % slopes (MU KeA) (websoilsurvey.nrcs.usda.gov). A pedon of Keith soil was sampled at this site

Site 5 is located in the NE ¼ of Section 8, T. 21 N., R.57 W. The approximate location of my vehicle at the time of the survey was 41.813867º N. Lat., and 103.949483º W. Long. The site is in a portion of a cultivated field that was mapped Keith loam, 1 to 3 % slopes (MU KeA), and Keith-Ulysses complex, 3 to 5 % slopes, eroded (MU KUB2) (websoilsurvey.nrcs.usda.gov). A pedon of Duroc soil was sampled at this site.

Table 1 lists the names and symbols for the soil map units that were traversed with EMI. The names of some of these map units will be changed as more information is gathered during the soil update. Table 2 lists the taxonomic classification of the soils identified in the map unit names or in excavated pits.

Table 1
Soil Map Units surveyed with EMI

Map Unit Name	Map Unit Symbol
Anselmo fine sandy loam, 3 to 5 % slopes	AnB
Anselmo fine sandy loam, 5 to 9 % slopes	AnC
Keith loam, 0 to 1 % slopes	Ke
Keith loam, 1 to 3 % slopes	KeA
Keith-Ulysses complex, 3 to 5 % slopes, eroded	KUB2
Mitchell fine sandy loam, 0 to 3 % slopes	MzA
Mitchell and Buffington soils, alkali, 0 to 5 % slopes	2MBB
Otero-Bayard fine sandy loams, 0 to 3 % slopes	OBA
Satanta fine sandy loam, 1 to 3 % slopes	Sa

Areas mapped as Anselmo fine sandy loam, 3 to 5 percent slopes, and Anselmo fine sandy loam, 5 to 9 percent slopes, have been re-correlated with Jayem as the dominant (99 to 100 % composition, respectively) soil component in both map units (soildatamart.nrcs.usda.gov). The very deep, well drained to somewhat excessively drained Jayem soil formed in sediments weathered from noncalcareous sandstone on uplands. The particle-size control section (weighted average) of Jayem soil averages between 5 to 18 percent clay. Areas mapped as Keith very fine sandy loam, 0 to 1 percent slopes, and Keith very fine sandy loam, 1 to 3 percent slopes, have been re-correlated with Bridget as the dominant (99 % composition) soil component in both map units (soildatamart.nrcs.usda.gov). The very deep, well drained Bridget soil formed in eolian materials on uplands. The depth to free carbonates ranges from about 0 to 38 cm (0 to 15 inches). The particle size control section of Bridget soil averages between 5 and 18 clay. Areas mapped as Keith-Ulysses complex, 3 to 5 % slopes, eroded, have been re-correlated with Bridget (60 % composition) and Otero (40 % composition) as the dominant soils (soildatamart.nrcs.usda.gov). The very deep, well or somewhat excessively drained Otero soil formed in alluvium and eolian materials on foot slopes, alluvial fans and stream terraces. The depth to free carbonates ranges from 0 to 25 centimeters (1 to 10 inches). The particle size control section of Otero soil averages between 5 to 18 percent clay.

Table 2
Names and Taxonomic Classification of Soil Series

Anselmo	Coarse-loamy, mixed, superactive, mesic Typic Haplustolls
Bayard	Coarse-loamy, mixed, superactive, mesic Torriorthentic Haplustolls
Bridget	Coarse-silty, mixed, superactive, mesic Torriorthentic Haplustolls
Buffington	Fine, smectitic, mesic Torriorthentic Haplustolls
Duroc	Fine-silty, mixed, superactive, mesic Pachic Haplustolls
Dwyer	Mixed, mesic Ustic Torripsamments
Jayem	Coarse-loamy, mixed, superactive, mesic Aridic Haplustolls
Keith	Fine-silty, mixed, superactive, mesic Aridic Argiustolls
Keota	Coarse-silty, mixed, superactive, calcareous, mesic Ustic Torriorthents
Mitchell	Coarse-silty, mixed, superactive, calcareous, mesic Ustic Torriorthents
Otero	Coarse-loamy, mixed, superactive, calcareous, mesic Aridic Ustorthents
Satanta	Fine-loamy, mixed, mesic Aridic Argiustolls
Ulysses	Fine-silty, mixed, superactive, mesic Aridic Haplustolls

