United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Soils – Electromagnetic Induction (EMI) training Date: 24 October 2007

To: David C. White
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Purpose:
Training was provided on the use and operation of the EM38 meter, Allegro CX field computer, and related software programs. These tools supply an additional layer of soil information. This technology can be used to provide more comprehensive information on management units than traditional sampling and surveying methods.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Bill Drummond, Soil Scientist, USDA-NRCS, Miles City, MT
Michelle Gorder, Soil Conservationist, USDA-NRCS, Forsyth, MT
Beth Graham, Volunteer, USDA-NRCS, Bridger, MT
Patrick Hensleigh, Agronomist, USDA-NRCS, Bozeman, MT
Rusty Irion, District Conservationist, USDA-NRCS, Miles City, MT
Holger Jensen, Area Resource Conservationists, USDA-NRCS, Miles City, MT
Robert Kilian, Rangeland Management Specialist, USDA-NRCS, Miles City, MT
Robert Mitchell, Resource Soil Scientist, USDA-NRCS, Miles City, MT
Joe Scianna, Resource Horticulturist, USDA-NRCS, Bridger, MT
Darren Zentner, Biological Science Technician (Plants), USDA-NRCS, Bridger, MT

Activities:
All activities were completed on 15 and 16 October 2007. A presentation on EMI tools, applications, and interpretations was provided on the morning of 15 October in the Miles City Service Center. During the afternoon, calibration and survey procedures were reviewed at a nearby site, where a pedestrian survey was completed by the participants. Later that afternoon, procedures for downloading, processing, and displaying apparent conductivity (EC_a) and global positioning system (GPS) data were reviewed in the field office. Results of the EMI survey were plotted using Surfer software and interpretations were discussed. On the morning of 16 October, a mobile EMI survey was completed at the ARS Site. Survey procedures and results were discussed in the field.

Summary:

1. Montana recently upgraded (RT conversion) one of its EM38 meters in order to provide a digital output; purchased software for collecting, storing, and processing both EC_a and GPS data; and also bought an Allegro CX field computer. These technologies support an advanced data collection system that can be used by various staffs involved with site assessments throughout the state.

2. Field training was provided on the operation of the EM38 meter, DAS70 Data Acquisition System, and supporting software. At each field site, an EMI survey was completed and the resulting EC_a data were transferred, processed, and displayed (as two-dimensional plots) using different software programs.

Participants interpreted the spatial EC_a patterns that appeared on contour plots of each study area. At the field sites selected for this training, major spatial EC_a patterns were related principally to differences in the soluble salt contents.

3. Some difficulties were experienced transferring data from the Allegro CX field computer into one of field office's PC when using either a "USB to serial adapter" or "nine pin" cables. No problems were experienced when a "cradle" or "docking station" (available from Juniper Systems; priced at about $120) was used. Direct communication with technicians from Juniper Systems is recommended to resolve the source of this problem. In subsequent conversations with Mike Catalano (Geonics Limited), the use of a flash card and card reader was recommended for transferring data. This problem needs to be resolved so that EC_a and GPS data can be easily and quickly downloaded into a PC for use with GIS.

4. I wish to commend the participants for their attention to instructions, quick mastery of subject matters, and enthusiasm in tackling this technology. However, the information overload was acute during this brief two day training period. A training DVD covering the fundamentals of this system has been provided by the National Soil Survey Center, to help users refresh their memory on the procedures covered.

5. Results contained in this trip report are interpretative and based on the methods and procedures used. As no sampling was carried out during the EMI surveys, interpretations are constrained.

It was my pleasure to work in Montana and to be of assistance to your staff. I wish to assure you that continued assistance will be provided by the National Soil Survey Center as your staff explores and develops uses for these technologies within Montana.

With kind regards,

James A. Doolittle
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cc:
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Background:
Soil surveys are expensive, time-consuming, and labor-intensive endeavors. In order to reduce the expenditure of resources, alternative methods are needed 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 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. Electrical conductivity 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 EMI response represents a single, depth-weighted estimate, which reflects all of these factors over the electromagnetic field's depth of influence. The apparent conductivity of soils increases with increases in soluble salts, water, and/or clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). Typically in soils, changes in the electrolyte concentration of the soil water and the soil water content produce the largest affect on EC_a (Johnston, et al., 1997).

