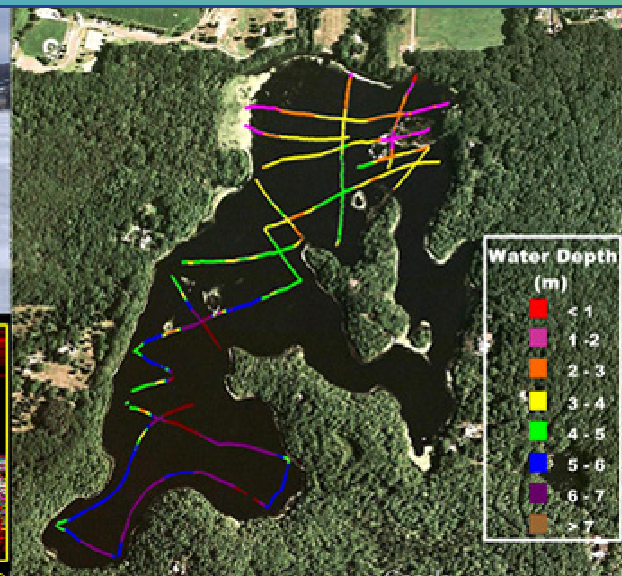
FastTIMES

December 2010
Volume 15, Number 4
www.eegs.org

Agriculture: A Budding Field in Geophysics



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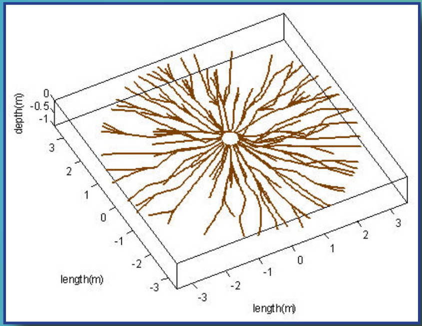

3D Root Morphology Map

Agricultural Resistivity Survey

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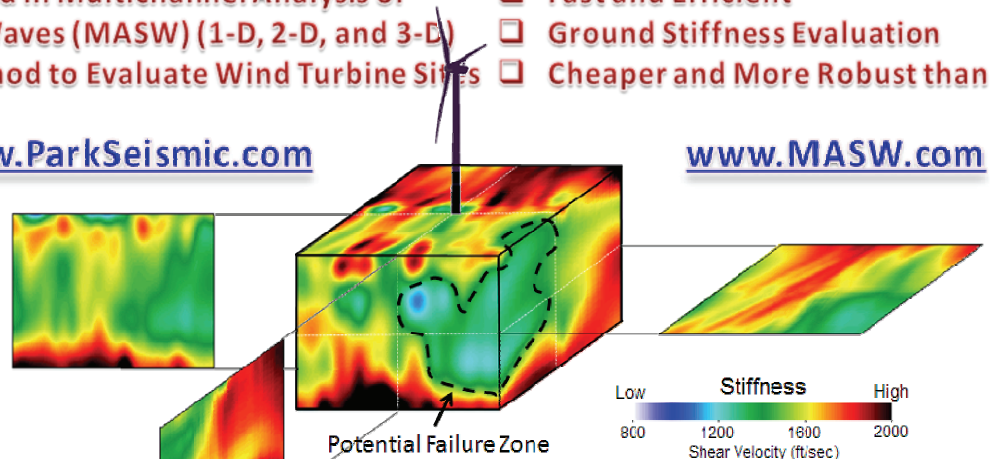

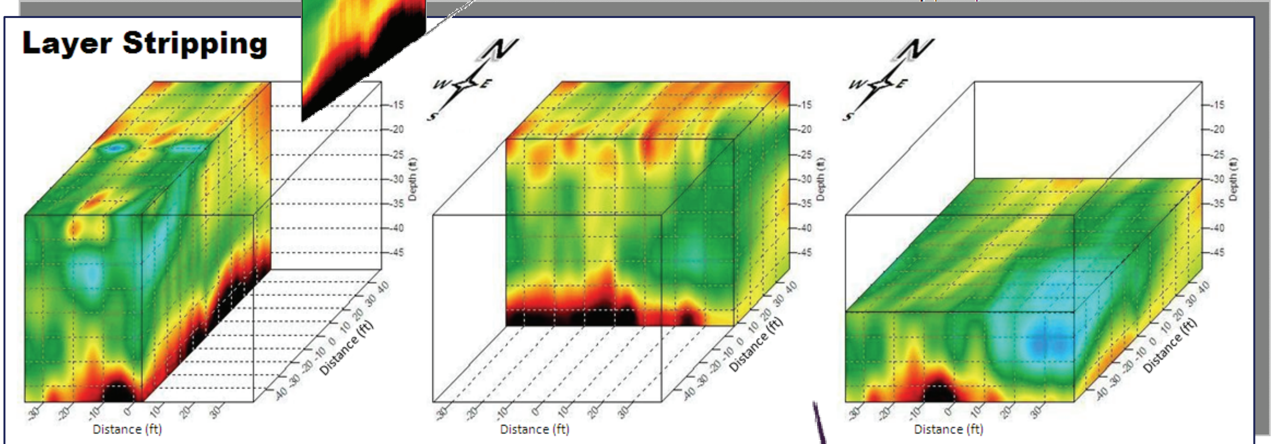

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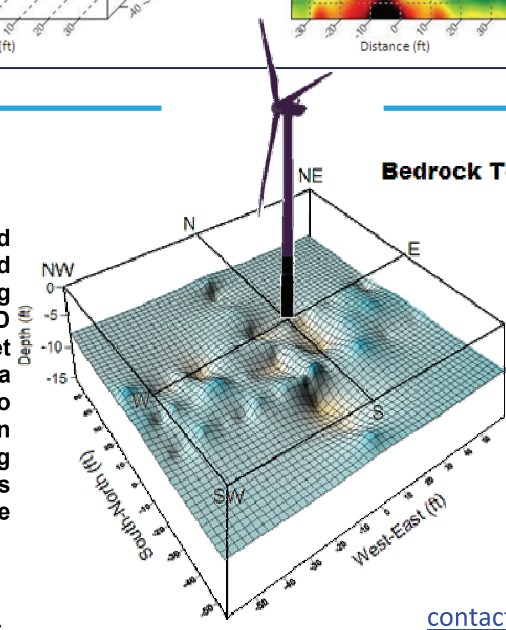

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On the Cover

This issue features advances in soil and agricultural investigations using geophysical techniques. **Top:** Subaqueous soil mapping (J. Doolittle). **Lower left:** Spatial soil health investigation with electrical conductivity sensing (N. Kitchen). **Lower Center:** 'Virtual Excavation' conducted by A. Mucciardi. **Lower Right:** Continuous soil resistivity mapping using a Veris 3100 system (B. Allred).

What We Want From You

The ***FastTIMES*** editorial team welcomes contributions of any subject touching upon geophysics. Our next issue will bring you a selection of the best SAGEEP articles in the past five years. ***FastTIMES*** also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the ***FastTIMES*** editorial team by February 21, 2011 to ensure inclusion in the next issue. We look forward to seeing your work in our pages.

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FastTIMES

FastTIMES (ISSN 1943-6505) is published by the Environmental and Engineering Geophysical Society (EEGS). It is available electronically (as a pdf document) from the EEGS website (www.eegs.org).

About EEGS

The Environmental and Engineering Geophysical Society (EEGS) is an applied scientific organization founded in 1992. Our mission:

"To promote the science of geophysics especially as it is applied to environmental and engineering problems; to foster common scientific interests of geophysicists and their colleagues in other related sciences and engineering; to maintain a high professional standing among its members; and to promote fellowship and cooperation among persons interested in the science."

We strive to accomplish our mission in many ways, including (1) holding the annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (**SAGEEP**); (2) publishing the ***Journal of Environmental & Engineering Geophysics (JEEG)***, a peer-reviewed journal devoted to near-surface geophysics; (3) publishing ***FastTIMES***, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

Joining EEGS

EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are currently $90 for an individual membership, $50 for a retired member $20 for a student membership, $50 developing world membership, and $650 to $4000 for various levels of corporate membership. All membership categories include free online access to JEEG. The membership application is available at the back of this issue, or online at www.eegs.org. See the back page for more information.

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To advertise in ***FastTIMES***, contact:

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FastTIMES is published electronically four times a year. Please send articles to any member of the editorial team by February 21, 2011. Advertisements are due to Jackie Jacoby by February 21, 2011.

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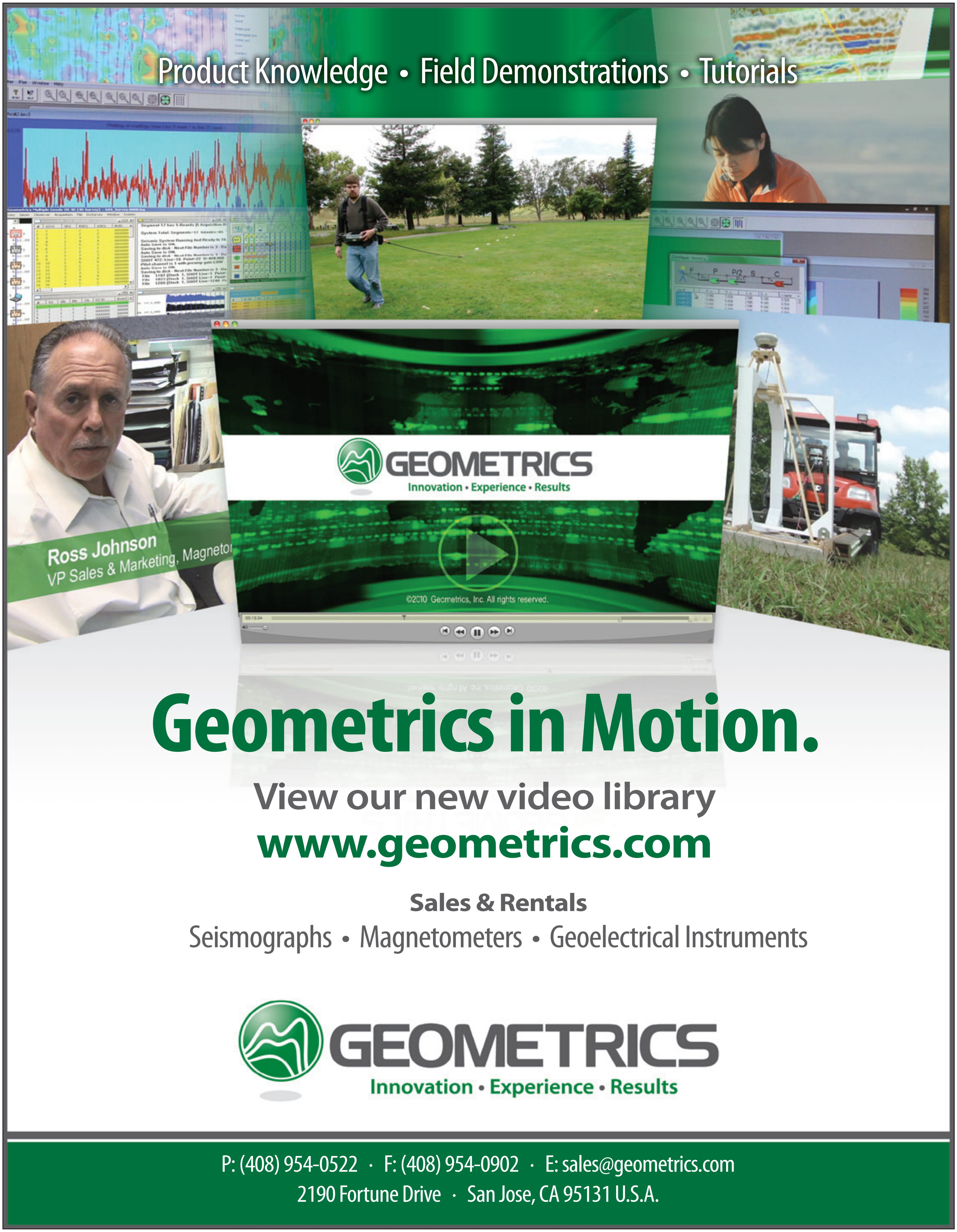
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Calendar

*Please send event listings, corrections or omitted events to any member of the **FastTIMES** editorial team.*

2011	
January 10–14	12th Multidisciplinary Conference on Sinkholes and Engineering and Environmental Impacts of KarstTM, St. Louis, Missouri
February 17-18	NAPE Expo. The World's Largest Prospect and Property Expo
February 21	Deadline for submission of articles, advertisements, and contributions to the March issue of *FastTIMES*
February 28	Deadline for submission of articles for the special issue of JEEG on Geophysics for Levee Safety
April 10–14	SAGEEP 2011: Symposium on the Application of Geophysics to Environmental and Engineering Problems, Charleston, SC
May 9–11	NovCare 2011: Novel Methods for Subsurface Characterization and Monitoring: From Theory to Practice, Ocean Edge Resort, Brewster, MA
May 15-19	Proximal Soil Sensing: Global Workshop on High Resolution Digital Soil Sensing and Mapping, McGill University, Montreal, Canada
May 23–26	73rd EAGE Conference & Exhibition: Unconventional Resources and the Role of Technology, Vienna, Austria
May 21	Deadline for submission of articles, advertisements, and contributions to the June issue of *FastTIMES*
May 31	Deadline for submission of abstract to the 10th SEGJ International Symposium, Kyoto, Japan
June 22–24	International Workshop on Advanced Ground Penetrating Radar 2011: presents a wide range of scientific and technical information of high standard to scientists, engineers and end-users of GPR technology. Aachen, Germany
June 28–July 7	IUGG General Assembly: International Union of Geodesy and Geophysics (IUGG) General Assembly invites researchers world-wide to participate in an exciting, multi-disciplinary conference on cutting edge science, Melbourne, Australia
August 21	Deadline for submission of articles, advertisements, and contributions to the September issue of *FastTIMES*

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Notes from EEGS

President's Message: Recent Activities

John Stowell, President (john.stowell@mountsopris.com)

As we look forward to 2011, it seems fitting to summarize the highlights of a very successful 2010 for your society. The problem with such a summary is that it is very easy to leave out important contributions and events, so I will start by apologizing for items not mentioned. What I can tell you is that your board and committee members were busy, and the society would not function without their hard work. We also are indebted to the staff at WMR who help keep everything moving forward and on schedule.

We added 113 new members to our society this year. This figure is important when we consider that we also lost quite a few, mostly due to the recession and resulting economic hardships. One of the primary goals of your board is to work on increasing membership in the coming year. While our annual meeting is a major revenue generator, our society needs a strong membership to continue as the premier near-surface geophysical organization. We will call upon our members to help us in this mission, and if anyone reading this desires to help out, contact John Dunbar or Barry Allred (e-mail addresses listed in the Board Members section).

As most of you are aware, the SAGEEP meeting held in Keystone was extremely successful. The SAGEEP 2011 committee, guided by General Chair Bill Doll and Technical Chair Greg Baker, are putting together the final program details. Make sure you have set aside the week of April 10-14th to come to Charleston and participate in this exciting event. We have accepted a record number of abstracts for the technical program, and have lined up an impressive list of featured speakers, workshops, and demonstrations, and exhibitors.

Regarding the success of SAGEEP, it seems like a good time to offer thanks to our government sponsors, who each year provide funds that help ensure the success of SAGEEP. They are also suffering from budget cuts due to the economic slowdown, and we are pleased that they can still help us out.

During the past year, on the publications side of our society, we have enjoyed several excellent FastTimes e-magazines, edited by Moe Momayez. Janet Simms has produced several very interesting JEEGS, with a joint EAGE-NS issue planned for 2011. We just received our first copies of the joint AGU-SEG-EEGS publication *Advances in Near-Surface Seismology and Ground-Penetrating Radar*. Contact Jackie Jacoby on the EEGS web site to order your copy. We also signed an agreement with EAGE to include our SAGEEP proceedings and the Journal on EARTHDOC; all EEGS members have access to the EAGE publications on that prestigious site.

EEGS will be launching our new website in a matter of months. We are excited about this new resource, and believe you will find it very useful. We are also looking into the various social networks and professional versions of the same. If you have any comments or suggestions about how we might benefit from such opportunities, please contact board member Chih-Ping Lin.

Look for more society interaction with the Geophysics without Borders Program. Our brand of geophysics lends itself to this type of work more than any other. We look forward to new opportunities and challenges in 2011, and as always, appreciate your comments and support.

EEGS Foundation makes great strides in its first years.

Since the launch of the EEGS Foundation, there are numerous accomplishments for which we can all be proud: Establishing and organizing a structure that serves the needs of EEGS; underwriting the legal process, achieving tax-exempt status; and soliciting and receiving support for SAGEEP. In addition, the Foundation helped underwrite the SAGEEP conference held this spring in Keystone.

These are only a few of the tangible results your donations to the Foundation have enabled. We would therefore like to recognize and gratefully thank the following individuals and companies for their generous contributions:

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It's time to renew your membership in EEGS – we've added options and increased benefits!

EEGS members, if you have not already received a call to renew your membership, you will – soon! There are a couple of changes of which you should be aware before renewing or joining.

Benefits - EEGS has worked hard to increase benefits without passing along big increase in dues. As a member, you receive a Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) registration discount big enough to cover your dues. You also receive the Journal of Environmental and Engineering Geophysics (JEEG), the *FastTIMES* newsletter, and full access to the EEGS research collection, which includes online access to all back issues of JEEG, SAGEEP proceedings, and SEG extended abstracts. You get all of this for less than what many societies charge for their journals alone.

Dues Changes - EEGS has worked hard to hold the line against dues increases resulting from inflation and higher costs. Instead, EEGS leadership sought ways to offer yesterday's rates in today's tough economic climate. Therefore, you can continue your EEGS membership without any rate increase if you opt to receive the JEEG in its electronic format, rather than a printed, mailed copy. Of course, you can continue to receive the printed JEEG if you prefer. The new rate for this membership category is modestly higher reflecting the higher production and mailing costs. A most exciting addition to EEGS membership choices is the new discounted rate for members from countries in the developing world. A growing membership is essential to our society's future, so EEGS is urging those of you doing business in these countries to please encourage those you meet to take advantage of this discounted membership category, which includes full access to the EEGS research collection. And, EEGS is pleased to announce the formation of a Retired category in response to members' requests.