Areas mapped as Mitchell and Buffington soils, alkali, 0 to 5 % slopes, are composed of 75 percent Mitchell and 24 percent Buffington soils (soildatamart.nrcs.usda.gov). The very deep, well drained Buffington and Mitchell soils formed in materials weathered from siltstone (Mitchell), and silty and clayey alluvium (Buffington) on alluvial fans and stream terraces. Carbonates occur throughout these soils. The particle size control sections average between 35 and 45 percent clay for the Buffington soil, and between 5 and 20 percent clay for the Mitchell soil. In this map unit, the Buffington soil is saline (8 to 16 mmhos/cm). The composition of the Otero-Bayard fine sandy loams, 0 to 3 percent slopes, map unit is 80 percent Otero and 20 percent Bayard soils. These very deep, well drained soils formed in loamy colluvium weathered mostly from sandstone. The particle size control section of Bayard soil averages less than 18 percent clay. Depth to carbonates ranges from 20 to 51 centimeters (8 to 20 inches). The very deep, well drained Satanta soil formed in loamy eolian or alluvial materials on uplands. Depth to free carbonates ranges from 30 to 91 centimeters (12 to 36 inches). The particle size control section of Satanta soil ranges from 15 to 35 percent clay.

Field Procedures:
The EM38 meter was operated in the vertical dipole orientation and in the continuous mode with measurements recorded at 1-sec intervals. The EM38 meter was carried at a height of about 3 cm above the ground surface with its long axis parallel to the direction of traverse (see Figure 1). Data collection was completed by using either the DAT38W or the Trackmaker38 programs with the Allegro field computer. Data shown in this report are not temperature corrected.

Results:
Table 3 provides basic statistics for the EMI surveys that were completed at the five study sites. In Table 3, with the exception of the number of observations at each site, all values represent apparent conductivity (EC_a) and are expressed in mS/m.

Table 3

Basic Statistic for the EMI Surveys

Site	Soil Map Unit Symbol	Observations	Minimum	25 % tile	75 % tile	Maximum	Mean	Std. Deviation
1	2MBB	1158	97.50	165.38	192.75	258.75	177.70	25.55
2	OBA, AnB & AnC	2343	6.30	16.50	23.38	44.25	20.48	5.43
3	AnC & Sa	2765	5.63	16.25	25.00	51.50	21.29	6.77
4	Ke & KeA	1034	9.75	23.5	31.00	56.00	27.16	7.10
5	KeA & KUB2	1140	13.00	22.38	26.88	48.75	24.65	5.20

Measured values of EC_a varied both within and between sites. These differences are attributed to differences in soil properties and soil types. The EMI survey conducted in the delineation of Mitchell and Buffington soils, alkali, 0 to 5 % slopes (2MMB), had the highest and most variable EC_a. Although the clay content is relatively high in Buffington soil, the higher and more variable EC_a is attributed principally to the presence of soluble salts. Areas of Anselmo fine sandy loam, 5 to 9 % slopes (AnC); Keith loam, 1 to 3 % slopes (KeA); Keith loam, 0 to 1 % slopes (Ke); and Keith-Ulysses complex, 3 to 5 % slopes, eroded (KUB2), have similar basic statistics with noticeably lower and less variable EC_a than areas of Mitchell and Buffington soils, alkali, 0 to 5 % slopes. These map units are dominated by very deep, well drained to excessively drained soils (principally re-correlated as Jayem, Bridget, and Otero soils) that are non-saline and have particle size control sections that average between 5 and 18 percent clay. These factors help to explain the lower EC_a of these soils.

Site 1:
Site 1 is in a cultivated field of Mitchell and Buffington soils, alkali, 0 to 5 % slopes (2MBB). Figure 2 is a plot of the EC_a data collected with the EM38 meter in the deeper-sensing (0 to 1.5 m) vertical dipole orientation at this site. In Figure 2, the isoline interval is 10 mS/m. The location of a sampled pit of Buffington soil is shown in this figure.