Apparent conductivity provides an additional layer of soil information that can be used to infer and map differences in soils and soil properties. In many areas, spatial EC_a patterns corresponded well with 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: simultaneous variations in more than one property may result in equivalent (or similar) EMI responses. In many landscapes, variations in more than one soil properties create interpretational ambiguities when attempts are made to relate EC_a to a specific soil property. Because of equivalence, a functional analysis of each soil-landscape or management units is recommended to decipher the exact site-specific cause(s) for variations in EC_a (Sommer et al., 2003).

Interpretations of EC_a 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 also been used to estimate soil water (Sheets and Hendrickx, 1995; Kachanoski et al., 1988), clay (Sommer et al., 2003; Williams and Hoey, 1987), exchangeable Ca and Mg (McBride et al., 1990), and soil organic carbon (Jaynes, 1996) contents, as well as 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 (Jaynes, 1995; Jaynes et al., 1995; Sudduth et al., 1995) and to evaluate soil properties that affect yields (Johnson et al., 2001). Jung et al. (2005) used EC_a to estimate properties in the upper 30 cm of soil profiles that are important to soil quality. In each of 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 sensed with EMI.

Electromagnetic induction surveys are commonly conducted with a field computer, which simultaneously records EC_a and global-positioning system (GPS) 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 sets to improve soil interpretations. A routine and convenient method of interpreting geo-referenced EC_a 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 or frequently undertaken.

Equipment:
The EM38 meter is manufactured by Geonics limited (Mississauga, Ontario).[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).

Geonics' DAS70 Data Acquisition System is used with the EM38 meter to record and store both EC_a and position data.[2] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin GPS Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS).[2] When attached to the acquisition system, EC_a and GPS measurements are automatically recorded in the field computer. The NAV38, DAT38W, and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.[2]

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to construct the simulations of EC_a data shown in this report.[2] Grids of EC_a data were created using kriging methods with an octant search.

Field Methods:
For each survey, the EM38 meter was operated in the deeper-sensing (0 to 1.5 m) vertical dipole orientation. Only quadrature phase (conductivity) data were collected. Data are expressed as values of EC_a in milliSiemens/meter (mS/m). The EM38 meter was operated in the continuous (measurements recorded at 1-sec intervals) mode. Using either the DAT38W or NAV38 program, both GPS and EC_a data were simultaneously recorded in the Allegro CX field computer. While surveying, the EM38 meter was held about 5 cm (about 2 inch) above the ground surface and orientated with its long axis parallel to the direction of traverse (see Figure 1). Surveys were completed by either walking (pedestrian survey) or driving an ATV (mobile survey) at a uniform pace, in a random or back and forth pattern across each site.

A pedestrian and a mobile (using an ATV) EMI survey was conducted at the first and second sites, respectively. The mobile EMI survey provides more comprehensive site coverage, in a shorter period of time, and with less effort than the pedestrian surveys. In this survey, an EM38 meter was towed behind an ATV in a plastic sled at speeds of 1 to 3 m/sec (see Figure 2).

The EC_a measurements discussed in this report were not temperature corrected.

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

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

Figure 1. Patrick Hensleigh and Michelle Gorder complete an EMI survey. Patrick is simultaneously operating an EM38 meter, Allegro field computer, and Garmin GPS receiver.

Figure 2. Darren Zentner prepares to conduct a mobile EMI survey of the ARS Site.

Study Sites:
The first field site (referred to as the Muggli Lane Site) is in an irrigated field of alfalfa, which contained barren spots caused by excess salts. The site is located off of Muggli Lane in the SW ¼ of Section 1, T. 8 N., R. 47 E. The site is located in an area of Kobase silty clay loam, 0 to 2 percent slopes (map unit 53A). The very deep, well drained Kobase soils formed in alluvium on stream terraces.

The second field site (referred to as the ARS Site) is in rangeland. The site is located between Main Street and I-94 in the NW ¼ of Section 9, T. 7 N., R. 47 E. The site is located in an area of Marvan-Vanda silty clay, 0 to 4 percent slopes (map unit 621B). The very deep, well drained Marvan and Vanda soils formed in alluvium derived mainly from semiconsolidated sedimentary bedrock on alluvial fans and stream terraces. The taxonomic classifications of these soils are listed in Table 1.