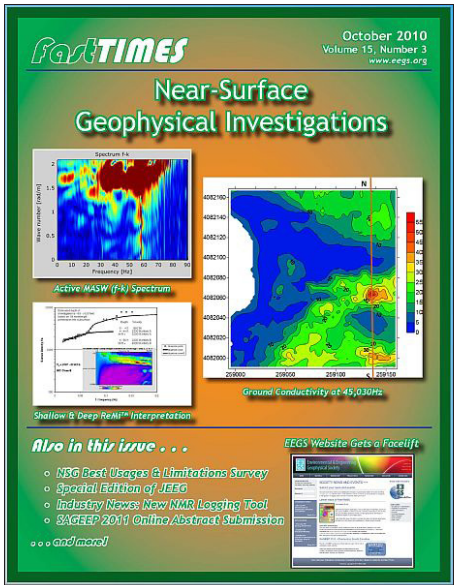
Descriptions of all the new membership options are outlined on EEGS' web site (www.eegs.org) in the membership section.

Renew Online - Last year, many of you took advantage of our new online membership renewal (or joining EEGS) option. It is quick and easy, taking only a few moments of your time. Online membership and renewal application form is available at www.eegs.org (click on Membership and then on Online Member Application / Renewal).

EEGS Foundation - EEGS launched a non-profit foundation (www.eegsfoundation.org) that we hope will enable our society to promote near-surface geophysics to other professionals, develop educational materials, fund more student activities, and meet the increasing demand for EEGS programs while lessening our dependence on membership dues. A call for donations (tax deductible*) to this charitable organization is now included with your renewal materials and can be found on the online Member Resources page of EEGS' web site (www.eegs.org/pdf_files/eegs_foundation.pdf).

Member get a Member - Finally, since the best way to keep dues low without sacrificing benefits is to increase membership, please make it your New Year's resolution to recruit at least one new EEGS member. If every current member recruited even one new member to EEGS, we could actually consider lowering dues next year!

*As always, seek professional advice when claiming deductions on your tax return.



From the FastTIMES Editorial Team

FastTIMES is distributed as an electronic document (pdf) to all EEGS members, sent by web link to several related professional societies, and is available to all for download from the EEGS web site at *www.eegs.org/fasttimes/latest.html*. The most recent issue (October 2010, cover image at left) has been downloaded more than 25,000 times as of November 2010, and past issues of ***FastTIMES*** continually rank among the top downloads from the EEGS web site. Your articles, advertisements, and announcements receive a wide audience, both within and outside the geophysics community.

To keep the content of ***FastTIMES*** fresh, the editorial team strongly encourages submissions from researchers, instrument makers, software designers, practitioners, researchers, and consumers of geophysics—in short, everyone with an interest in near-surface geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, professional opportunities, problems needing solutions, and advertisements for hardware, software, or staff positions.

The ***FastTIMES*** presence on the EEGS web site has been redesigned. At *www.eegs.org/fasttimes*, you'll now find calls for articles, author guidelines, current and past issues, and advertising information.

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The JEEG Page

*The **Journal of Environmental & Engineering Geophysics (JEEG)**, published four times each year, is the EEGS peer-reviewed and Science Citation Index (SCI®)-listed journal dedicated to near-surface geophysics. It is available in print by subscription, and is one of a select group of journals available through GeoScienceWorld (www.geoscienceworld.org). **JEEG** is one of the major benefits of an EEGS membership. Information regarding preparing and submitting **JEEG** articles is available at http://jeeg.allentrack.net.*

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Journal of Environmental & Engineering Geophysics

December 2010 Volume 15 Issue 4

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The Environmental and Engineering Geophysical Society

Journal of Environmental & Engineering Geophysics
v. 15, no. 4, December 2010

Editor's Scratch

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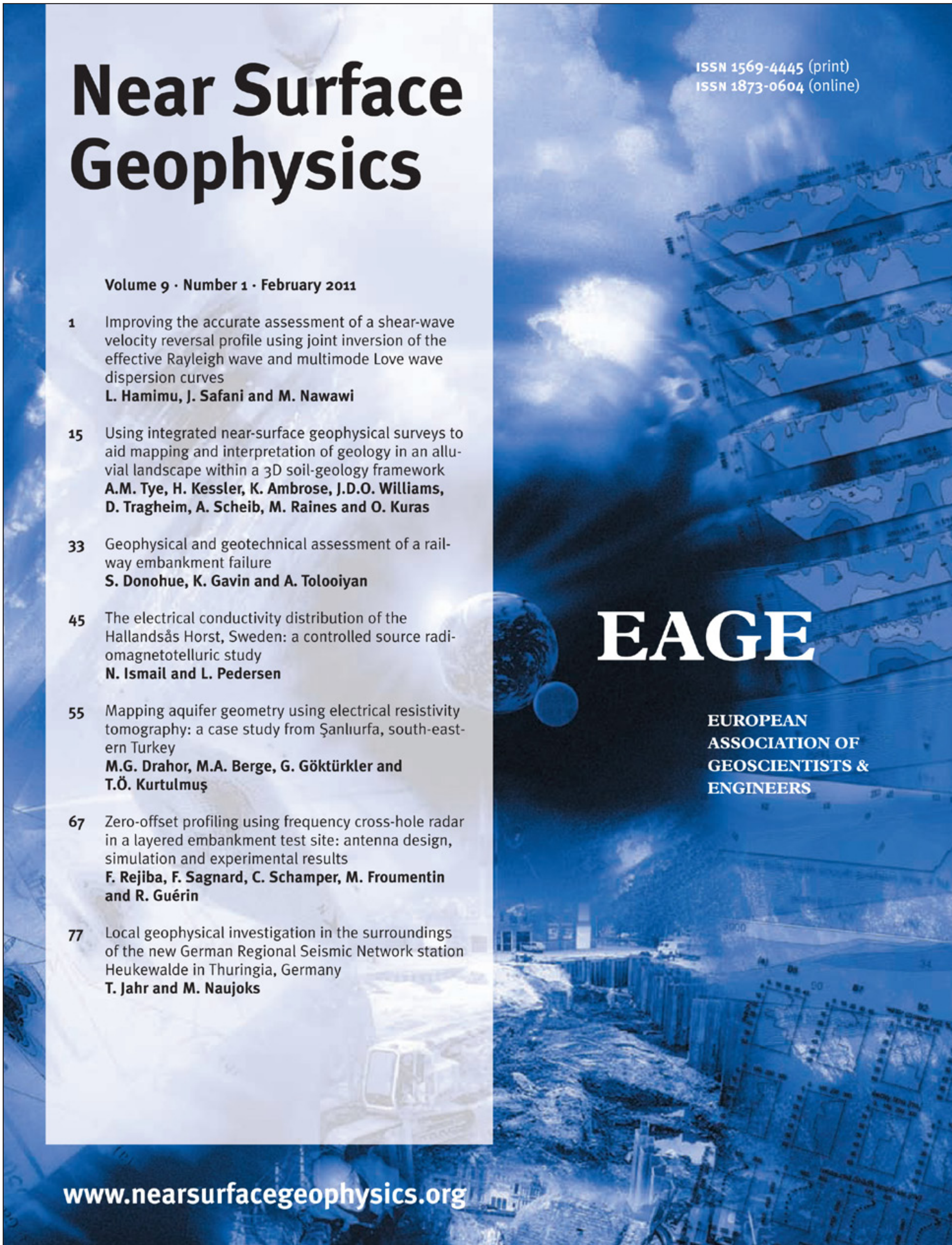
The ***Journal of Environmental and Engineering Geophysics (JEEG)*** is the flagship publication of the Environmental and Engineering Geophysical Society (EEGS). All topics related to geophysics are viable candidates for publication in ***JEEG***, although its primary emphasis is on the theory and application of geophysical techniques for environmental, engineering, and mining applications. There is no page limit, and no page charges for the first ten journal pages of an article. The review process is relatively quick; articles are often published within a year of submission. Articles published in ***JEEG*** are available electronically through GeoScienceWorld and the SEG's Digital Library in the EEGS Research Collection. Manuscripts can be submitted online at www.eegs.org/jeeg/index.html.

EAGE’s Near Surface Geophysics Journal, February 2011

*As a courtesy to the European Association of Geoscientists and Engineers (EAGE) and the readers of **FastTIMES**, we reproduce the table of contents from the October issue of EAGE’s **Near Surface Geophysics** journal.*



Near Surface Geophysics

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EAGE

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Success with Geophysics

FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, soil science, hydrology, archaeology, and astronomy. In the articles that follow, the authors present examples of geophysical techniques applied to soil and agricultural investigations.

Application of Geophysical Methods to Agriculture: An Overview

Barry J. Allred, USDA/ARS – Soil Drainage Research Unit, Columbus, OH (barry.allred@ars.usda.gov)
Robert S. Freeland, Biosystems Engineering and Soil Science, University of Tennessee, Knoxville, TN (rfreelan@utk.edu)

Settings, Scales, and Complexities of Agricultural Geophysics

Geophysical methods are becoming an increasingly valuable tool for application within a wide range of agroecosystems. An agroecosystem can be simply defined as a spatially and functionally consistent landscape unit devoted to some form of agricultural activity (e.g. crop production, raising of farm animals, development of timber resources, turfgrass management, etc.). Figure 1 provides a few examples of agroecosystem settings where geophysical methods can and have been employed. The scale for geophysical applications to agriculture can be extremely small, on the order of centimeters,

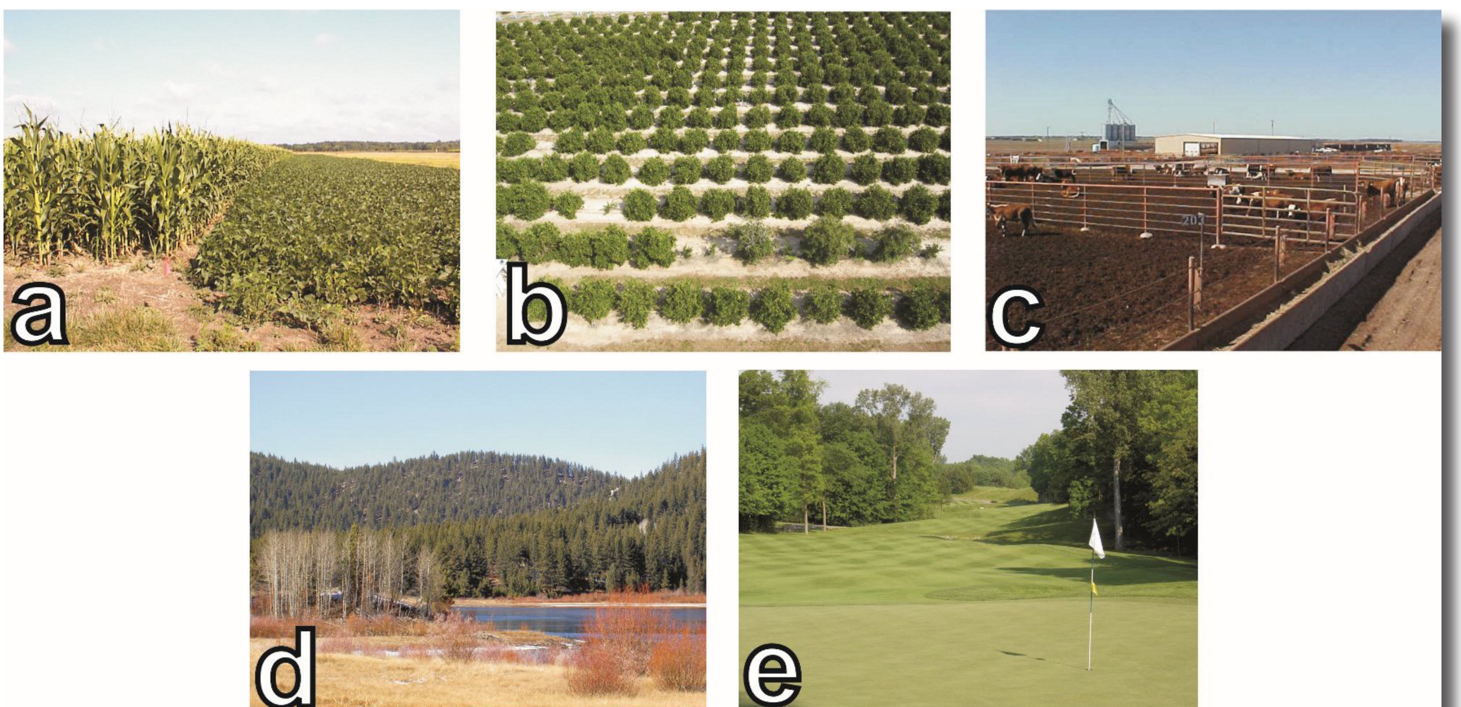

Figure 1. Examples of agroecosystems where geophysical methods have been employed; (a) farm fields, (b) orchards, (c) cattle feedlots, (d) managed forests, and (e) golf courses.

such as might be the case for tree trunk disease investigations (al Hagrey, 2007) or imaging of root crop development directly beneath the ground surface (Konstantinovic and others, 2008). For geophysical soil investigations, interest is often focused on an interval from the ground surface down to a depth of 2 meters. This depth interval generally contains the whole soil profile, including the crop root zone (Allred and others, 2008). Although the depth of interest is oftentimes rather shallow, the area covered by an agricultural geophysics soil investigation can vary widely in scale, from experimental plots

(10s to 100s of square meters), to farm fields (10s to 100s of hectares), and potentially up to the size of watersheds (10s to 1000s of square kilometers). With respect to agricultural geophysics applications, this extremely shallow 2 m depth of interest is certainly an advantage, since most geophysical methods presently available have investigation depth capabilities that can exceed 2 m.

Although investigation depths can be rather shallow, there are complexities associated with agriculture geophysics that are not always encountered with the application of geophysical methods to other industries or disciplines. One such complexity involves the transient nature of certain soil conditions and properties that affect geophysical measurements. For instance, apparent soil electrical conductivity (ECa) measured using resistivity and electromagnetic induction methods, is significantly influenced by temperature and moisture conditions, and these temperature and moisture conditions can change appreciably over a period of days or even hours, in turn significantly altering the measured ECa over the same timeframe. Moisture conditions also govern the soil relative permittivity (or dielectric content); thereby impacting ground penetrating radar results obtained within agroecosystem settings. Measured ECa is additionally affected by soil nutrient levels and salinity that sometimes exhibit little variation over long periods, but will then change rapidly with an irrigation or fertilizer application event. Other soil properties affecting ECa, if they vary temporally at all, do so at a much slower rate, and in this category are properties including pH, organic matter content, amount and type of clay minerals present, cation exchange capacity, specific surface, etc.

Another complexity regarding agricultural geophysics is that the soil conditions and properties impacting geophysical measurements vary not only temporally, but also spatially, often exhibiting substantial variability over very short horizontal and vertical distances. For soils without salinity or nutrient build-up concerns, it has been noted that although average ECa values for an agricultural field may vary with changes in soil temperature and moisture, the ECa spatial pattern itself within an agricultural field tends to remain relatively consistent over time, regardless of the transient temperature and shallow hydrologic conditions, thus indicating that ECa spatial patterns were governed predominantly by the spatial variations in the more stable soil properties (Banton and others, 1997; Lund and others, 1999; Farahani and Buchleiter, 2004; Farahani and others, 2005; Allred and others, 2005a; Allred and others, 2006). In many cases, ECa is a quantitative proxy for a single soil property such as for salinity within some irrigated agricultural areas of California (Rhoades and Ingvalson, 1971; Lesch and others, 1992); but conversely, there are also agricultural areas in which a complex relationship exists between ECa and several soil properties (Johnson and others, 2001; Allred and others, 2005a; Carroll and Oliver, 2005; Allred and others, 2009).

Predominant Geophysical Methods Utilized for Agriculture

The three geophysical methods predominantly employed for agricultural purposes are resistivity, electromagnetic induction (EMI), and ground penetrating radar (GPR). Continuous measurement galvanic contact resistivity systems integrated with Global Positioning System (GPS) receivers have been developed specifically for agriculture. Steel coulters (disks) that cut through the soil surface are utilized as current or potential electrodes. These resistivity systems can have more than one four-electrode array providing shallow investigations depths of 0.3 to 2 m, with short time periods (~ 1 per second) or distance intervals between the continuously collected discrete soil electrical conductivity (ECa) measurements. The location for each ECa measurement is determined accurately by GPS. Consequently, these resistivity systems, with their fast ECa measurement rates and integrated GPS receivers, are capable of surveying large farm fields in a relatively short period of time. Figure 2 shows an example of a continuous measurement galvanic contact resistivity system employed for agricultural applications. It should be noted that capacitively-coupled resistivity systems integrated with GPS receivers also have substantial potential for agricultural use (Allred and others, 2006), but these systems have not yet been extensively employed for this purpose.

Figure 2. Example of a continuous measurement galvanic contact resistivity system; (a) Veris 3100 Soil EC Mapping System (Veris Technologies, Salina, Kansas, U.S.A.) and (b) close-up of steel coulters used for current and potential electrodes by the Veris 3100 Soil EC Mapping System.

Some EMI ground conductivity meters have been developed, which are particularly well suited for agricultural applications. The ground conductivity meters typically employed for obtaining agricultural ECa measurements have intercoil spacings of around 1 m; and as a consequence, effective investigations depths of 1.5 m or less when positioned near the ground surface, based on McNeill (1980). Vertical, horizontal, and perpendicular dipole orientations of the ground conductivity meter transmitter and receiver coils can provide different ECa investigation depths within an agricultural setting. Most of these EMI ground conductivity meters can easily be integrated with GPS receivers to provide accurate locations of continuously collected discrete ECa measurements. As with the previously described resistivity systems, the proper EMI ground conductivity meter integrated with a GPS receiver is capable of relatively quick ECa mapping over large farm fields. Although primarily used to map ECa, ground conductivity meters can also be used to measure magnetic susceptibility, a property that has been demonstrated useful for delineating hydric soils (Grimley and Vepraskas, 2000; Grimley and others, 2008; Wang and others, 2008). Two examples of ground conductivity meters commonly used for agricultural applications are shown in Figure 3.