Roads parallel the western and southern borders of Site 1. The presences of buried utility lines, parked vehicles, and slightly better soil drainage may account for the lower EC_a recorded along portions of these boundaries. Salt-affect soils display highly variable and complex spatial EC_a patterns. Small and scattered EC_a patterns appear to dot, speckle or pock-mark the site with no apparent causal explanation other than variations in surface topography. Though not confirmed, it appears that the concentration of soluble salts (with associated higher EC_a) is higher on slight convex swells or low ridges and lower in concave swales or depressions. In the field, lighter-colored surface layers, with presumably greater concentration of calcium carbonates, were observed on convex surfaces.

At Site 1, EC_a averaged about 178 mS/m and ranged from about 98 to 259 mS/m. One-half of the measurements had an EC_a that was between 165 and 193 mS/m. On the basis of these statistics, the location of the sampling pit (EC_a of 180 mS/m) appears to be very representative of the averaged EC_a for Site 1.

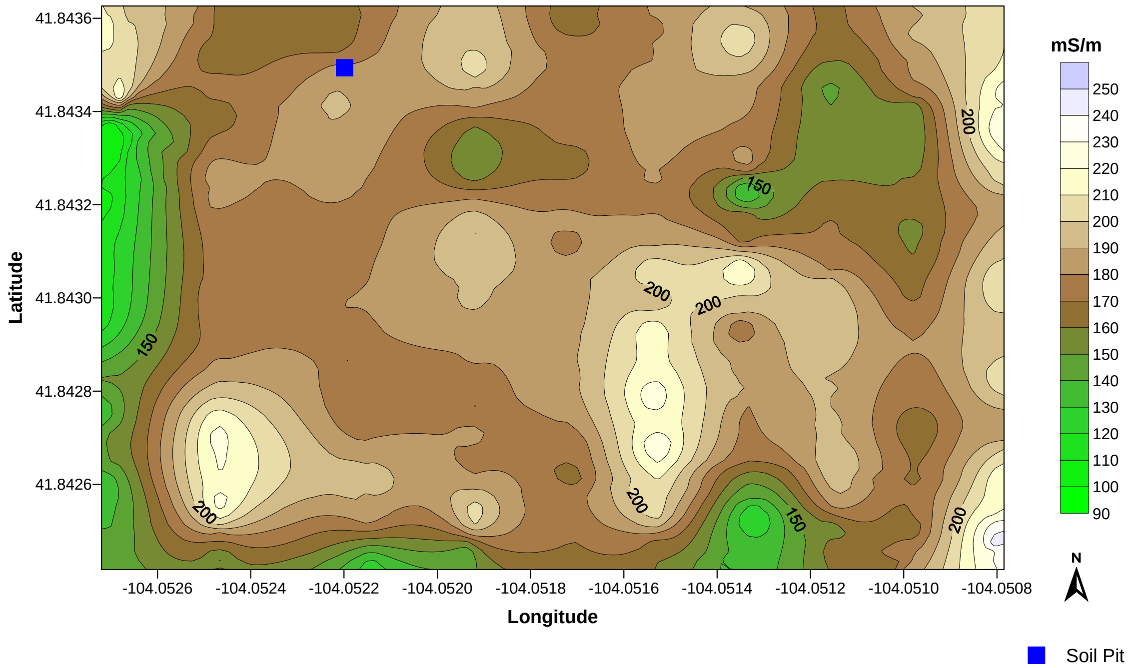

Figure 2. Spatial EC_a patterns collected with the EM38 meter in an area of Mitchell and Buffington soils, alkali, 0 to 5 % slopes.