Series	Taxonomic Classification
Kobase	fine, smectitic, frigid Torrertic Haplustepts
Marvan	fine, smectitic, frigid Sodic Haplusterts
Vanda	Fine, smectitic, calcareous, frigid Torrertic Ustorthents

Results:
Muggli Lane Site:
Within Muggli Lane Site, EC_a was relatively high and variable and ranged from about 53.7 to 219.2 mS/m. EC_a averaged 116.7 mS/m with a standard deviation of 30.1 mS/m. One-half of the EC_a measurements were between 96.8 and 135.9 mS/m. The high and variable EC_a was attributed to the evaporation of irrigation waters and the accumulations of salts in surface layers.

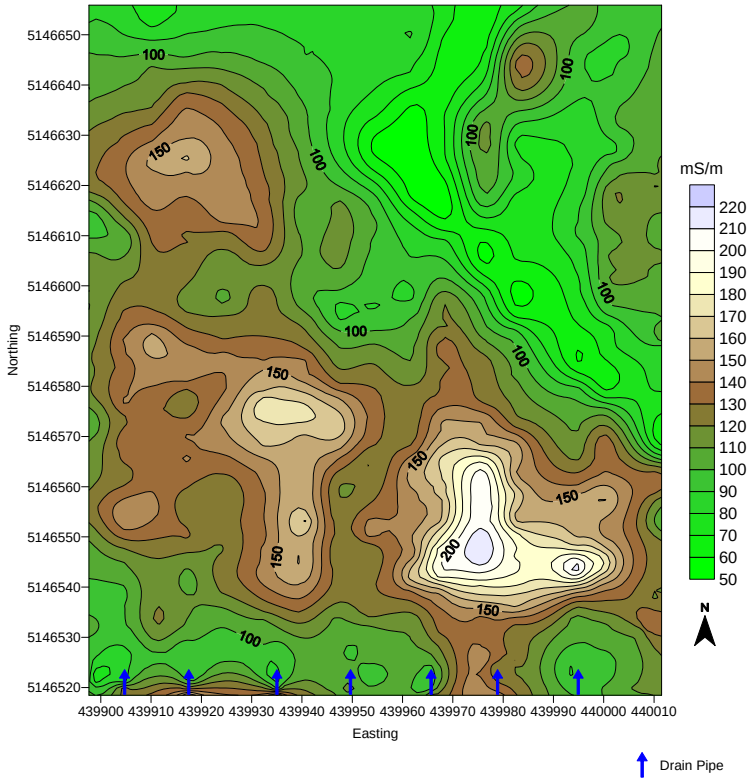

Figure 3. Areas of higher EC_a within the Magguli Lane Site are attributed to more saline soils.

Initially, it was suspected that the evaporation of ponded irrigation water has led to the accumulation of excess salts at the Muggli Lane Site. The land has been leveled and is partitioned into narrow, north-south orientated rectangular management units, which are separated and defined by low berms or dikes. Culverts (shown as blue arrows in Figure 1) permit water to flow into these units of management. In general, areas immediately adjacent to these culverts receive more water and, because of greater leaching, have noticeably lower EC_a. Because of land-leveling, depressions are very slight and not conspicuous across the site. The spatial EC_a patterns evident in Figure 3 suggest contrasting bands of soils with differing physical and chemical properties. As the site is located on the floodplain of the Yellowstone River, these bands may represent contrasting alluvial deposits. Differences in particle-size distributions and permeability among these inferred bands of contrasting alluvium could be influence the flow of soil moisture and be responsible for the salinity patterns evident within these units of management.

<u>ARS Site:</u>
Compared with the Muggli Lane Site, EC_a within ARS Site was lower and less variable. Based on 1841 measurements, EC_a ranged from about 39.6 to 144.2 mS/m. EC_a averaged 94.6 mS/m with a standard deviation of 23.1 mS/m. One-half of the EC_a measurements were between 77.1 and 115.4 mS/m. As observed by Robert Kilian, the noticeable zone of higher EC_a (see northwest portion of survey area in Figure 4) corresponds with an area infested with greasewood. These plants are more tolerant of soils with higher sodium and salt contents and cycle these components into the surface layers.

Results obtained by Stroh et al. (1993) in south Texas suggest that EMI can be a cost-effective tool for exploration applications in plant ecology. As such, EMI is useful for rapidly locating and mapping subsurface discontinuities, thereby reducing the number of ground truth soil samples needed for accurate mapping of soil map unit and ecological boundaries. The study by Stroh et al. (1993) demonstrated the potential of EMI for enabling rapid, extensive screening of plant-soil relationships across landscapes where soil properties and the depth and development of soil horizons may vary.