The GPR systems utilized within agroecosystem settings typically employ antennas with center frequencies in the range of 100 MHz to 1.5 GHz. This antenna frequency range covers many agricultural scenarios where the goal is to image shallow buried features/objects within 2 m of the surface. The anticipated depth and size of the subsurface feature/object of interest will provide guidance on the antenna frequency to use. For example, 250 MHz antennas are appropriate for locating a 20 cm diameter subsurface drainage system pipe main at 1.5 m depth in a silt loam soil, while 1.5 GHz antennas might be a good choice for imaging 0.5 cm tree roots at depths up to 0.5 m in a well-drained, sandy soil. Again, as with the resistivity and EMI systems, most GPR systems can be integrated with GPS receivers to provide accurate locations for GPR measurements; and because of fast GPR measurement rates, GPR systems integrated with GPS receivers are capable of surveying large farm fields in a relatively short amount of time. Finally, although resistivity, EMI, and GPR are by far the dominant geophysical methods currently employed, other geophysical methods such as magnetometry, self-potential, seismic, are now being increasingly evaluated for various agricultural purposes. Allred and others (2008) provide further discussion of the different geophysical methods that can be used for agriculture.

Figure 3. Examples of ground conductivity meters used in agroecosystem settings; (a) DUALEM-1S (Dualem Inc., Milton, Ontario, Canada), and (b) EM38-MK2 (Geonics Limited, Mississauga, Ontario, Canada).

Past Developments in Agricultural Geophysics

Some of the earliest agricultural geophysics research activity occurred in the 1930s and 1940s, and this work focused on soil water monitoring through soil electrical conductivity (ECa) measurement with resistivity methods (McCorkle, 1931; Edlefson and Anderson, 1941; Kirkham and Taylor, 1949). Soil water monitoring using the resistivity method, and now electromagnetic induction (EMI) and ground penetrating radar (GPR) methods, can provide useful insight for scheduling irrigation and controlled drainage operations within an agricultural field. The application of geophysical methods to agriculture did not substantially gain momentum until the 1960s, and to a greater extent the 1970s, with the use of resistivity methods for soil salinity assessment (Shea and Luthin, 1961; Roades and Ingvalson, 1971; Halvorson and Rhodes, 1974; Rhoades and others, 1976). Through the use of resistivity methods, and now EMI methods, geophysical ECa measurements are successfully employed to gauge salinity levels in soil, so that field operations, such as soil profile water flushing, can be initiated well before salinity build-up causes crop damage. One of the more recent and exciting developments regarding the use of geophysics for salinity assessment is the use of airborne EMI to evaluate salinity risks and management options for large agricultural areas (Paine and others, 1999; George and Woodgate, 2002; Beirwirth and Brodie, 2006). Starting in the late 1970s and on into the 1980s, another important development in agricultural geophysics was the use of GPR for updating and improving U.S. national program soil survey mapping (Collins and others, 1986; Collins and Doolittle, 1987; Doolittle, 1987;

Schellentrager and others, 1988). In this regard, GPR has proved extremely valuable with respect to reducing soil survey mapping time, providing more accurate delineation of map unit boundaries, and isolating representative pedons for soil sampling.

In the mid-1990s, ECa mapping with resistivity and EMI methods became an increasingly important precision farming tool. Precision farming is a growing agricultural trend that combines geospatial datasets, state-of-the-art farm equipment technology, geographic information systems (GIS), and Global Positioning System (GPS) receivers to support spatially variable field application of fertilizer, soil amendments, pesticides, and even tillage effort (National Research Council, 1997; Morgan and Ess, 1997). The benefits to farmers are maximized crop yields and/or reduced input costs. Better protection of the environment is an additional benefit. Since precision farming operations result in just the right amounts of fertilizer, soil amendments, pesticides, and tillage being applied on different parts of the field, there are less agrochemicals and sediment released offsite via subsurface drainage and surface runoff. With less offsite release of these chemical and sediment contaminants, adverse environmental impacts on adjacent waterways are in turn reduced. So in essence, precision farming techniques allow an agricultural field to be divided into different management zones for the overall purpose of optimizing economic benefits and environmental protection.

Horizontal spatial variations in ECa have commonly been found to correlate relatively well with horizontal spatial variations in both crop yield (Jaynes and others, 1995a; Lund and others, 1999) (see Figure 4) and soil properties (Banton and others, 1997; Lund and others, 1999; Carroll and Oliver, 2005). As a consequence, ECa mapping with resistivity and EMI geophysical methods can often be used to delineate the horizontal spatial patterns in soil properties that strongly influence within field variations in crop yield. These ECa maps can in turn be used to partition an agricultural field into different management zones so that precision farming techniques (variable rate application of agrochemicals and tillage) can be employed to maximize economic benefits and environmental protection. It should be noted that advancements in the 1990s such as the availability of personal computers, technologies to store/process large amounts of data, the GPS, and GIS are what made precision farming and the geophysical methods used for precision farming practical for widespread use.

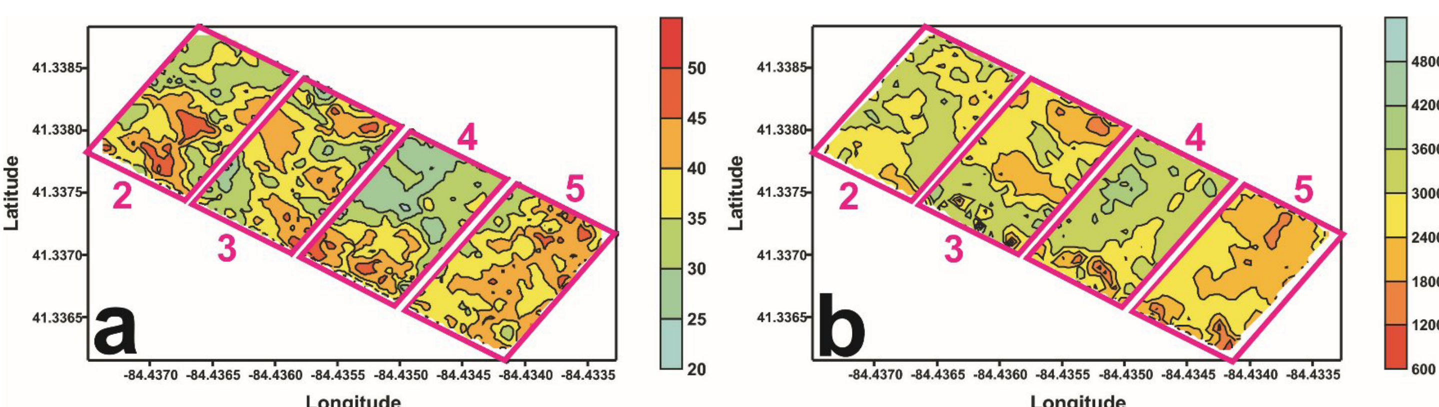

Figure 4. Comparison of soil electrical conductivity (ECa) and soybean yield spatial patterns from an agricultural test plot facility near Defiance, Ohio; (a) ECa map with values given in mS/m and (b) soybean yield map with values given in kg/ha. The moderately strong spatial correlation (r) between ECa and soybean yield is -0.52.

Present Agricultural Geophysics Research

Recently, within the past 15 years, there has been a rapid expansion of research related to potential agricultural geophysics applications. Most of these research activities are again focused on resistivity, electromagnetic induction (EMI), and ground penetrating radar (GPR) methods; however, research is now also being conducted on possible agricultural uses for other geophysical methods, such as magnetometry, self-potential, and seismic. Besides soil water monitoring, salinity assessment, soil survey mapping, and precision farming; geophysical methods are presently being employed or evaluated in a wide range of additional agricultural topic areas including forestry, high value crops, animal waste management, soil hydrologic characterizations, buried infrastructure location/assessment, etc. Table 1 highlights some of the more recent research related to agricultural applications of geophysical methods which have not already been mentioned previously.

Future Trends in Agricultural Geophysics

Agricultural geophysics has in the past been a rapidly evolving discipline, which is still true at present, and therefore in the future, there is every expectation of continued development of new/innovative methods, equipment, and field procedures. In this regard, based primarily on Allred and others (2008) and discussions held at the Soil Science Society of America – "Bouyoucos Conference on Agricultural Geophysics" (September 8-10, 2009, Albuquerque, New Mexico), the following list was produced which summarizes probable future trends in agricultural geophysics.

1. New applications will continue to be discovered for the geophysical methods that are already commonly used in agriculture; resistivity, electromagnetic induction (EMI), and ground penetrating radar (GPR).
2. Geophysical methods not traditionally employed in the past for agricultural purposes will find more significant use in the future. The geophysical methods likely to make further inroads into agriculture include, magnetometry, self-potential, and seismic. Agricultural opportunities for other geophysical methods, such as nuclear magnetic resonance, induced polarization, seismoelectric, etc., may also exist.
3. The incorporation of Global Positioning System (GPS) receivers will become the norm, especially with regard to real-time kinematic (RTK) GPS, which will allow geophysical measurement positions to be determined with horizontal and vertical accuracies of a few centimeters or less. Guidance devices, video display tracking systems, or even simple on-the-go guesstimates of the spacing distance between transects, when integrated with an accurate GPS, can provide the capability of efficiently conducting geophysical surveys over large agricultural field areas without the need to mark out a well-defined grid at the ground surface. For some geophysical methods, the computer processing procedures used for horizontal mapping of measurements may require some modification for input of data collected along a set of transects with somewhat irregular orientations and spacing distances.
4. Geophysical surveying with more than one sensor will become a standard approach, because of the variety of field information required to make correct agricultural management decisions. Multi-sensor systems based on a single geophysical method have already been produced, and these systems are certainly beneficial to agriculture. Examples include EMI or GPR systems having more than one set of transmitter/receiver coils or antennas, and continuously-pulled resistivity electrode arrangements containing more than one four-electrode array. However, multi-sensor systems based

on more than one geophysical method still need to be developed for agricultural purposes, something likely to happen in the near future. These multi-sensor systems might even be directly integrated with farm machinery to allow on-the-go decisions regarding precision farming operations.

Table 1. Recent agricultural geophysics research

Geophysical Method	Agricultural Application	Literature Source
Resistivity	Soil Drainage Class Mapping	Kravchenko and others, 2002
Resistivity	Small-Scale Soil Crack Imaging	Samouëlian and others, 2003
Electromagnetic Induction (EMI)	Determining Clay-Pan Depth	Doolittle and others, 1994 Sudduth and others, 2010
EMI	Estimation of Herbicide Partition Coefficients in Soil	Jaynes and others, 1995b
EMI	Mapping Flood Deposited Sand Depths on Farmland Near River	Kitchen and others, 1996
EMI	Soil Nutrient Monitoring from Manure Applications	Eigenberg and Nienaber, 1998 Eigenberg and others., 2002; 2010 Woodbury and others, 2010
EMI	Soil Salinity Assessment	Doolittle and others, 2001 Kaffka and others, 2005
Ground Penetrating Radar (GPR)	Indicator for Perched Water Table in Soil Profile	Freeland and others, 1998
GPR	GPR Soil Suitability Maps	Doolittle and others, 2003; 2010
GPR	Tree/Crop Root Biomass Surveying	Butnor and others, 2001; 2003 Barton and Montagu, 2004 Konstantinovic and others, 2007; 2008
GPR	Identification of Subsurface Flow Pathways	Gish and others, 2002 Freeland and others, 2006
Seismic	Soil Water Potential	Lu and Sabatier, 2009
Seismic	Soil Compaction	Lu and others, 2004
Resistivity and EMI	Sand Blow Location in Alluvial Soils	Doolittle, and others, 2002
Resistivity and Seismic	Tree Trunk Imaging	al Hagrey, 2007
Resistivity, Electrical Resistance Tomography, EMI, GPR, Seismic, and Self-Potential	Soil Water Content Determination and Soil Water Flow Monitoring	Zhou and others, 2001 Grote and others, 2003; 2010 Huisman and others, 2003 Blum and others, 2004 Maineult and others, 2004 Lunt and others, 2005 Lambot and others, 2006 Weihermüller and others, 2006 Tromp-van Meerveld and McDonnell, 2009
GPR and Magnetometry	Agricultural Field and Golf Course Drainage Pipe Detection	Boniak and others, 2002 Allred and others, 2004; 2005b; 2005c Rogers and others, 2005; 2006 Allred and Redman, 2010

5. Multiple geophysical datasets integrated and analyzed together along with other geospatial information can provide agricultural insight not available when analyzing each geophysical dataset separately. Geostatistical analysis techniques can be especially useful in this regard. Geographic information systems (GIS) are particularly well adapted for integration and geostatistical analysis of multiple geophysical and non-geophysical spatial datasets. Consequently, GIS will play a greater and greater role in the analysis of geophysical data collected in agroecosystem settings. Furthermore, as the practice of precision farming continues to grow, there is expected to be an increasing

need to input geophysical data into the GIS used to make proper management decisions in regard to different areas of an agricultural field.

6. Expert system computer software will be developed for specific agricultural applications, so as to automatically analyze and interpret geophysical data.
7. There is likely to be a substantial increase beyond present levels in the use of inverse modeling and enhanced data visualization computer software to analyze agricultural geophysics data.
8. Tomographic procedures will be employed given certain circumstances to obtain geophysical data in agroecosystem settings. It is usually not possible to conduct geophysical surveys in an farm field during the growing season, once the crop emerges and begins to develop. Tomographic data collection and analysis procedures are a potential solution to this field access problem, allowing the within field horizontal spatial pattern of a physical property(s) to be determined from information obtained by geophysical sensors placed along the field periphery instead of inside the field itself. Tomographic data collection and analysis procedures can also provide valuable geophysical information for smaller-scale scenarios and even for circumstances when field access is not a problem.
9. Outreach efforts provided by those with an agricultural geophysics background will accelerate as there becomes a greater need to educate the general agricultural community not only on the many possible applications of agriculture geophysics but also on the strengths and limitations of the various geophysical methods employed for agricultural purposes.

Summary and Conclusions

Geophysical methods can be an important tool for application within agroecosystem settings. Past developments in agricultural geophysics have included the use of resistivity, electromagnetic induction (EMI), and ground penetrating radar (GPR) methods for soil water monitoring, soil salinity assessment, soil survey mapping, and precision farming. At present, the agricultural applications of resistivity, EMI, and GPR geophysical methods continue to increase rapidly, and in addition, other geophysical methods, such as magnetometry, self-potential, and seismic are now beginning to find agricultural use. Future advancements in agricultural geophysics are likely to include: (1) further expansion in potential agricultural applications for resistivity, EMI, and GPR methods; (2) greater employment of geophysical methods that have not traditionally been applied to agriculture; (3) integration of geophysical equipment with real-time kinematic Global Positioning System (RTK-GPS) receivers; (4) construction of multi-sensor geophysical equipment platforms; (5) more utilization of geographic information systems (GIS) for enhanced agricultural interpretations based on combined analysis of multiple geophysical and non-geophysical spatial datasets; (6) development of agricultural geophysics expert system computer software; (7) increased use of inverse modeling and enhanced data visualization computer software to evaluate agricultural geophysics data; (8) employment of tomographic procedures; and (9) accelerated outreach efforts to the agricultural community in general. These future advancements in agricultural geophysics will require close collaboration between those in both the agricultural and environmental/engineering geophysics communities.

Authors Note

The use of manufacturer names are provided for informational purposes only and do not imply endorsement by the authors or the organizations they represent.

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Tree Root Morphology Mapping by Ground-Penetrating Radar

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Introduction

Ground-penetrating radar (GPR) is an established technique that has been used worldwide for over 30 years to locate objects underground, including pipes, barrels, drums, and other engineering and environmental targets. Use of GPR instrumentation for internal trunk decay detection and subsurface structural root mapping is a novel and recent application to the arboricultural field that has been developed and patented by TreeRadar™, Inc. under the name TRU™ (Tree Radar Unit) (www.treeradar.com). TRU is a complete system for forestry and urban applications and includes both the GPR equipment as well as the TreeWin™ analysis software for internal trunk and structural roots detection and mapping.

The GPR equipment, shown in Figure 1, consists of three components: (1) radar antenna with attached encoder survey wheel for automatic data collection of trunks, (2) field computer, a custom field-rugged PC-based data collection module, and (3) scanning cart with attached encoder survey wheel for automatic roots data collection. The TreeWin analysis software enables the user to create trunk cross-sectional images – "virtual saw cuts" – after a circumferential scan is conducted at any elevation, including at heights reachable by either a bucket truck or by climbers. The ensemble of these virtual saw cuts shows the progression of decay within the trunk. TreeWin also enables the user to create cross-sectional images of the soil – "virtual trench" – to establish the root layout and density along each scan line. It additionally enables root density and 3D root morphology maps to be created from the ensemble of these 2D virtual trenches.