Electromagnetic induction (EMI) provides a very rapid and reasonably accurate means for measuring soil salinity (Johnson et al., 1997). Wollenhaupt (1984) found that the EC_a is directly related to soil salinity. However, the interpretation of EMI measurements has presented a major challenge to users. The response of the EM38 meter is not uniform with depth. Measured EC_a must be converted into a more commonly used measure, the electrical conductivity of the saturated paste extract (EC_e). A number of approaches have been developed to relate EC_a to EC_e. Several models are discussed and evaluated by Johnson et al. (1997). Johnson et al. (1997) noted that calibration models are not highly accurate, but do provide a useful index of soil salinity. The accuracy of these models appears to be adversely affected by spatial and vertical variations in soil moisture and texture. However, these parameters can be estimated accurately enough for salinity mapping by the *feel method* (Rhoades et al., 1989b). The accuracy of models is less at lower soil water contents (Rhoades et al., 1989b). The established coefficient approach of Rhoades et al. (1989a) was found to be only slightly less accurate and to have a broader applicability than the multiple regression approach (Corwin and Rhoades, 1990).

The ESAP 2.35 program is a statistical software package for estimating field scale spatial salinity patterns from EC_a data. This program has been used by USDA-NRCS staffs in Colorado. The ESAP software program is designed to be used by personnel at the field office level who are monitoring, mapping and/or assessing salt-affected soils. The ESAP 2.35 program developed by the USDA-ARS Salinity Laboratory (Riverside, CA) (http://www.ars.usda.gov/Services/docs.htm?docid=8918) is CCE certified and can be installed on field computers.

Site 2:

Site 2 is located in an area that was mapped as Otero-Bayard fine sandy loams, 0 to 3 percent slopes (OBA), Anselmo fine sandy loam, 3 to 5 % slopes (AnB), and Anselmo fine sandy loam, 5 to 9 % slopes (AnC). Figure 3 is the plot of the EC_a data collected with the EM38 meter in the deeper-sensing (0 to 1.5 m) vertical dipole orientation at this site. In Figure 3, the isoline interval is 5 mS/m. The location of a sampled pit of Jayem soil is also shown in this figure.

The pit is located in an area of Otero-Bayard fine sandy loams, 0 to 3 percent slopes. The pit is at the base of a slope and near a soil boundary line that separates a delineation of Anselmo fine sandy loam, 5 to 9 % slopes (to the west), from a delineation of Otero-Bayard fine sandy loams, 0 to 3 percent slopes (to the east). In Figure 3, a segmented blue-colored line has been drawn to approximate the crest of a higher-lying ridge line. Soils on the summit and shoulder slope components of this ridge are better drained and coarser textured (Dwyer soil). These factors account for the lower EC_a along this ridge line. The base of the slope closely follows the area of higher EC_a near "A." Here, the higher EC_a is attributed to slightly greater clay and moisture contents. The topography is more subdued and elevations are less in the eastern portion of the survey area. This area has been principally mapped as Anselmo fine sandy loam, 3 to 5 % slopes. However, an area of Mitchell fine sandy loam, 0 to 3 % slopes (MzA), extends into the extreme northeast corner of the survey area. In this portion of the survey area, the higher EC_a is attributed mostly to the increased clay and/or moisture contents of the soils. However, the presence of some soluble salts is also suspected to have contributed to the higher EC_a. The highest EC_a was recorded in a depression that is identified by the symbol "B" in Figure 3.