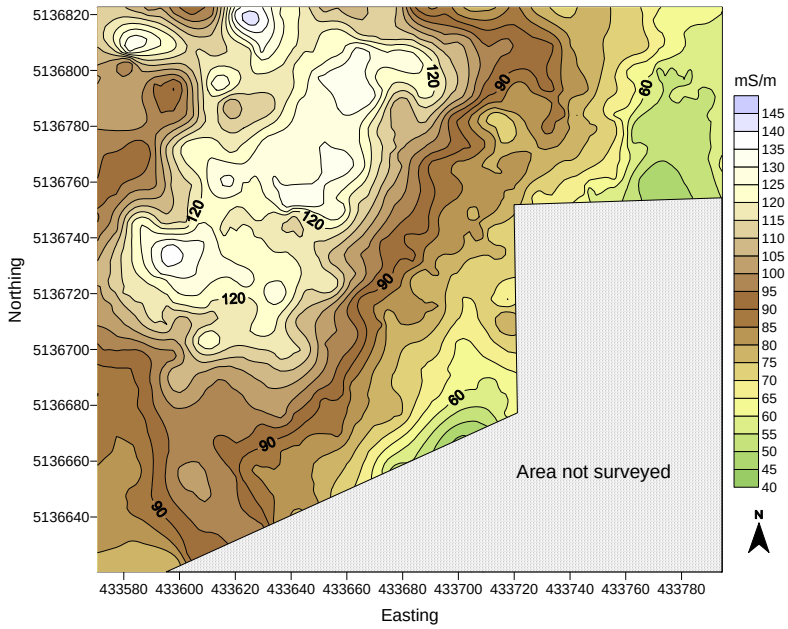

Figure 4. Areas of higher EC_a within the ARS Site correspond with an infestation of greasewood.

References:

Corwin, D. L. and S. M. Lesch, 2005. Characterizing soil spatial variability with apparent soil electrical conductivity. Part I. Survey protocols. Computers and Electronic in Agriculture 46: 103-133.

Doolittle, J., R. Murphy, G. Parks, and J. Warner, 1996. Electromagnetic induction investigations of soil delineation in Reno County, Kansas. Soil Survey Horizons 37:11-20.

Doolittle, J. A., K. A. Sudduth, N. R. Kitchen, and S. J. Indorante, 1994. Estimating depth to claypans using electromagnetic inductive methods. J. Soil and Water Conservation 49(6): 552-555.

Fenton, T. E. and M. A. Lauterbach, 1999. Soil map unit composition and scale of mapping related to interpretations for precision soil and crop management in Iowa. 239-251 pp. IN: Robert, P. C., R. H. Rust, and W. E. Larson (Eds.) Proceeding of the 4th International Conference on Site-Specific Management. St Paul, MN, July 19-22, 1998. American Society of Agronomy. Madison, WI.

Freeland, R. S., R. E. Yoder, J. T. Ammons, and L. L. Leonard. 2002. Mobilized surveying of soil conductivity using electromagnetic induction. Applied Engineering in Agriculture 18(1): 121-126.

Geonics Limited, 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Greenhouse, J. P., and D. D. Slaine, 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Jaynes, D. B., 1995. Electromagnetic induction as a mapping aid for precision farming. 153-156 pp. IN: Clean Water, Clean Environment, 21st Century: Team Agriculture. Working to Protect Water Resources. Kansas City, MO. 5 to 8 March 1995.

Jaynes, D.B., 1996. Improved Soil Mapping using Electromagnetic Induction Surveys. 169-179 pp. Proc. 3rd Int. Conf. on Precision Agriculture, Minneapolis, June 23-26, 1996. ASA-CSSA-SSSA. Madison, WI.

Jaynes, D. B., T. S. Colvin, J. Ambuel, 1993. Soil type and crop yield determination from ground conductivity surveys. 1993 International Meeting of American Society of Agricultural Engineers. Paper No. 933552. ASAE, St. Joseph, MI.

Jaynes, D. B., J. M. Novak, T. B. Moorman, and C. A. Cambardella, 1994. Estimating herbicide partition coefficients from electromagnetic induction measurements. J. Environmental Quality. 24:36-41.