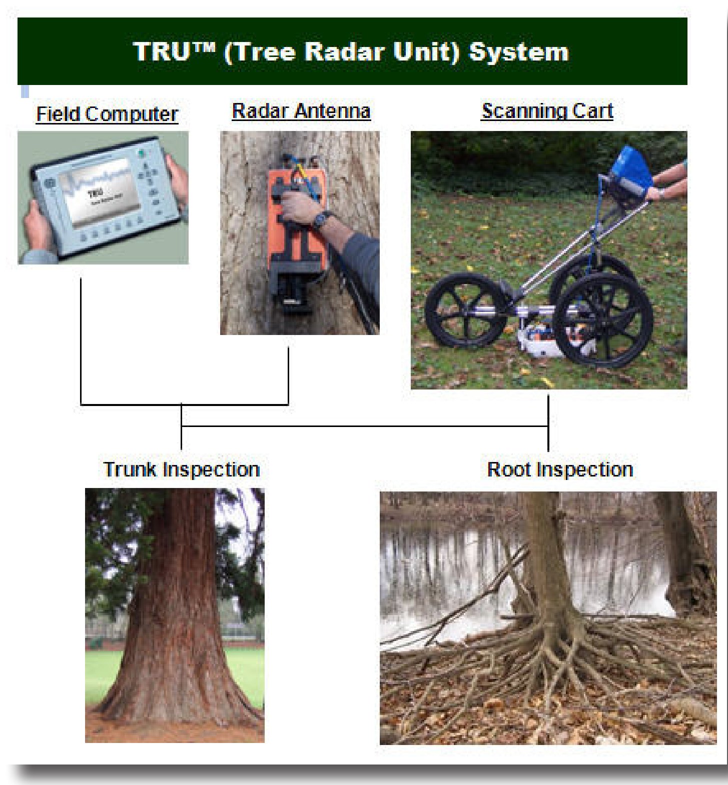


Figure 1. TRU geophysical equipment and potential arboricultural applications.

An air-filled trunk (hollow), or partially air-filled incipient decay zone, are excellent reflectors for detection by GPR systems. In addition, electromagnetic differences between tree roots and the surrounding soil provide the necessary contrast and reflection properties that are detected by GPR.

GPR measurement as a method of mapping tree roots has several advantages over other methods: (1) it is capable of scanning root systems of large trees under field conditions in a short time, (2) it is completely non-invasive, does not disturb the soil or damage the trees examined, (3) being non-invasive, it allows repeated measurements that reveal long-term root system development, (4) it allows observation of root distribution beneath hard surfaces (concrete, asphalt, brick, pavers), roads and buildings,

(5) its accuracy is sufficient to find structural roots with diameters as small as 1 cm (0.4in).

Root detection is possible in principle because of the moisture content within the woody root that provides an excellent contrast with the soil matrix (Figure 2). Roots that are dying will have very little or no moisture content, due to fungal attack for instance, and will be either weak or non-reflective targets and, hence, not detectable. In fact, this is an inferential way to determine root health. Even roots located in high clay and in high water table soils are detectable via advanced signal processing means.

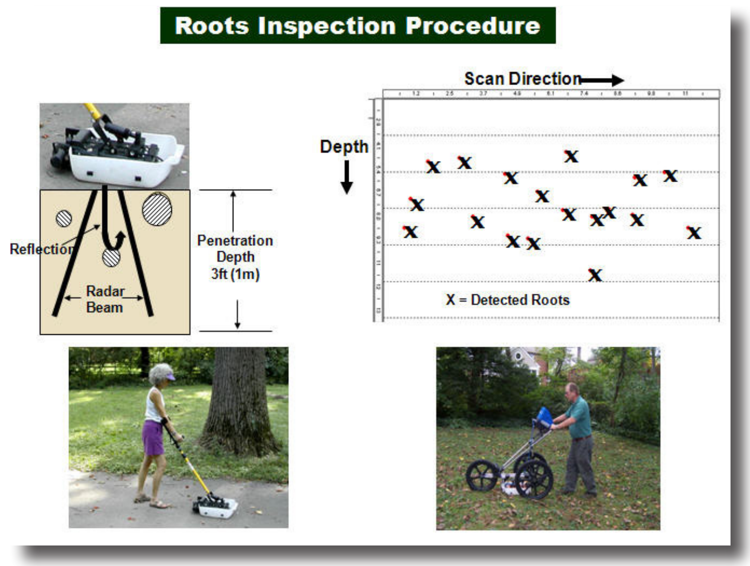


Figure 2. Tree root inspection principles.

TRU System for Subsurface Structural Roots Inspection

TRU offers a non-invasive method for roots inspection that provides the following information:

- 2D planar image of each line scanned showing root locations along the scan line and depth – "Virtual Trench"
- 3D top-down image showing root layout at any desired depth slice – "Virtual Excavation"

The 2D planar view is called a "Virtual Trench" because it is the same view that would be seen if a backhoe were to dig a trench as long as the line scanned and an observer were to step down into the trench and examine the severed root endings to determine their location, depth, and diameter. The 3D top-down view shows the image that would be seen by an observer in a bucket truck looking down into the soil. The root layout is seen along with its density in any direction from the trunk.

Steps for Structural Roots Detection and Mapping

1. Prepare a root scan layout.

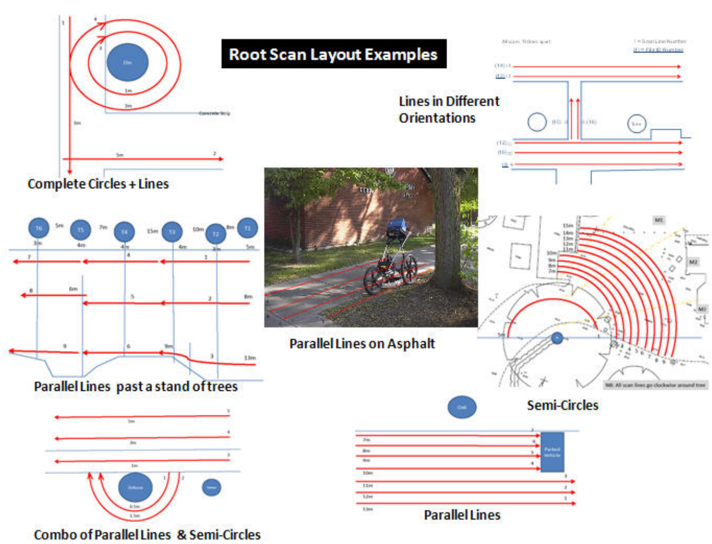


Figure 3. Field survey layout examples.

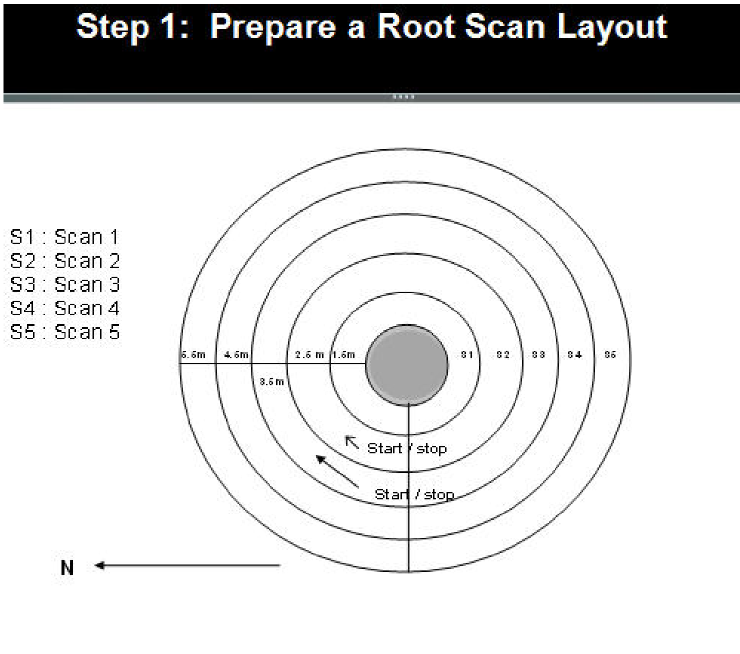


Figure 4. First step in tree root detection and mapping.

2. Create a grid to implement the root scan layout.

Figure 5. Second step in tree root detection and mapping.

3. Scan each grid line using GPR with data acquisition automatically triggered by a distance-encoding survey wheel which provides a reading every 5mm (0.2in) of movement along the scan line.

Figure 6. Third step in tree root detection and mapping.

4. Process each scan line using the TreeRadar TreeWin™ software analysis program to create a 2D Virtual Trench map showing distance along the scan line (X coordinate) vs depth of each detected root (Y coordinate).

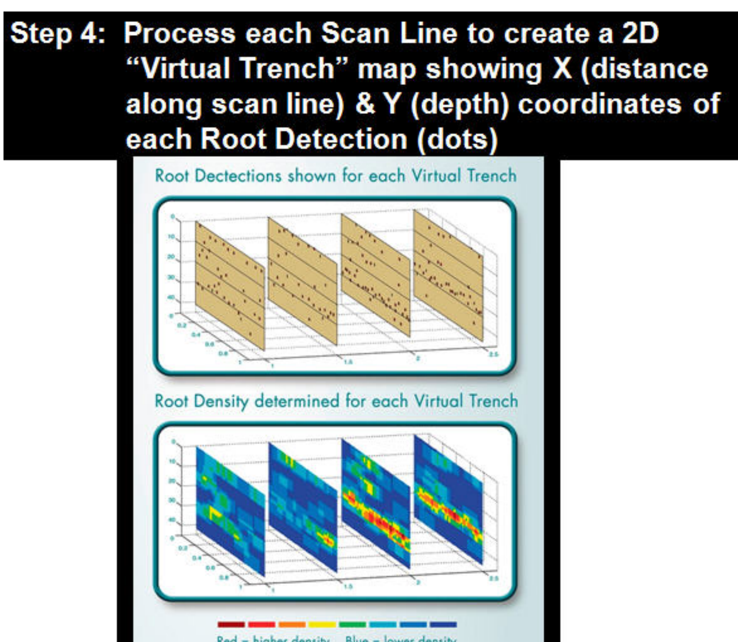


Figure 7. Fourth step in tree root detection and mapping.

5. Create a 3D Virtual Excavation root morphology map that algorithmically connecting the detected roots found on each scan line.

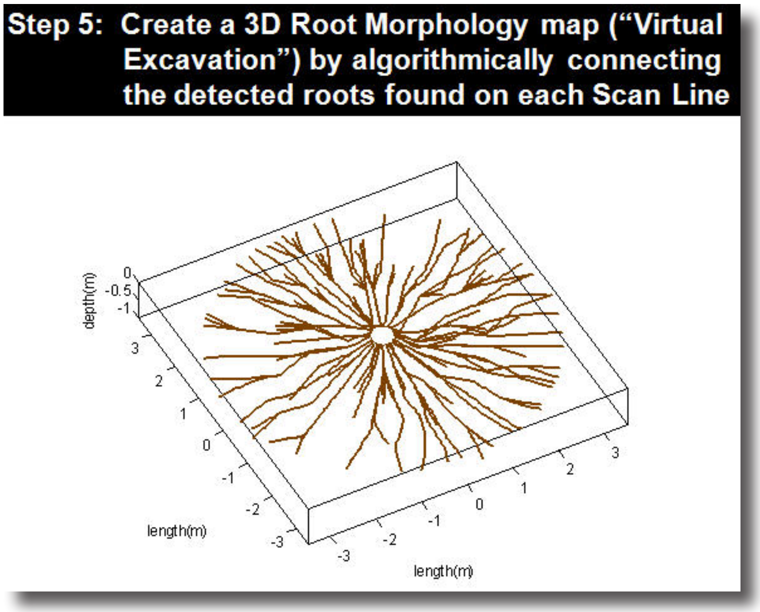


Figure 8. Fifth step in tree root detection and mapping.

6. Process the 3D root morphology map to create a root density map.

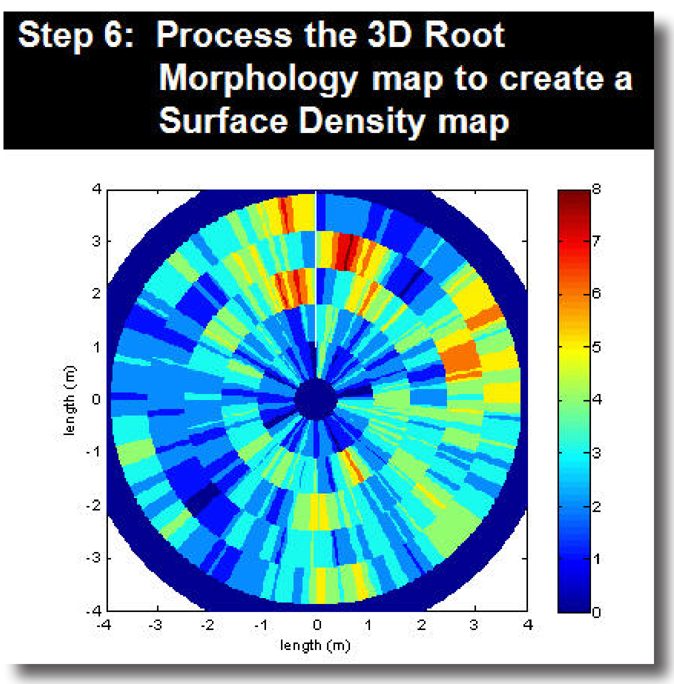
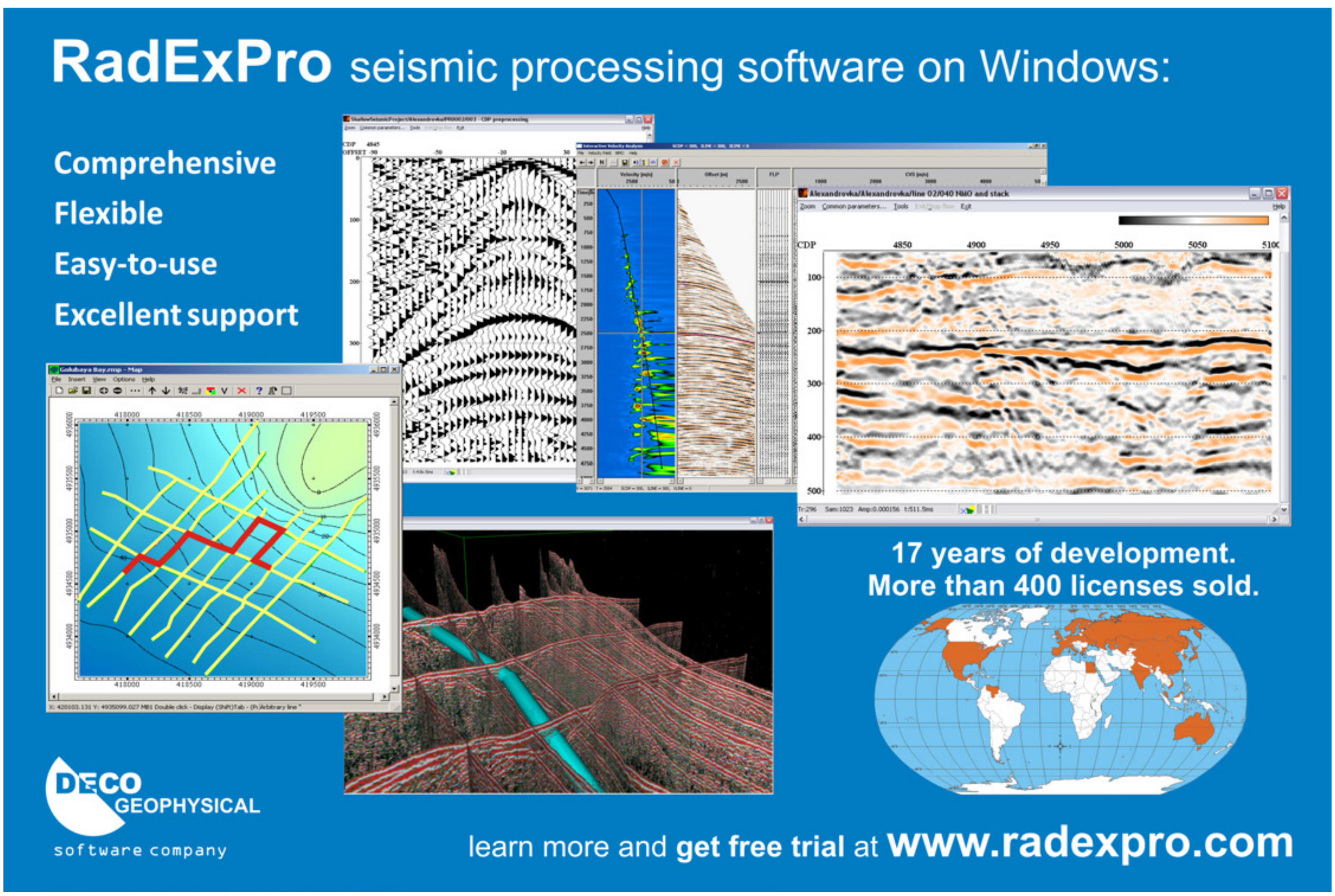
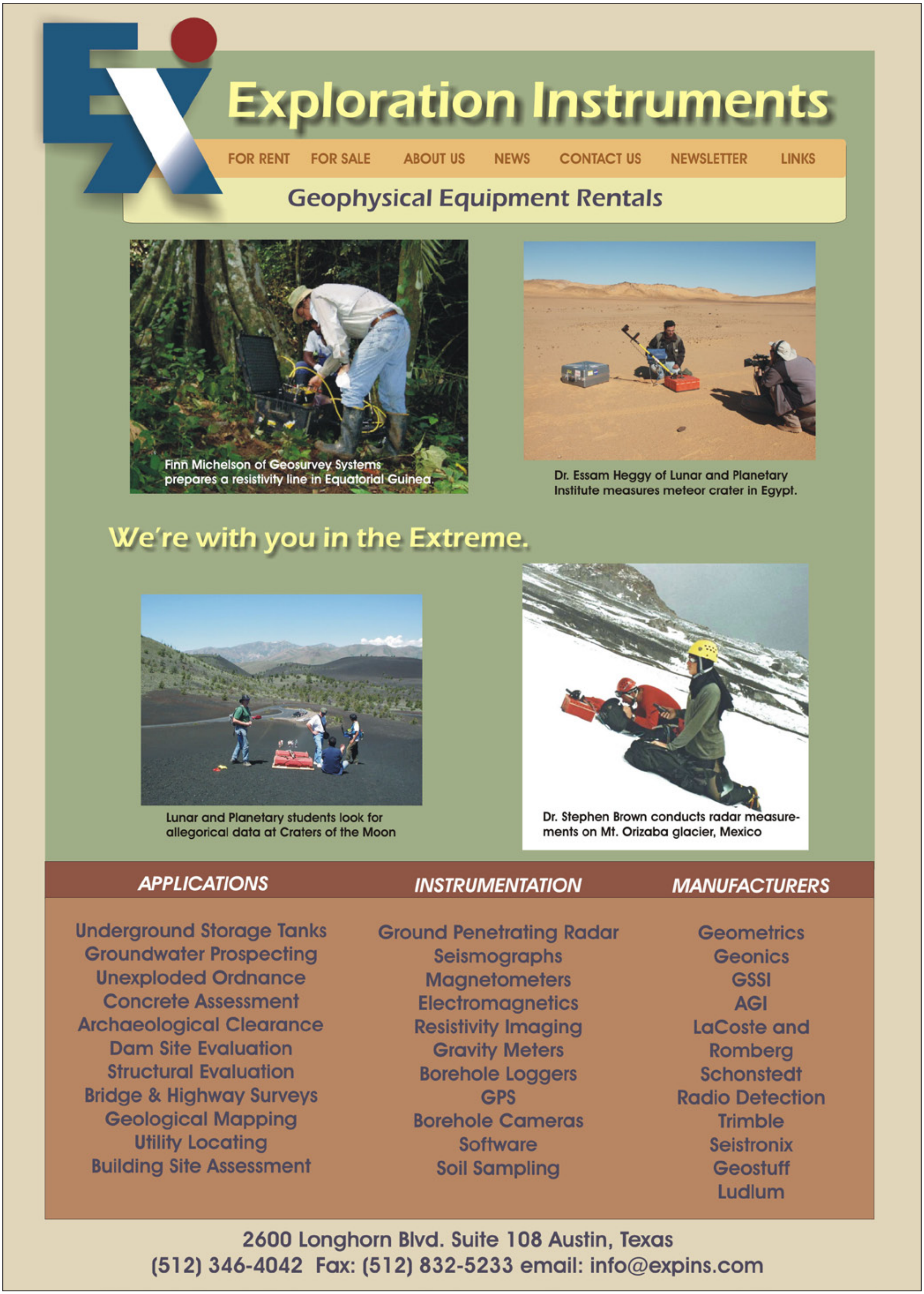


Figure 9. Sixth step in tree root detection and mapping.