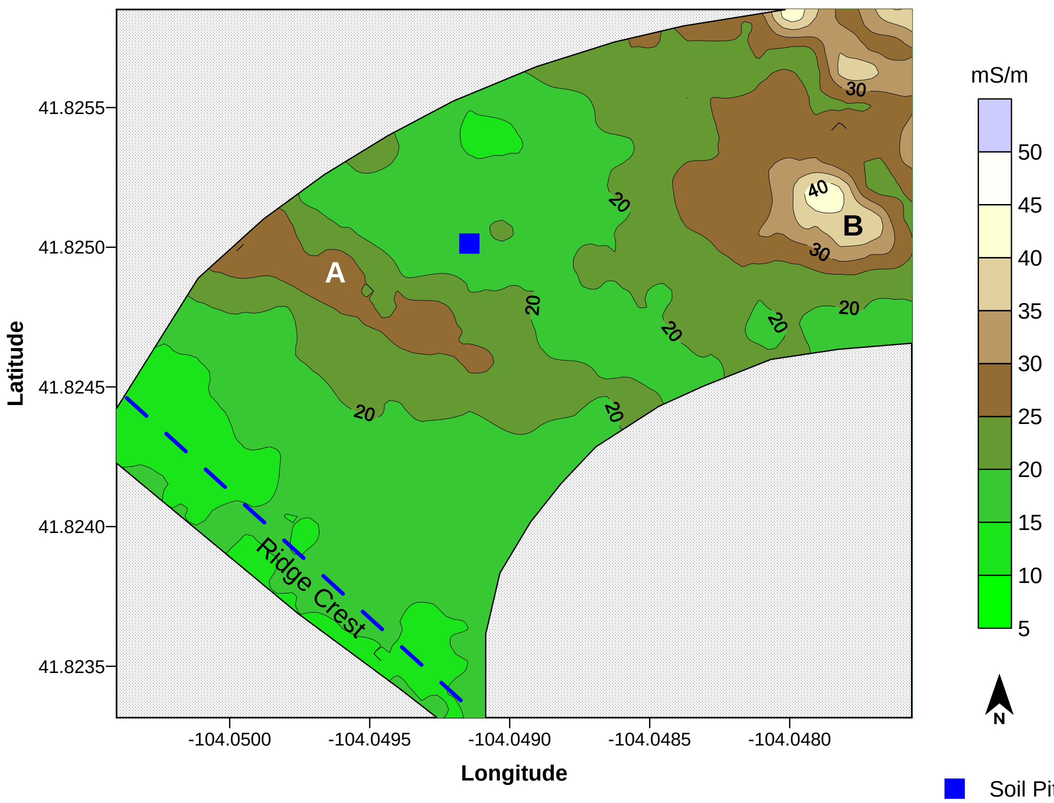

Figure 3. Spatial EC_a patterns collected with the EM38 meter at Study Site 2.

Study Site 2 contains contrasting soils with dissimilar EC_a. Spatial EC_a patterns appear to conform to landforms, major slope breaks, and soil delineations. At Site 2, EC_a averaged about 20.5 mS/m and ranged from 6.3 to 44.2 mS/m. One-half of the measurements had an EC_a that was between 16.5 and 23.4 mS/m. The EM38 meter delineated major soil boundaries and to identified areas of included soils. At the sampled pit, the EC_a was about 18 mS/m, which is fairly representative of the EC_a at this site.

<u>Site 3:</u>

Site 3 is located in an area that was mapped as Anselmo fine sandy loam, 5 to 9 % slopes (AnC), and Satanta fine sandy loam, 1 to 3 % slopes (Sa). Figure 4 is the plot of the EC_a data collected with the EM38 meter in the deeper-sensing (0 to 1.5 m) vertical dipole orientation at this site. In Figure 4, the isoline interval is 5 mS/m. The location of a sampled pit of Dywer soil is also shown in this figure.