Jaynes, D. B., T. S. Colvin, and J. Ambuel, 1995. Yield mapping by electromagnetic induction. 383-394 pp. IN: Robert, P. C., R. H. Rust, and W. E. Larson (editors). Proceedings of Second International Conference on Precision Management for Agricultural Systems. Minneapolis, MN. March 27-30, 1994. American Society of Agronomy, Madison, WI.

Johnson, C. K., J. W. Doran, H. R. Duke, B. J. Wienhold, K. M. Eskridge, and J. F. Shanaha, 2001. Field-scale conductivity mapping for delineating soil condition. Soil Sci. Soc. Am. J. 65:1829-1837.

Johnson, M. A., M. J. Savage, J. H. Moolman, and H. M. du Plessis, 1997. Evaluation of calibration methods for interpreting soil salinity from electromagnetic induction measurements. Soil Sci. Soc. Am. J. 61: 1627-1633.

Jung, W. K., N. R. Kitchen, K. A. Sudduth, R. J. Kremer, and P. P. Motavalli, 2005. Relationship of apparent soil electrical conductivity to claypan soil properties. Soil Sci. Soc. Am. J. 69: 883-892.

Kachanoski, R. G., E. G. Gregorich, and I. J. van Wesenbeeck, 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

Kitchen, N. R., T. S. Drummond, E. D. Lund, K. A. Sudduth, and G. W. Buchleiter, 2003. Soil electrical conductivity and topography related yield for three contrasting soil-crop systems. Agronomy Journal 95: 483-495.

Kitchen, N. R., K. A. Sudduth, D. B. Meyers, S. T. Drummond, and S. Y. Hong, 2005. Delineating productivity zones on claypan soil fields using apparent soil electrical conductivity. Computers and Electronic in Agriculture 46: 285-308.

Kravchenko, A. N., G. A. Bollero, R. A. Omonode, and D. G. Bullock, 2002. Quantitative mapping of soil drainage classes using topographical data and soil electrical conductivity. Soil Sci. Soc. Am. J. 66:235-243.

McBride, R. A., A. M. Gordon, and S. C. Shrive, 1990. Estimating forest soil quality from terrain measurements of apparent electrical conductivity. Soil Sci. Soc. Am. J., 54:290-293.

McNeill, J. D., 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6. Geonics Ltd., Mississauga, Ontario.

Rhoades, J. D., and D. L. Corwin, 1981. Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci. Soc. AM. J. 45: 255-260.

Rhoades, J. D., P. A. Raats, and R. J. Prather, 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Sheets, K. R., and J. M. H. Hendrickx, 1995. Noninvasive soil water content measurements using electromagnetic induction. Water Resources Research 31: 2401-2409.

Slavich, P.G., and J. Yang, 1990. Estimation of field scale leaching rates from chloride mass balance and electromagnetic induction measurements. Irrig. Sci. 11:7-14.

Sommer, M., M. Wehrhan, M. Zipprich, U. Weller, W. zu Castell, S. Ehrich, B. Tandler, and T. Selige, 2003. Hierarchical data fusion for mapping soil units at field scale. Geoderma 112: 179-196.

Stroh, J., S. R. Archer, L. P. Wilding, and J. Doolittle, 1993. Assessing the influence of subsoil heterogeneity on vegetation patterns in the Rio Grande Plains of south Texas using electromagnetic induction and geographical information system. College Station, TX. The Station (Mar 93): 39-42.

Stafford, J. V., 2000. Implementing precision agriculture in the 21st Century. J. Agric. Engineering Research 76: 267-275.

Sudduth, K. A., and N. R. Kitchen, 1993. Electromagnetic induction sensing of claypan depth. Paper No. 93-1550. Presented at the December 1993, Winter Meetings of the American Society of Agricultural Engineers. St. Joseph, MI.

Sudduth, K. A., N. R. Kitchen, D. H. Hughes, and S. T. Drummond, 1995. Electromagnetic induction sensing as an indicator of productivity on claypan soils. pp. 671-681. IN: Robert, P. C., R. H. Rust, and W. E. Larson (editors). Proceedings of Second International Conference on Precision Management for Agricultural Systems. Minneapolis, Minnesota. March 27-30, 1994. American Society of Agronomy, Madison, WI.

Williams, B. G., and D. Hoey, 1982. An electromagnetic induction technique for reconnaissance surveys of salinity hazards. Australian Journal of Soil Research 20: 107-118.