Summary

- Tree roots can be detected and mapped accurately, as confirmed by test excavations, using non-invasive ground-penetrating radar; this permits root protected zones to be scientifically set instead of using rules-of-thumb based on trunk dimensions
- Soils that are generally considered hostile to GPR, such as clay, can be inspected successfully by applying signal processing on the collected radar reflection data
- Soil "clutter" can be significantly minimized by a data processing step using a combination of signal processing algorithms to enhance the signal/noise ratio
- 2D virtual trench maps can be created from the detected roots along each line scanned
- 3D root morphology map can be created by software that automatically connects the X,Y detected root coordinates
- Root surface density map can be created that shows the overall root layout and density

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Characterizing Subaqueous Landscape Units with Ground-Penetrating Radar

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Pedogenic (soil-forming) processes and properties have been recognized in shallow (typically < 2.5 m water depth) submersed marine, lacustrine and estuarine sediments (Demas and Rabenhorst, 1999). These observations have resulted in amending the definition of soils in Soil Taxonomy (Soil Survey Staff, 2010) to include shallow water environments. Permanently submersed sediments that support rooted aquatic vegetation are now being classified and mapped as subaqueous soils in the U.S. (Erich and others, 2010). This new frontier of soil surveys is motivated by management issues such as the inventory and restoration of submersed aquatic vegetation, organisms, and habitats, the improvement of water quality, and the assessment of carbon sequestration potentials.

Present information on shallow water habitats is limited (Demas and Rabenhorst, 1999, 2001). The sampling, mapping and characterization of shallow, submersed environments can be improved if soil-landscape relationships are established (Demas and Rabenhorst, 2001). Demas and Rabenhorst (2001) observed that once the relationships among subaqueous soils and landscapes are recognized in a given setting, soil types can be inferred by identifying the landscape unit. Each subaqueous landscape unit is characterized by distinct soils, sediments, topography, flora and fauna (Demas and Rabenhorst, 1999; Bradley and Stolt, 2003; Osher and Flannagan, 2007). Subaqueous landscape units are identified on the basis of bathymetry, slope, landscape shape, sediment type, and geographical location (Bradley and Stolt, 2003). Knowledge of the distribution of different subaqueous landscape units can help partition diverse, shallow, submersed environments into more homogenous units, and improve the characterization and management of these ecosystems (Bradley and Stolt, 2003).

In order to assess and characterize subaqueous soils, greater knowledge of water depths, bottom topography, sediment types and thickness, and subaqueous processes is needed (Demas and Rabenhorst, 1999, 2001). Traditional point-sampling tools and methods of observation are often inappropriate for use in subaqueous soil investigations (Erich and others, 2010). Over open water, acoustical fathometers, side-scan sonar, and sub-bottom profilers; and radio-frequency ground-penetrating radar (GPR) have proven to be effective (Feurer and others, 2008). Ground-penetrating radar has been used extensively in bathymetric surveys of fresh water lakes (Fischer and others, 2007; O'Driscoll and others, 2006; Buynevich and Fitzgerald, 2003; Hunter and others, 2003; Moorman, 2001) and rivers (Sambuelli and others, 2009; Feurer and others, 2008). In these studies, GPR provided continuous, highly detailed records of sub-bottom topography, sediment type and thickness. In addition, GPR is not limited for bathymetric mapping in areas of thick subaquatic vegetation, where acoustical methods have been less effective for determining bottom depths. These studies illustrate how, in some fresh-water systems, GPR can provide more comprehensive coverage of bottom and sub-bottom conditions than possible from point-sampling methods alone. Traditional coring methods are labor-intensive and have very high cost/area ratios (Feurer and others, 2008). As a consequence of their higher cost, the number of cores is limited. Limited measurements and reduced spatial coverage have resulted in an oversimplification of many relatively complex subaqueous environments (Stevens and others, 2009).

Ground-penetrating radar can provide complete and continuous records of water depths, submersed topographies, and bottom sediments. Bathymetric surveys with GPR have been conducted in boats and, in higher latitudes, on ice-covered water bodies (Annan and Davis, 1977). However, while suited to bathymetric surveys of freshwater systems that contain low total dissolved solids, GPR is ineffective in brackish or salt waters because of their high electrical conductivity and attenuation rates, which severely restricts penetration depths.

Ground-penetrating radar is an effective tool for mapping subaqueous soil and sediment structures. The following examples illustrate the use of GPR to profile water columns, identify differences in subaqueous soils and substrates, and differentiate soil-landscape units.

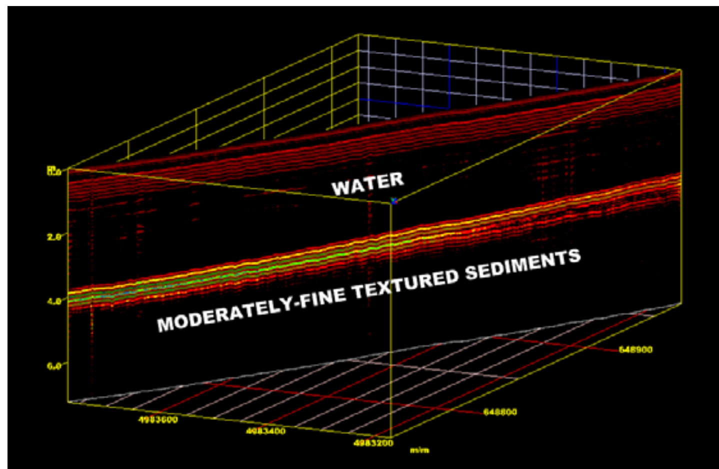

Figure 1. The radar record in this 3D block diagram was collected with the 70 MHz antenna over a deeper portion of Missisquoi Bay, Lake Champlain, in northwestern Vermont.

Figure 1 is a three-dimensional (3D) block diagram of a georeferenced radar record that was collected with a 70 MHz antenna across an interior portion of Missisquoi Bay, Lake Champlain, in northwestern Vermont. At the time of this survey, the bay was covered by 40 to 50 cm of ice. In Figure 1, a clear and continuous interface exists between the water and bottom sediments. In this portion of the bay, this interface maintains a uniform depth of about 3.9 m. Other than reverberations from this and a closely-spaced interface, little additional sub-bottom information is available. The radar energy has been attenuated and penetration depths restricted by the relatively high clay and silt contents of the sub-bottom materials. This radar record is indicative of a deep-water, low-energy, depositional, subaqueous environment. The depth of water precludes the occurrence of subaqueous soils in this submersed setting. For deeper, level portions of Missisquoi Bay, similar radar imagery provides a unique and identifiable radar facies. A radar facies is a mappable 3D unit composed of GPR reflections whose parameters (internal reflection patterns and characteristics) differ from adjoining units (Jol, 2009).

Figure 2 is a diagram of a georeferenced radar record that was collected with the 200 MHz antenna over a shallower, near-shore area of Missisquoi Bay. This radar record captures the structural components of several subaqueous landscape units that differ in water depths, topography, and subaqueous substrates. Compared with the radar record obtained over the deeper portion of the bay (Figure 1), penetration depths are greater through the sub-bottom materials shown in Figure 2. As signal attenuation is less, the bottom sediments were presumed to consist of coarser-textured materials. This inference was confirmed in core samples collected from the area.

Three distinct subaqueous landscape units are evident in Figure 2. In the extreme left-hand and central portions of this diagram, two distinct landscape units (Figure 2, see A & B) can be distinguished by their contrasting internal reflection patterns. Subaqueous landscape unit "A" is characterize as being a shallow, level to gently sloping, near-shore, subaqueous landscape unit that is underlain by stratified coarse-textured sediments. Subaqueous landscape unit "B" is higher-lying. Here, water depths are very shallow, and the soil may be partially or entirely emergent at times. The substrate displays more chaotic, internal reflection patterns which are more indicative of till than stratified sediments. These properties characterize a shallow, level to gently sloping, near-shore, subaqueous landscape unit that is underlain by moderately coarse textured till.

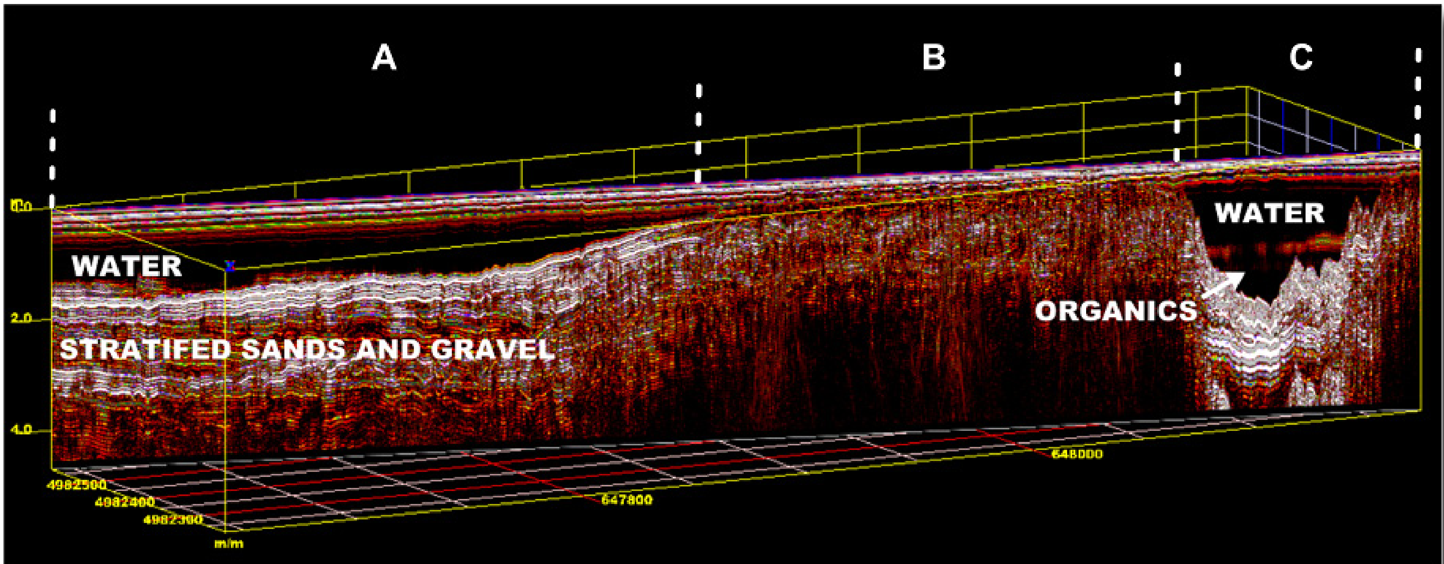

Figure 2. The radar record shown in this 3D block diagram was collected with the 200 MHz antenna over a shallower portion of Missisquoi Bay. A greater variation in water depths, submersed topography and substrates are evident on this 3D image.

In the extreme right-hand portion of Figure 2, the cross-section of a submersed relict channel is evident (see “C”). Within this channel, the low-amplitude, segmented planar reflections at a depth of about 1.5 m identify an interface that separates water from underlying organic materials. Submersed organic materials are often distinguishable by low-amplitude reflections along the interface with the overlying water column, and by the absence of high-amplitude internal reflection patterns. Within this submersed channel, a deeper interface separating organic and mineral substrates provides noticeable, high-amplitude reflections. The underlying mineral substrate has an irregular topography and appears stratified. Because of its higher amplitudes, the mineral substrate is presumed to consist of alternating strata of sands and gravels. This subaqueous landscape unit is characterized by irregular topography with high relief, the presence of organic materials within depths of 2.5 m, and underlying stratified coarse-textured sediments.

Figure 3 was collected with the 200 MHz antenna over a shallow, sheltered, near-shore portion of Missisquoi Bay that is underlain by submersed organic materials. The water/organic material interface is nearly level and continuous across most of this radar record, but slopes and deepens towards the right (and into the deeper interior portion of the bay). The thickness of the submersed organic materials thins from left to right with the deepening of the water column. Beneath the submersed organic deposit, the radar reflections suggest the presence of stratified coarse-textured materials. Thus, the radar record shown in Figure 3 represents yet another subaqueous landscape unit: a shallow, sheltered, nearly level, near-shore, subaqueous environment consisting of submersed organic materials that are underlain by stratified coarse-textured materials.

Interpreted radar data can be displayed in geographical information systems (GIS) and other imaging software packages. Figure 4 shows the results of a GPR bathymetric survey on a small pond in Rhode Island. In this figure, the bathymetric depth interval is 3 feet. Figure 5 is an aerial photograph of Ninigret Pond in Rhode Island. In this image, different subaqueous landscape units have been identified.

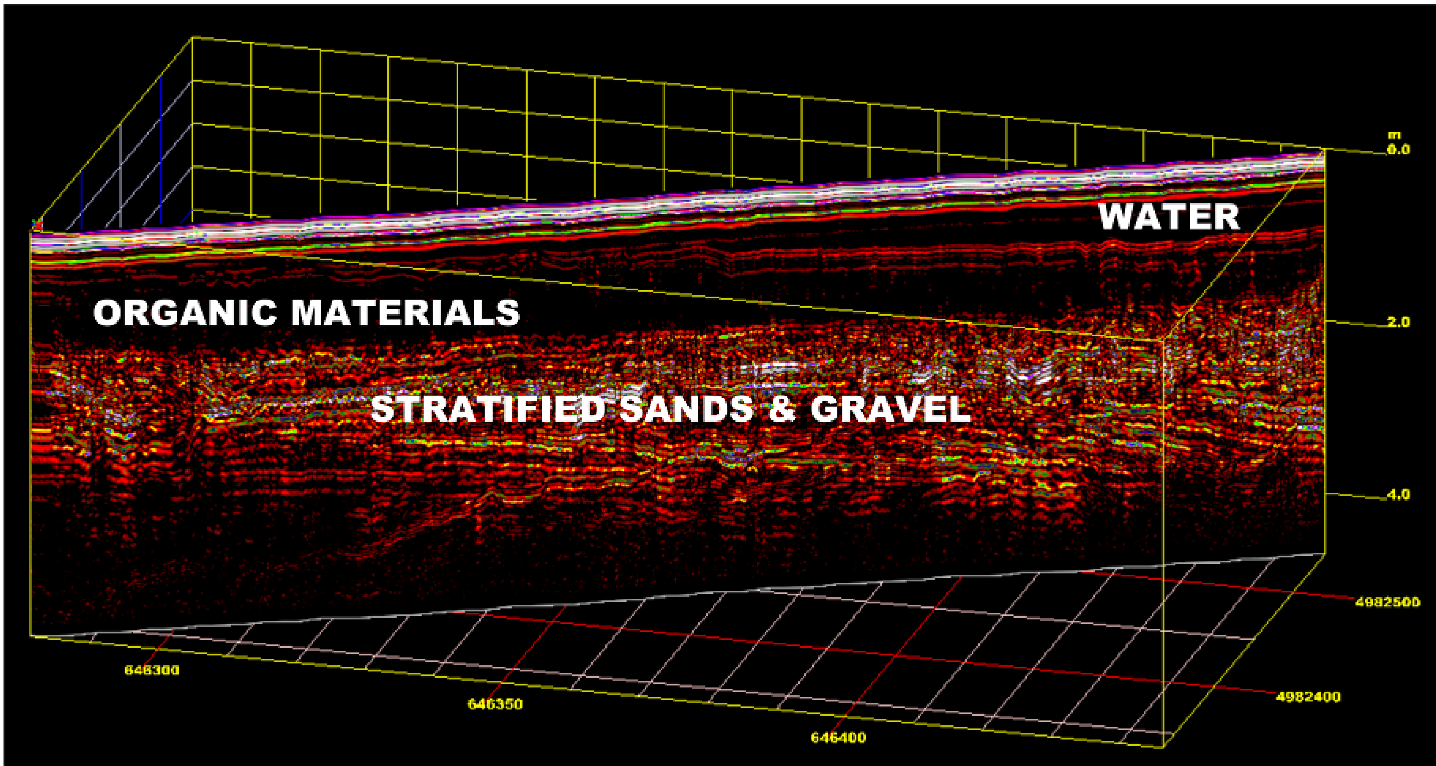

Figure 3. The radar record shown in this 3D block diagram was collected with the 200 MHz antenna over a shallow, sheltered portion of Missisquoi Bay. Here, a submersed blanket deposit of organic materials overlies stratified sands and gravels. The water column deepens towards the right and the interior of the bay.