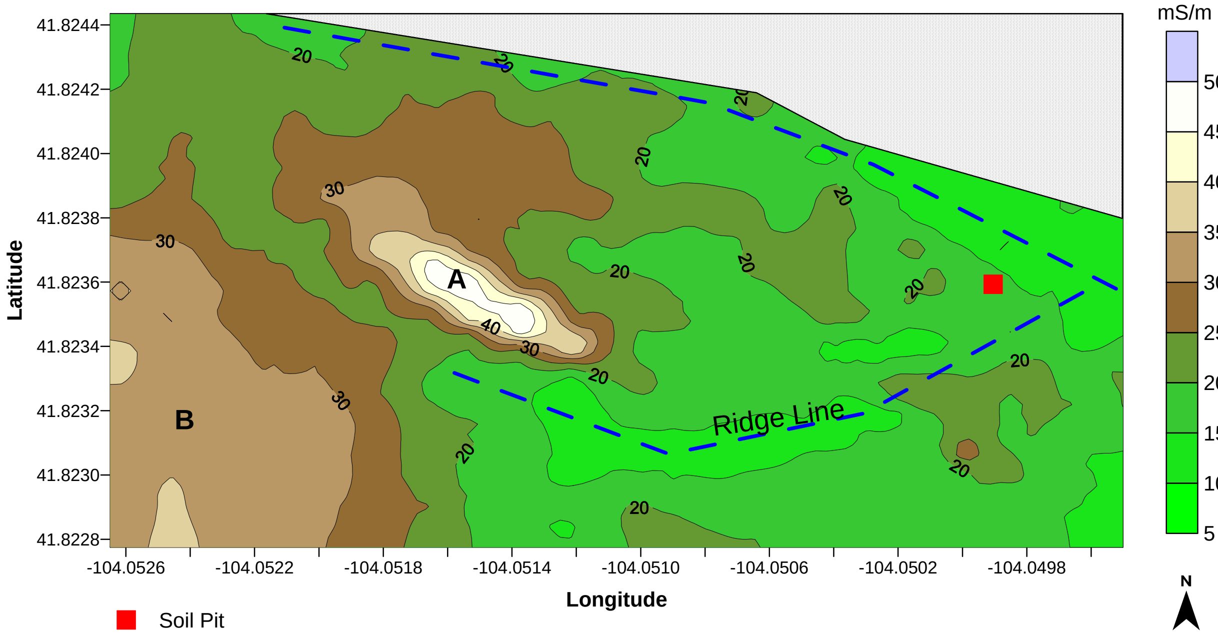

Figure 4. Spatial EC_a patterns collected with the EM38 meter at Study Site 3.

In Figure 4, segmented, blue-colored lines are used to approximate the crest of higher-lying ridge lines. Apparent conductivity is lower on these higher-lying portions of the site. Areas of Anselmo fine sandy loam, 5 to 9 % slopes, occur on higher-lying surfaces and have an EC_a less than 20 mS/m. In general, surface elevations decline towards the west and south. A noticeable swale (in Figure 4, see "A") with higher EC_a is sandwiched between the two intersecting ridgelines. Areas mapped as Santa soil have higher (>25 mS/m) EC_a. This unit has been mapped in the lower-lying and relatively level area that surrounds the symbol "B" and in the swale identified with the symbol "A."

Study Site 3 contains contrasting soils with dissimilar EC_a. At Site 3, EC_a averaged about 21.3 mS/m and ranged from 5.6 to 51.5 mS/m. One-half of the measurements had an EC_a that was between 16.2 and 25.0 mS/m. At this site, the EM38 meter delineated major soil boundaries and identified areas of included soils.

At the sample pit of Dwyer soil, the EC_a was about 16 mS/m. The location of the sampling pit appears to be fairly representative of the EC_a at this site. Compared with the Jayem soil at Site 2 the EC_a of Dwyer soil was slightly, but not significantly lower (18 versus 16 mS/m). The particle size control sections for Jayem and Dwyer soils have overlapping clay content ranges (5 to 18 % and 2 to 10 % clay, respectively). Though taxonomically distinct, the EC_a of Jayem and Dwyer soils is considered too similar to distinguish these two soils.

<u>Site 4:</u>

Site 4 is located in a cultivated area that was mapped as Keith loam, 0 to 1 % slopes (Ke), and Keith loam, 1 to 3 % slopes (KeA). Figure 5 is the plot of the EC_a data collected with the EM38 meter in the deeper-sensing (0 to 1.5 m) vertical dipole orientation at this site. In Figure 5, the isoline interval is 5 mS/m. The location of a sampled pit of Duroc soil is also shown in this figure.

The spatial EC_a pattern shown in Figure 5 are most intriguing. The topography of the site is basically level. The area has been mapped as two consociations of Keith soil. Soils and soil properties are not expected to vary significantly across this site. However, spatial EC_a patterns are very complex and reminiscent of the speckled and pock-mark appearance of the salt-affected soils at Site 1 (see Figure 2). Numerous, small, isolated clusters of higher EC_a dot the study site and suggest contrasting soils and subsurface materials. As no evidence of salt-affected soils was evident at this site, the possible occurrence of bedrock outliers and pinnacles of the underlying Brule formation is a possibility. These features would presumably have higher EC_a than the overlying soil columns and, where sufficiently shallow, influence the EMI response. Regardless of the source, EC_a patterns suggest the presences of included soils and soil map units that are complexes rather than consociations.