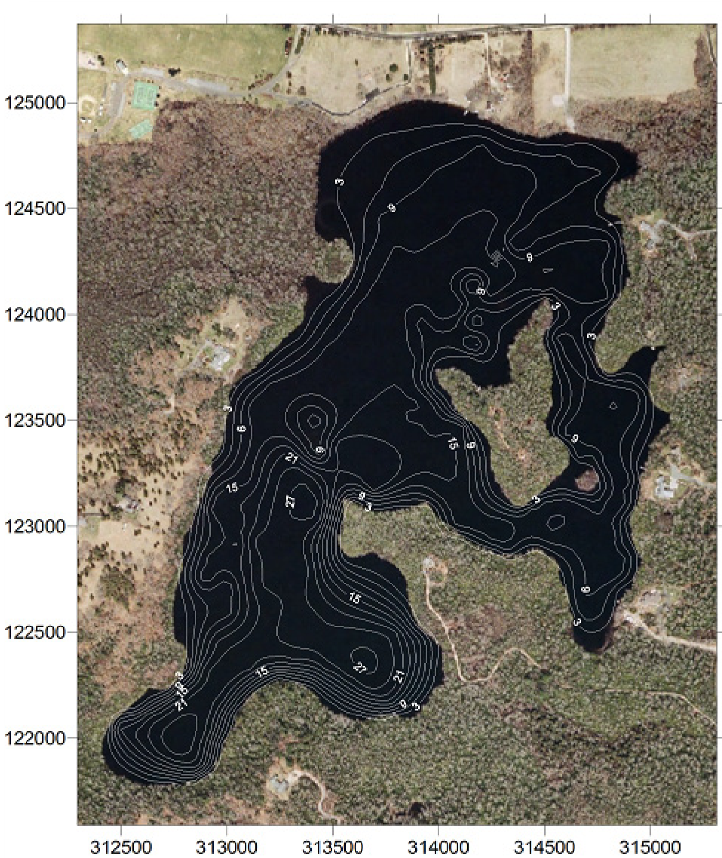

Figure 4. Detailed bathymetry of a freshwater pond in Rhode Island data derived from GPR data. The contour interval is 3 feet.

Figure 5. In this aerial photograph of Ninigret Pond in Rhode Island, different subaqueous landscape units are identified.

Summary

Ground-penetrating radar can provide high resolution, continuous records of many freshwater subaqueous environments. These records can help document spatial changes in subaqueous landforms, soils and substrates. Radar facies can be used to identify differences in substrates and help to distinguish different subaqueous landscape units. The identification of subaqueous landscape units can help partition submersed areas and locate points for further study and sampling. Local, state, and federal agencies managing freshwater aquatic environments can use GPR-derived information and interpretations as part of the decision-making toolbox for responding to many water quality concerns, such as improving estimates of sedimentation rates, nutrient inputs and pools, and carbon sequestration rates in subaqueous soils; and forecasting the potential spread of invasive aquatic species.

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Mapping the Soil Health of Agricultural Fields via Soil Electrical Conductivity

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Introduction

Application of geophysical sensing techniques for mapping agricultural production fields has accelerated in recent years. Where previously the standard was soil sampling and lab analysis to evaluate the condition of a soil for its various purposes (medium for plant growth, recycling, habitat, water supply/purification), in situ sensing techniques are proving to be a very effective way for assessing variation in soil properties. For agricultural landscapes the obvious advantage of in-field geophysical sensing techniques is, once sensors are mobilized and linked with GPS, fields can be evaluated quickly and with better coverage. The latter is especially necessary for those cropped fields that express a high degree of spatial variability. A classic example of highly-variable fields is with what is described as the "claypan soils" of the U.S. Midwest.

Background

Claypan soils have highly-contrasting textural layers that undulate at varying depths across a landscape. The undulating claypan horizon has an especially dominating influence on crop growth and hydrology. The claypan is defined by an abrupt increase in clay, more than doubling from ~20% up to ~60% clay, between the topsoil (A or E horizon) and the initial argillic (i.e., high clay content) horizon. The depth of this claypan varies from 0 to 1.0 m, depending on landscape position and degree of erosion or downslope deposition. The low saturated hydraulic conductivity within the claypan leads to perched water tables creating a high probability of runoff in most years during the winter and spring periods. As such, claypan soils are usually classified as somewhat poorly to poorly drained. Due to the high shrink-swell potential of smectitic clays, there is also a high probability of annual shrinkage cracks forming during late summer and early fall. Thus, soils with these characteristics provide an ideal setting for testing and evaluating sensors for high resolution soil mapping.

Much of the claypan soil landscape of the USA Midwest has only been under cultivation for about 100 to 120 years. Early in the 1900's improvements in agricultural mechanization allowed farmers to crop larger tracts. Additionally, soaring grain prices during World War I resulted in plowing previously-grazed grasslands for the first time. However under cultivation, intense storms caused devastating erosion that filled steams and rivers with sediment. It wasn't until the 1970's and later that conservation measures (e.g., tillage practices shifting to minimum- and no-till) began to reduce the degrading effects of water erosion on these soils. So after only ~100 years of crop production, many claypan soil fields have experienced extensive soil quality degradation. Such degradation affects their current productivity and their long term sustainability for food and biofuel production. Because of the site-specific nature of degradation within these fields, research is needed to achieve cost-effective sensing and mapping of soil and landscape properties that quantify the soil's current ability to produce crops and provide ecosystem services- the fundamental concepts of soil health (sometimes called soil quality) (Doran and Parkin, 1994).

Soil quality is complex due to the interaction of physical, chemical, and biological soil processes performing various functions. Adding to this complexity are changes in soil quality across landscapes.

Further, the task of evaluating on-going agronomic and conservation effects on soil quality is daunting. Therefore, site-specific characterization of soil quality is needed to provide a baseline understanding of the impact of past and future management. Such assessment is also used for targeting remediation with precision agriculture methods. The objective of this article is to summarize our work on apparent soil electrical conductivity (EC_a) sensing for high-resolution mapping of soil quality indicators for claypan soils.

Methodology

Investigations over a 20-yr period on a 36-ha claypan soil field located in north-central Missouri USA (39.2297 N., -92.1169 W. – see Figure 1) are summarized here. The soils on this field are generally classified as Adco (fine, smectitic, mesic aeric Vertic Albaqualfs) and Mexico (fine, smectitic, mesic aeric Vertic Epiaqualfs) using the USDA NRCS classification system. Details regarding the management employed on this field can be found in Lerch and others (2005).

Figure 1. Aerial photo of a 36-ha claypan soil field located in north-central Missouri USA that has been the site of intensive soil ECa sensing the last 15 years.

Under different soil conditions and during different years we obtained apparent soil electrical conductivity (ECa) using two different sensor systems [non-contact, electromagnetic induction–based sensors (Geonics EM38; DUALEM-2S) and coulter-based sensors (Veris 3100 and Veris 2000 – see Figure 2)]. ECa surveys were usually run on transects spaced approximately 10 m apart with data being recorded on a 1-s interval (~ 4- to 6-m data spacing). Data obtained by differential GPS was associated with each sensor reading to provide positional information with an accuracy of 1.5 m or better. From these data sets, methods were developed for estimating topsoil depth (Sudduth and others, 2003; Sudduth and others, 2010). At the time of an ECa survey, between 12 and 20 sampling sites were selected within the field to cover the range of ECa values present. At these sites a 120-cm length soil core was obtained using a hydraulic soil coring machine. Cores were examined within the field by a skilled soil scientist and pedogenic horizons identified. Cores were segmented by horizon for laboratory analysis of soil texture, soil organic C, bulk density, and other soil chemical properties. These soil measurements were related to soil ECa. The ECa data were also related to other soil quality characteristics as explained below.

Figure 2. Soil EC_a sensing on a agricultural fields has led to a better understanding of the spatially-variable soil health measures.

One important application of soil EC_a has been relating it to soil's ability to grow crops—sometimes referred to as the soil productivity. This 36-ha claypan soil field is one of few field-scale experiments with 15+ years of continuous, high-quality spatially-referenced, cleaned yield monitor data. Although yield has been mapped, management has been conventional, with uniform inputs applied across the field. Thus, yield maps provide insight into yield variation and associated agronomic interpretations that occur due to spatial processes. Combines equipped with commercially available yield sensing systems were used to collect data for 1993-2002 yield maps. Individual points where yield data were unreliable due to combine operation or yield sensor issues were removed. Cleaned yield monitor data was interpolated with the geostatistical technique of block kriging. Further details on yield mapping procedures can be found in Kitchen and others (2005).

Soil EC_a has also been related to soil hydraulic properties important in agricultural fields. One hypothesis assessed was whether EC_a could be used directly to estimate plant available water content (PAWC). Here we use ECa to estimate the lower (-1500 kPa soil water pressure) and upper (after field capacity was reached) limits of PAWC, determined from sample profiles at various calibration-point locations within the 36-ha field. Plant available water was determined by the difference between the upper and lower values. Calculations were on a 1.2-m deep soil profile basis. A second study tested the idea that maximum PAWC could be approximated with a hypothetical two-layer soil profile comprised of a topsoil layer (usually silt loam in texture) and a sub-layer (silty clay or clay in texture) to the bottom of the rooting depth. The texture-specific PAW fraction values needed to calculate profile available water are commonly available through the USDA-NRCS.

Results

Claypan Topsoil Depth and Crop Yield

Because the claypan morphology presents a hostile environment for crop root growth, the depth of soil above the claypan is an important indicator of soil quality. The relationship of topsoil depth and ECa varies by field, soil moisture, temperature, and sensor type, but usually we have found regression r2 values between 0.7 and 0.9. Applying a regression model developed from a calibration dataset allows transforming a field soil ECa survey into a high resolution topsoil depth map as shown in the "today" map (left side of Figure 3). Further, using a combination of soil ECa, bare-soil remotely-sensed images, and profile descriptions of nearby un-cultivated soil sites allowed us to develop a model estimating topsoil loss caused by farming over the past ~120 yrs (right side of Figure 3) (Lerch and others, 2005). The majority of the field has lost topsoil, with an average of 13 cm of topsoil loss. The darker brown color areas on the top soil loss map highlight field areas that have experienced

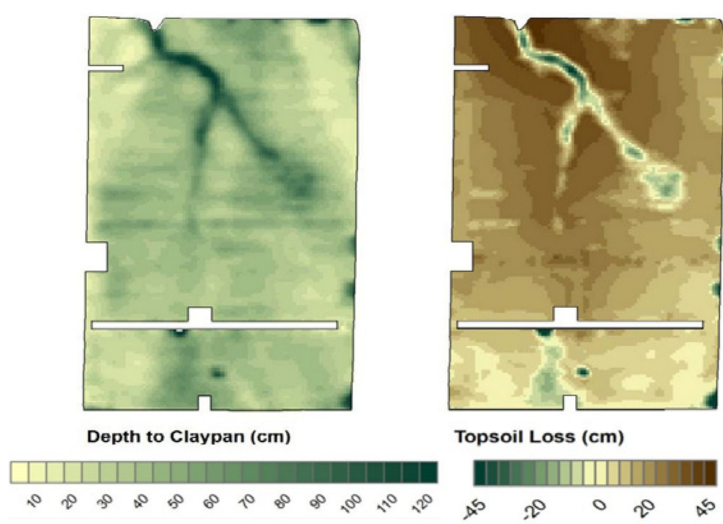

Figure 3. Left: Topsoil depth for a 36-ha claypan soil field in Missouri developed from soil EC_a. Right: map of modeled topsoil loss due to farming over the past ~120 years for the same field (prior to modern farming and tillage practices that reduce erosion) based on using soil EC_a, bare-soil remotely-sensed images, and profile descriptions of nearby uncultivated soil sites.

the greatest amount of erosion, losing up to ~45 cm of topsoil. The darker green, narrow areas on the north end of the field (right side of Figure 3) define a small area along the drainage channel that has accumulated sediments. We find that the visual representation of historical erosion provided with this set of maps is extremely valuable in educational programs and to help reinforce the need for conservation practices.

Comparing the thin topsoil areas to yield maps has demonstrated the importance of topsoil to crop productivity and the instability of corn yield as shown in a 5-yr average yield map and yield coefficient of variation map (Figure 4). Low yielding areas (brown color areas in Figure 4 left map) correspond to highest year-to-year corn yield variability (red color areas on Figure 4 right map), meaning yield is low and less predictable on thin topsoil areas.

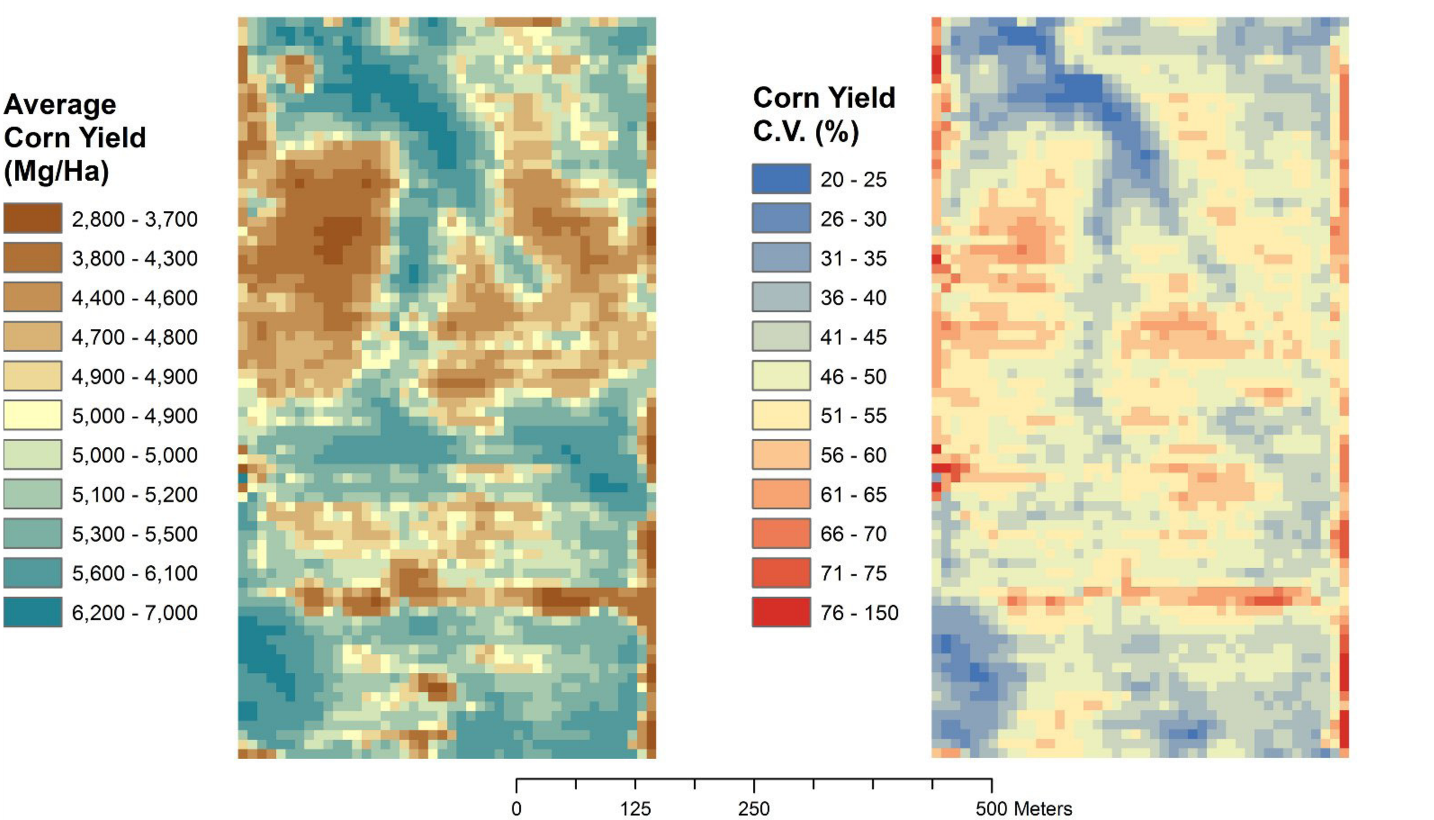

Figure 4. Five-year (1993, 1997, 1999, 2001, 2003) average corn yield map (left) and coefficient of variation (right) for a Missouri claypan soil field.

Areas with low topsoil identified by soil ECa have also been identified as creating the greatest on-going environmental concerns (Lerch and others, 2005), and therefore should be high priority sites for targeting with precision conservation. A precision agricultural system employing multiple production and environmental goals was developed and initiated on this field in 2003. The plan for this system was developed on the premise that mapped crop and soil information from ECa sensors was fundamental to understanding what crops should be grown and what other management and conservation practices should be adopted. Precision nutrients, crop type and rotation, tillage, and herbicides are components embraced with this system and are described in detail in Kitchen and others (2005). The plan calls for conservation practices targeted to degraded field areas to help remediate soil to a higher level of soil quality (Kitchen and others, 2005).

Claypan Hydraulic Properties

Another aspect of soil quality relates to hydraulic characteristics. As briefly described above, the claypan has dramatic effects on hydrology of claypan soil watersheds. Understanding variability in the claypan depth over the landscape is essential in more accurately modeling soil water storage and infiltration rate, and therefore runoff potential. In our work reported by Jiang and others (2007), soil ECa using both electromagnetic induction and coulter-based EC_a sensors was applied in two separate procedures to estimate plant available water content (PAWC) of claypan soils. In the first procedure, simple regression modeling between measured PAWC and EC_a showed a significant relationship with an r2 of 0.67 and RMSE of 30 mm. These results were derived from the significant relationship of EC_a to the lower limit of the profile PAWC, which is highly correlated with topsoil thickness. In the second procedure PAWC was simplified by hypothesizing a two-layer soil profile comprised of a silt loam topsoil layer and a silty clay subsurface layer. The boundary between these layers (i.e., topsoil depth) can be conveniently estimated by EC_a as previously described. Compared to measured PAWC, the results were promising as documented in Jiang and others (2007). The two-layered approach was used to create a high resolution map of PAWC (Figure 5). Transforming the sensor information into a measure like PAWC allows one to view problem areas in a metric that has direct meaning to the crop's physiology. Such PAWC maps are also useful for site-specific decision making with regard to soil and water management.

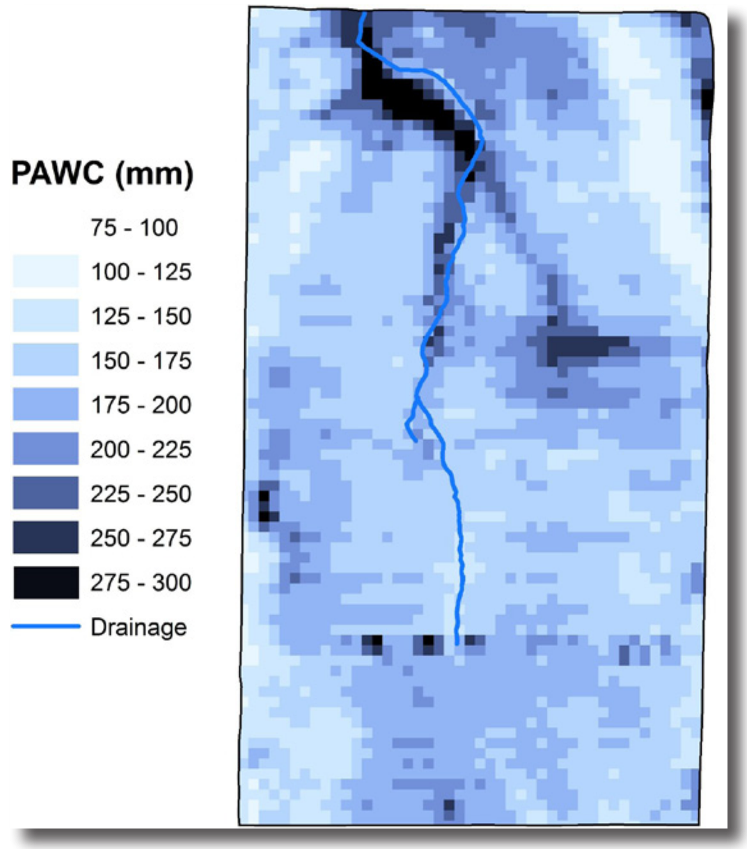

Figure 5. High resolution plant available water capacity (PAWC) mapping can be obtained from EC_a surveys of claypan soils.

In other work we've done, soil EC_a was negatively correlated with saturated hydraulic conductivity (K_s) (Jung et al., 2007) and bulk density in the 15-30 cm soil sampling depth (Jung et al., 2005) of claypan soils. While the EC_a x K_s relationship was weak, it could also be mapped to screen for variations in hydraulic conductivity at a field scale and then isolate areas most prone to generating surface runoff.

Soil Organic Carbon

Soil organic carbon has long been recognized as one of the most important characteristics for soil quality. While more direct sensor measurements have also been explored, in some situations indirect sensing of soil organic carbon using ECa may be achieved. In work by Jung and others (2007), soil ECa was weakly correlated with surface soil organic carbon (r of ~0.70) on claypan soils. This relationship was hypothesized as a reason ECa and infiltration were related, as previously described.

Nutrients

Another aspect of soil quality is a soil's ability to supply nutrients to plants. For convenience, typically only the surface ~ 20 cm of soils are sampled for nutrient analysis. However, the sub-soil can be rich in nutrients and significantly contribute to crop nutrient needs. The challenge is assessing subsoil nutrients without costly deep soil sampling. We found that claypan topsoil depth was strongly related to profile soil nutrient content. After summing P and K soil-test values over a 90-cm soil profile, a significant relationship to topsoil thickness was found (Figure 6). Soil-test K levels decreased with increasing topsoil thickness. Soil-test P levels also decreased with topsoil thickness, but then slightly increased with deeper topsoil depth. This finding is significant because estimates of topsoil thickness using soil ECa sensing may then be used to help estimate the total nutrients in the rootzone and to predict the response of crop plants to fertilizer inputs. In related studies we found a more probable response to P and K fertilization where claypan soil topsoil depth was the greatest (Kitchen and others, 1999).

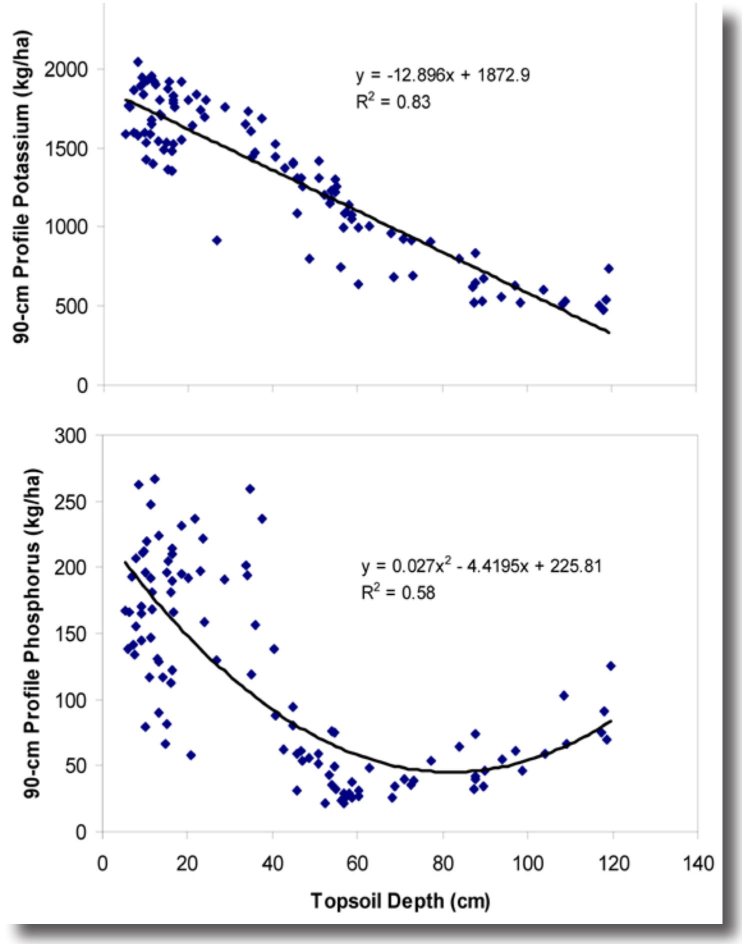

Figure 6. Profile potassium (top) and phosphorus (bottom) have been shown to be highly related to topsoil depth on claypan soils.

Conclusions

Claypan soils vary greatly in their ability to produce crops and provide ecological services for minimal environmental impact. These soils lost resiliency when topsoil eroded over the last ~120 yrs of cultivation. The sensors and methods described in this chapter help define, with high resolution, the spatial variability of soil quality. These results can help land managers identify the practices needed and where they should be applied for improved precision conservation.

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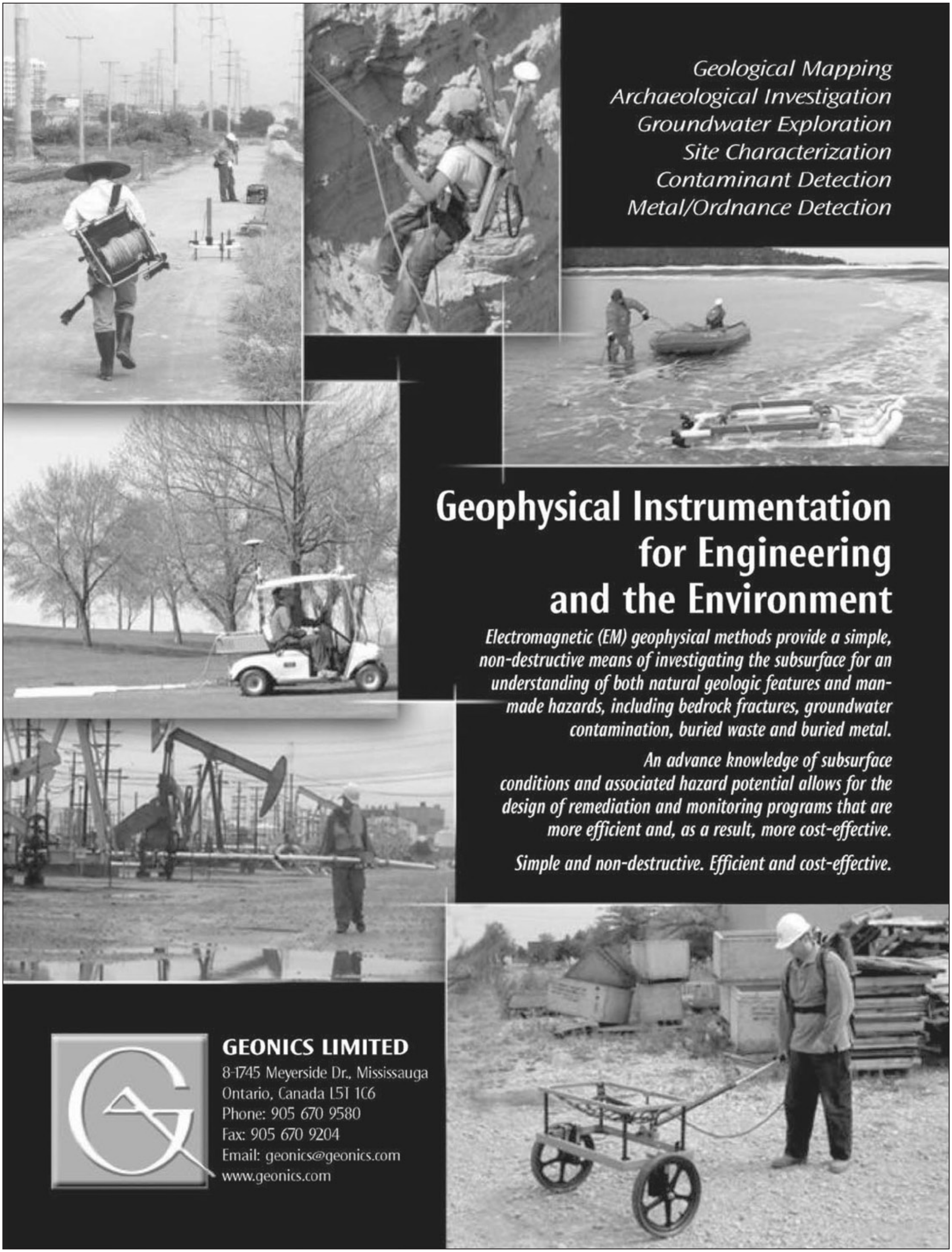
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Location and Assessment of Drainage Pipes Beneath Farm Fields and Golf Course Greens Using GPR: A Research Summary

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Introduction

A 1985 economic survey (Pavelis, 1987) showed that the states comprising the Midwest U.S. (Illinois, Indiana, Iowa, Ohio, Minnesota, Michigan, Missouri, and Wisconsin) had by that year approximately 12.5 million hectares, predominantly cropland, that contained subsurface drainage pipes systems. Enhancing the efficiency of soil water removal, and in turn crop production, within farm fields already containing a functioning agricultural subsurface drainage system, typically involves installing new drain lines between the old ones. However, before this approach can be attempted, the older drainage pipes need to be located. Finding drainage pipe is not an easy task, especially for systems installed more than a generation ago. Often, records have been lost, and the only outward appearance of the farm field subsurface drainage system is a single pipe outlet extending into a water conveyance ditch. From this, little can be deduced about the network pattern used in drainage pipe placement. Without records that show precise locations, finding farm field drain lines with heavy trenching equipment causes pipe damage requiring costly repairs, and the alternative of using a hand-held tile probe metal rod is extremely tedious at best.

In addition, there are over 16,000 golf courses throughout the U.S. (Data-Lists.com, 2005). Golf course upkeep requires continual maintenance and occasional renovation. The superintendents and architects responsible for golf course maintenance and renovation efforts need non-destructive tools for obtaining shallow subsurface information, particularly with regard to determining drainage pipe locations beneath golf course greens. Historically, drainage pipe was comprised primarily of clay tile prior to the late 1960s (Figure 1a), but from the late 1960s onward, corrugated plastic tubing (CPT) replaced clay tile as the material of choice for drainage pipe fabrication (Figure 1b). Recent research findings, described as follows, indicate that ground penetrating radar (GPR) may be an effective/efficient method for non-destructive detection and assessment of clay tile and CPT drainage pipes beneath both farm fields and golf course greens.

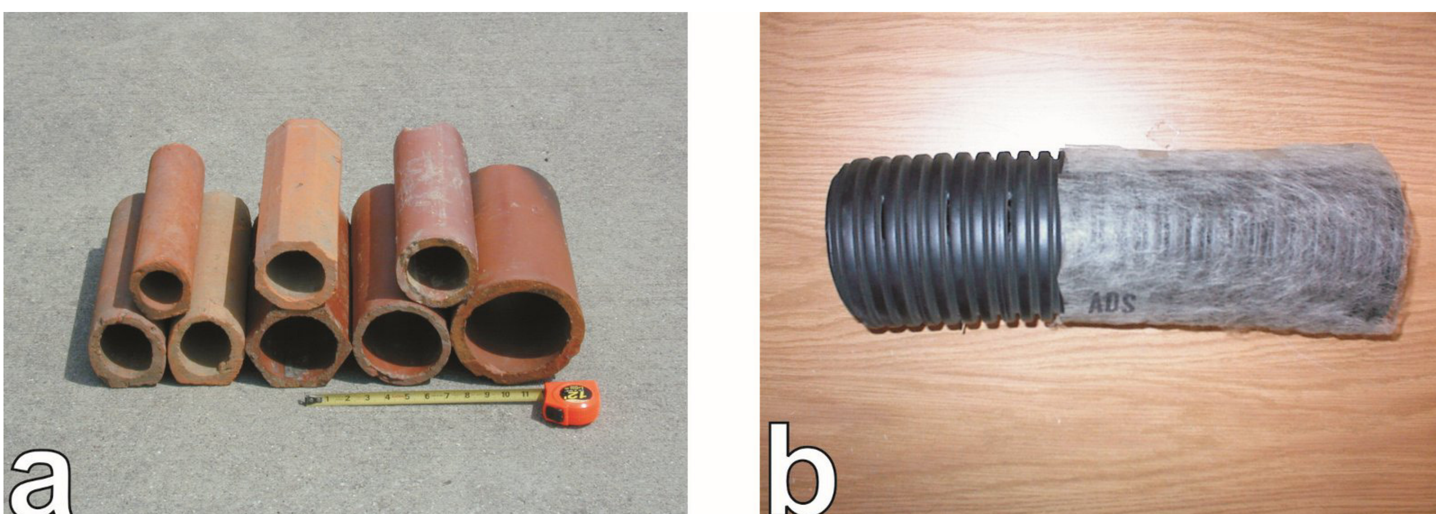

Figure 1. (a) Clay tile drainage pipes and (b) corrugated plastic tubing (CPT) drainage pipe with filter sleeve.

Locating Farm Field Drainage Pipes

Figure 2 is a schematic illustrating drainage pipe placement within the soil profile typical of Ohio agricultural fields where research was conducted. (Schematic is oriented perpendicular to drain line trend.) The tilled zone is commonly less than 0.3 m in thickness. The pipe, typically 0.1 m in diameter, is placed at the bottom of the trench, which is then backfilled. The trench itself is typically 0.2 to 0.5 m wide with its bottom depth ranging between 0.5 and 1 m. Trench bottom and drainage pipe depth can be as much as 1.5 m elsewhere in the Midwest U.S. The drainage pipe itself can be air-filled, water-filled, or contain both air and water depending on shallow hydrologic conditions in the soil.

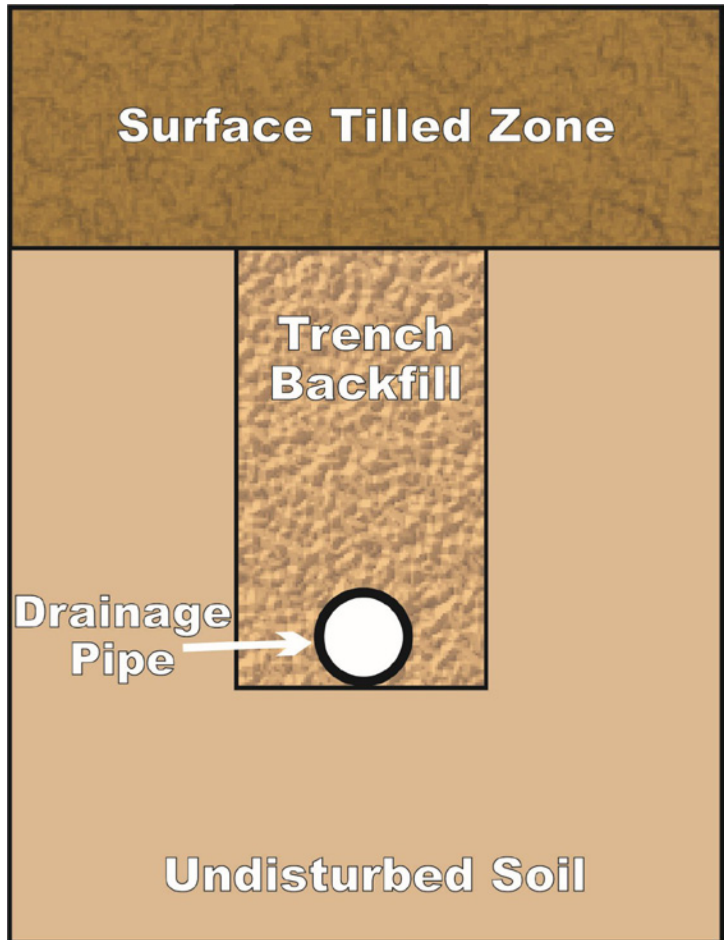

Figure 2. Schematic of soil profile drainage pipe placement within a farm field.