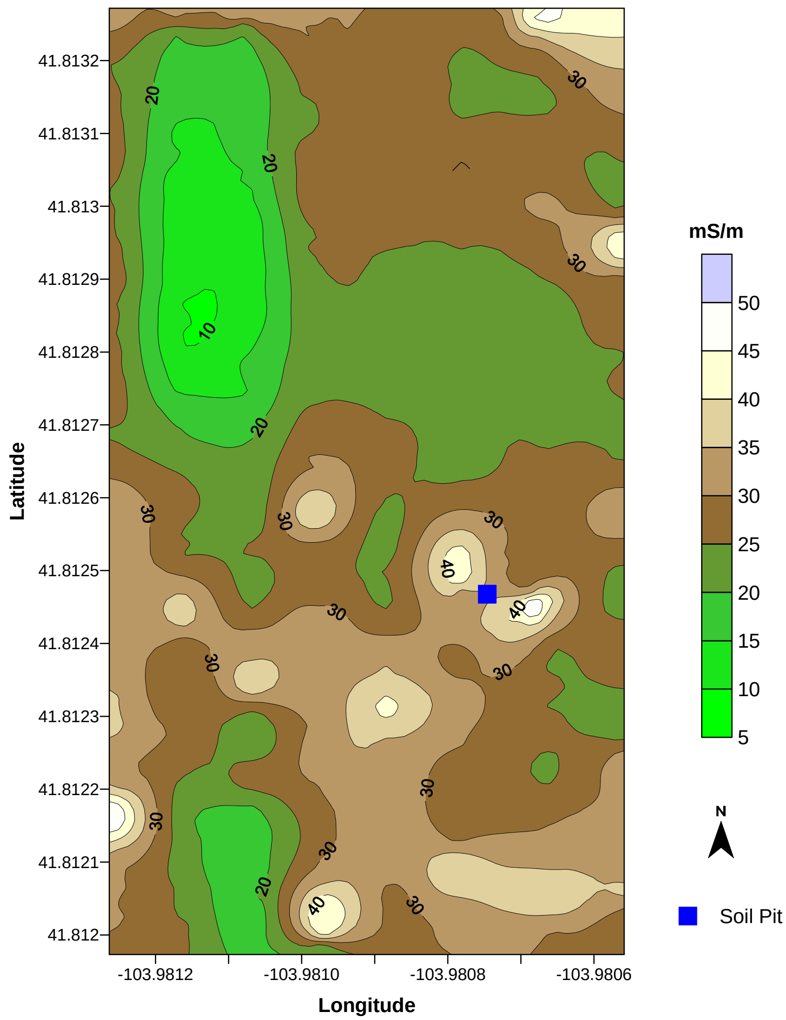

Figure 5. Spatial EC_a patterns collected with the EM38 at Study Site 4.

The two anomalously high (> 35 mS/m) EC_a areas that are located on either side of the excavated soil pit represents the electromagnetic inference from two parked vehicles.

Study Site 4 contains contrasting soils with dissimilar EC_a. At Site 4, EC_a averaged about 27.2 mS/m and ranged from 9.8 to 56.0 mS/m. One-half of the measurements had an EC_a that was between 23.5 and 31.0 mS/m. At the sampled pit, the EC_a was about 34 mS/m. On the basis of these statistics, the excavated pit is located in an area of slightly higher EC_a and is considered non-representative of soils at this site.

<u>Site 5:</u>

Site 5 is located in an area that was mapped as Keith loam, 1 to 3 % slopes (KeA), and Keith-Ulysses complex, 3 to 5 % slopes eroded (KUB2). Figure 6 is a plot of the EC_a data collected with the EM38 meter in the deeper-sensing

(0 to 1.5 m) vertical dipole orientation at this site. In Figure 6, the isoline interval is 5 mS/m. The location of a sampled pit of Duroc soil is also shown in this figure.

Though dominated by the same named soil (Keith), compared with Site 4, the relief, topography, soil patterns and boundary lines are more distinct at Site 5. In Figure 6, blue, segmented lines have been drawn to appropriate the base and crest of a low ridge that traverses the site from west-northwest to east-southeast. The base of the slope approximates the boundary separating a unit of Keith loam, 1 to 3 % slopes (to the north), from a unit of Keith-Ulysses complex, 3 to 5 % slopes, eroded (to the south). As shown in Figure 6, the location of the excavated and sampled soil pit appears representative of the Keith loam, 1 to 3 % slopes, map unit. A zone of higher EC_a (25 to 35 mS/m) parallels the base of the slope and is believed to represent soils with slightly higher moisture and/or clay contents. Other areas of higher EC_a are apparent on the more nearly level area of Keith soil, located in the northern portion of this site. As these patterns are linear, they suggest subsurface stratigraphic or lithologic features, which may be significant to interpretations and should be investigated.

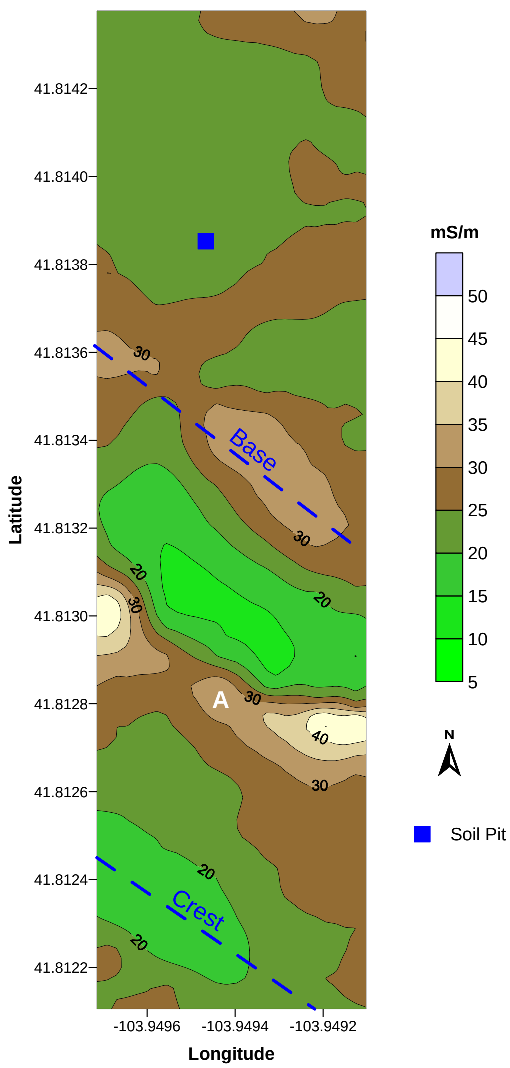

Figure 6. Spatial EC_a patterns collected with the EM38 meter at Study Site 5.

In Figure 6, the summit and shoulder slope components of the ridge have lower (< 25 mS/m) EC_a suggesting better drained and perhaps coarser-textured soils. Midway along the back slope component of this ridge a linear zone of high EC_a is apparent and warranted our investigation. Soil core revealed an included area of Keota soil. Keota soil is moderately deep to siltstone of the Brule formation. The linear band of higher EC_a represents the strike of the sub-cropping Brule formation and an included area of Keota soil. The moderately deep, well drained Keota soils formed in calcareous, silty and loamy materials weathered from the Brule formation.

As with other sites, this site contains contrasting soils with dissimilar EC_a. At Site 5, EC_a averaged about 24.6 mS/m and ranged from 13.0 to 48.8 mS/m. One-half of the measurements had an EC_a that was between 22.4 and 26.90 mS/m. At the sampled pit, the EC_a was 22.5 mS/m. The location of the sampling pit is uniquely representative of the EC_a at this site.

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