Allred and others (2004) tested various near-surface geophysical methods, including magnetometry, electromagnetic induction, resistivity, and ground penetrating radar (GPR), but determined that only GPR exhibited promise for finding farm field drainage pipes. It should be noted that there has been some documented success mapping drainage pipes with magnetometry methods (Rogers and others, 2004; Rogers and others, 2005). Investigations by Allred and others (2004; 2005a; 2008a) found that GPR was successful in locating on average 74% of the total amount of drainage pipe present at fourteen test plots in southwest, central, and northwest Ohio (100% of the pipe located at seven sites, 90% at one site, 75% at two sites, 50% at two sites, and 0% at two sites). Ground penetrating radar worked relatively well in finding clay tile and corrugated plastic tubing (CPT) drainage pipe down to depths of around 1 meter within a variety of different soil materials from clay to sandy loam. There was little effect on the GPR response due to whether the drainage pipe was comprised of clay tile or CPT.

Additional research has focused on various factors that are potentially important for achieving success using GPR to find farm field drainage pipes. Results with respect to equipment parameters indicate that choosing the proper antenna frequency is crucial, and antennas with a center frequency of around 250 MHz seemed to be most appropriate for the conditions encountered during this research. Also, data quality is similar over a sampling interval range of 2.5 to 10 cm (1 to 4 inches) between points along a measurement transect and for averaging 4 to 32 signal traces at a measurement point. In regard to site conditions, shallow hydrology, soil texture, and drainage pipe orientation all influence the GPR response. Moist soils with pipes at least partially filled with air provide advantageous GPR field conditions, assuming the radar signal penetrates to the drain line depth. Sandy soils allow greater radar signal penetration than do clayey soils. With respect to field survey operations, spacing distances of 2 m or less between adjacent parallel GPR measurement transects may be needed to map extremely complex drainage pipe networks. Furthermore, in regard to field survey operations, while a single set of parallel GPR measurement transects may be sufficient for mapping drainage pipes in the case where all the drain lines trend in the same known direction; usually, two sets of parallel GPR measurement transects, with the sets perpendicular to one another, will be required to map drainage pipe systems where drain line trends are uncertain. The computer processing steps applied to the GPR data collected to locate farm field drainage pipes is another important consideration. Computer processing of the GPR depth profiles involved application of a signal saturation correction filter to remove low frequency noise, followed by signal amplification, which was accomplished using either a spreading and exponential compensation gain function or constant gain function. The computer processing steps used to produce GPR amplitude maps included a signal saturation correction filter, signal trace enveloping, 2-D migration, and sometimes a spatial background subtraction filter.

Figure 3 displays some representative GPR drainage pipe detection results obtained from a northwest Ohio farm field having sandy clay loam to sandy loam soils. The traditional orientation of GPR antennas perpendicular to the measurement transect direction was employed. Ground penetrating radar measurement transects were south-to-north and west-to-east. The spacing distance between adjacent parallel GPR measurement transects was 1.5 m. Ground penetrating radar depth profiles are shown in Figures 3a and 3b. As depicted in these profiles, the GPR response to different buried drainage pipe orientations range from upside down u-shaped reflection hyperbolas (when the angle between the GPR measurement transect and drain line is relatively large to distinct banded linear features (when the GPR measurement transect is along trend over a drain line). Figure 3c is a GPR amplitude map representative of the radar energy reflected back to the surface from a depth interval of 0.9 to 1.4 m. The lighter shaded drain line responses show up clearly in Figure 3c. Figure 3d is an interpreted map based on the GPR data with drain lines represented by dashed lines. The blue line on Figure 3d indicates the line position along which the Figure 3a GPR profile data were collected. The red line on Figure 3d indicates the line position along which the Figure 3b GPR profile data were collected.

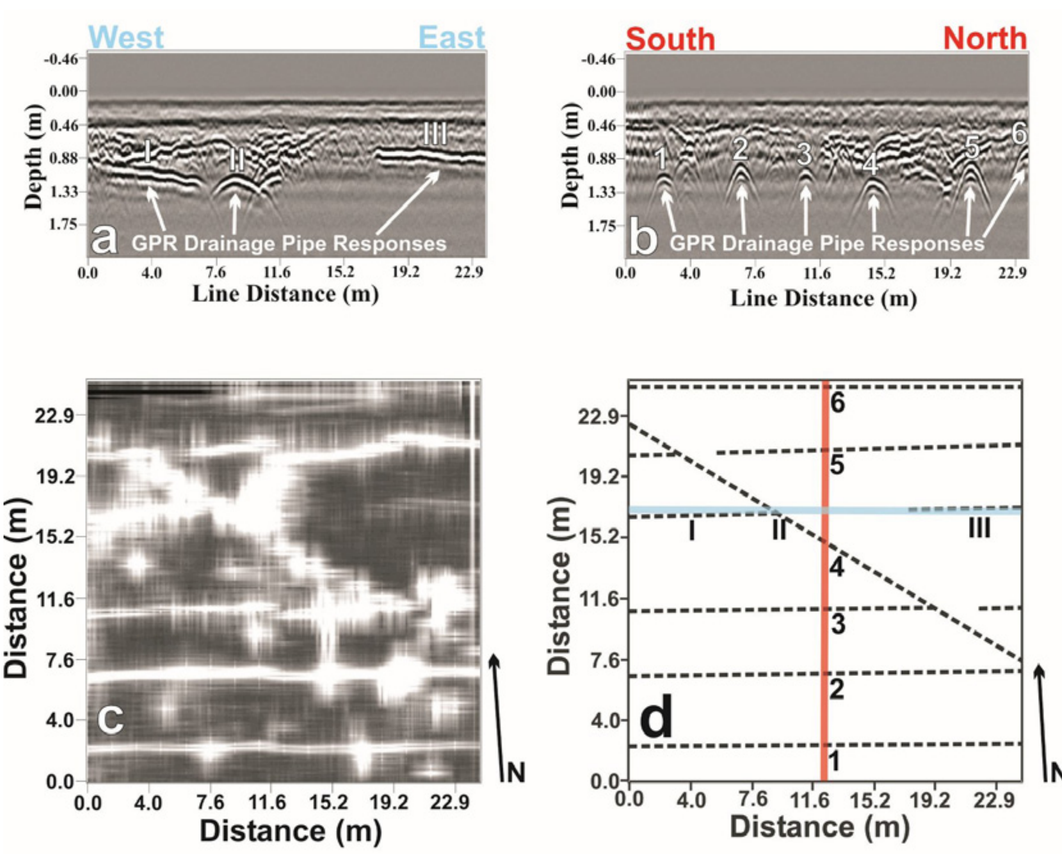

Figure 3. GPR drainage pipe location results obtained with 250 MHz antennas from a northwest Ohio farm field; (a) west-to-east GPR depth profile. (b) south-to-north GPR depth profile, (c) GPR amplitude map, and (d) interpreted map of subsurface drainage pipe system (dashed lines) based on GPR results.

Locating Golf Course Green Drainage Pipes

Today, there are generally two types of golf course greens that are constructed. One is called a United States Golf Association (USGA) green and the other is called a California green (Hurdzan, 1996). Some of the design characteristics for these two types of greens are presented in Figure 4. For either the USGA green or California green, rectangular or herringbone patterns are typically used for placement of the drainage pipe system. With the rectangular pattern, the drainage pipe laterals merge with the main conveyance pipe at an angle of 90 degrees. With the herringbone pattern, the drainage pipe laterals merge with the main conveyance pipe at an angle other than 90 degrees. The spacing distance between the drainage pipe laterals within a green is usually between 3 to 5 m (Boniak et al., 2002).

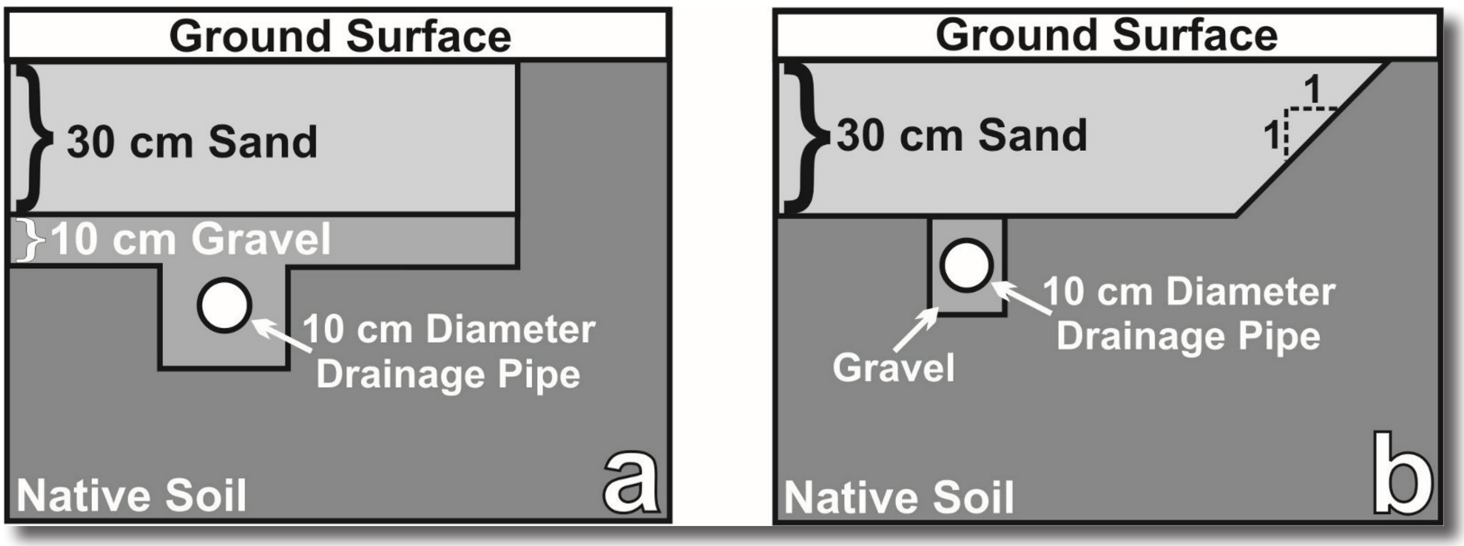

Figure 4. Edge of green schematics showing design characteristics for the two main types of golf course greens; (a) USGA green and (b) California green.

Allred and others (2005b) found that golf course greens tend to be an extremely good environment for collecting ground penetrating radar (GPR) data. A rather wide range of antenna frequencies, from 250 to 1000 MHz, work reasonably well for mapping drainage pipe systems. The lower frequency GPR antennas (250 MHz) are slightly better for locating drainage pipes; however, higher frequency antennas (900 to 1000 MHz) are a better choice if sand/gravel layer thickness determinations are needed in addition to drainage pipe mapping. With regard to field survey operations, due to the complex drainage pipe networks typically present on golf course greens, spacing distances of 1 m or less between adjacent parallel GPR measurement transects are needed and two sets of parallel GPR measurement transects, with the sets perpendicular to one another, are usually required. Computer processing of the golf course green GPR depth profiles involved application of a signal saturation correction filter to remove low frequency noise, followed by signal amplification using a constant gain function (Allred and others, 2008b). The computer processing steps used to produce golf course green GPR amplitude maps included a signal saturation correction filter, signal trace enveloping, 2-D migration, and a spatial background subtraction filter (Allred and others, 2008b).

Figure 5 provides examples of GPR results for a USGA green (Figures 5a, 5c, and 5e) and a California green (Figures 5b, 5d, and 5f). Antennas with a 250 MHz center frequency were used to obtain these results, and both of the golf course greens investigated are in Dublin, Ohio. Native soils at both golf course sites had high clay content. Figures 5a and 5b are GPR depth profiles with representative drain-

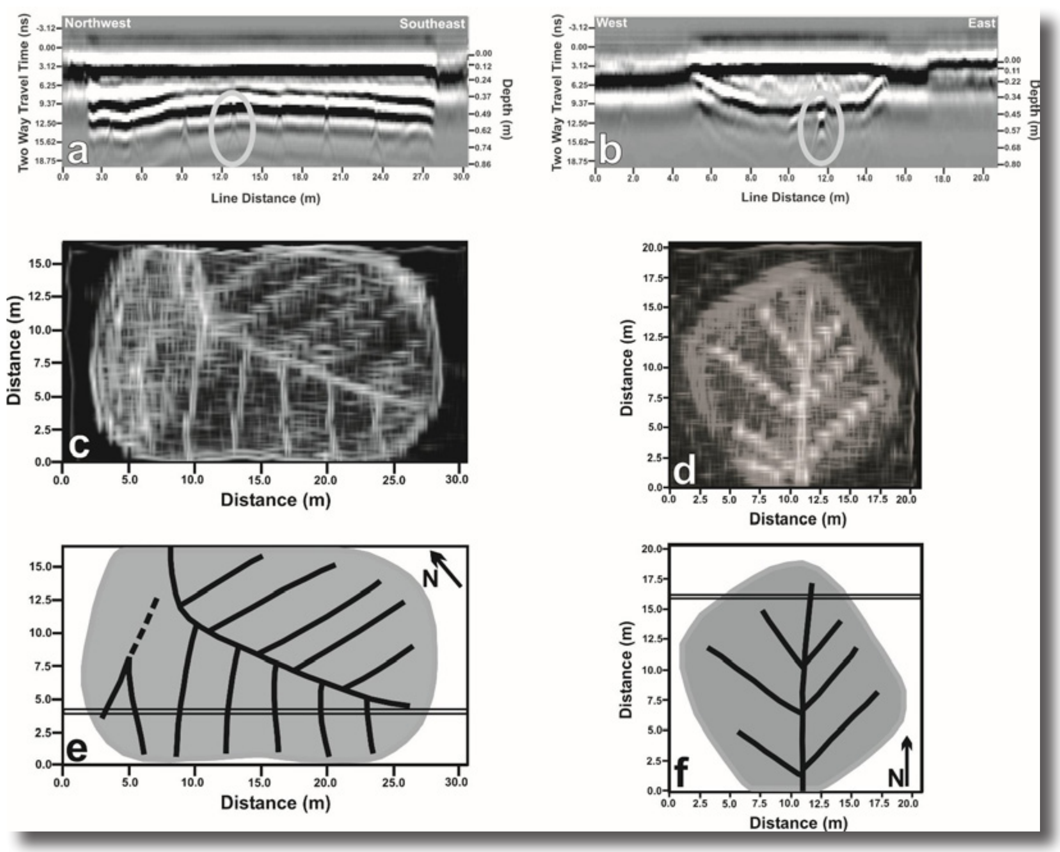

Figure 5. GPR drainage pipe location results for a USGA golf course green and a California golf course green; (a) GPR depth profile from a USGA green, (b) GPR depth profile from a California green, (c) GPR amplitude map from a USGA green, (d) GPR amplitude map from a California green, (e) interpreted drainage pipe map from a USGA green, and (f) interpreted drainage pipe map from a California green.

age pipe reflection hyperbola responses highlighted by oval-shaped gray lines. Figures 5c and 5d are GPR amplitude maps showing lightly shaded linear features that are representative of drain lines and the green boundaries. The Figure 5c GPR amplitude map is based on a depth interval of 0.38 to 0.68 m, while the Figure 5d GPR amplitude map is based on a depth interval of 0.34 to 0.61 m. Interpretation of golf course green drainage pipe networks (thick black lines), as deduced from the GPR data, are displayed in Figures 5e and 5f. Both of the drainage pipe networks exhibit typical herringbone patterns. The thin double black line on Figure 5e indicates the line position along which the Figure 5a GPR profile data were collected. The thin double black line on Figure 5f indicates the line position along which the Figure 5b GPR profile data were collected.

Assessment of Drainage Pipe Functionality

It is important to know whether a drain line is functioning properly. A drain line obstruction prevents free flow of water through the drain line, which can in turn produce water-logged soil conditions within parts of a farm field or even a golf course green. Water flow obstructions along a drain line are oftentimes isolated at a single point, where for example a drainage pipe has collapsed or been severed. During wet periods of the year, after a large rainfall event, and given a properly functioning drain line, the up-gradient, higher elevation portions of a drain line will empty first and become air-filled, while the down-gradient, lower elevation portions of the drain line are still water-filled. When an obstruction to water flow is present within the drain line, a reversed situation may prevail after a large rainfall event where the up-gradient, higher elevation portions of the drain line backs up and remains water-filled, while down-gradient, lower elevation portions of the drain line are emptied and become air-filled. Consequently, if ground penetrating radar (GPR) methods are capable of accurately determining whether a drainage pipe is air-filled or water-filled, then given the proper shallow hydrologic conditions, GPR could be employed to indicate whether there is an obstruction along a drain line that inhibits the flow of water.

Allred and Redman (2010) demonstrated that the difference in response between an air-filled pipe versus a water-filled pipe depicted on a GPR profile can indeed be employed to locate a drain line water flow obstruction, especially if the GPR data is collected along a transect that follows directly along trend over the drain line. For wet soils with GPR data collected along trend over a drain line, the water-filled drainage pipe response on a GPR profile is a generally weak banded linear feature, while the air-filled drainage pipe response on a GPR profile tends to be an extremely strong banded linear feature. Figure 6 is a good example of a GPR profile oriented along trend of a drain line showing the location of a pipe flow obstruction. The pipe flow obstruction location in Figure 6 is clearly marked by the spot where there is an abrupt transition from a weak water-filled up-gradient drain line GPR response to a strong air-filled down-gradient drain line GPR response. Therefore, given the proper shallow hydrologic conditions and a precise prior knowledge of where a drain line is located, GPR data can then be collected along trend over the drain line in order to find a pipe flow obstruction.

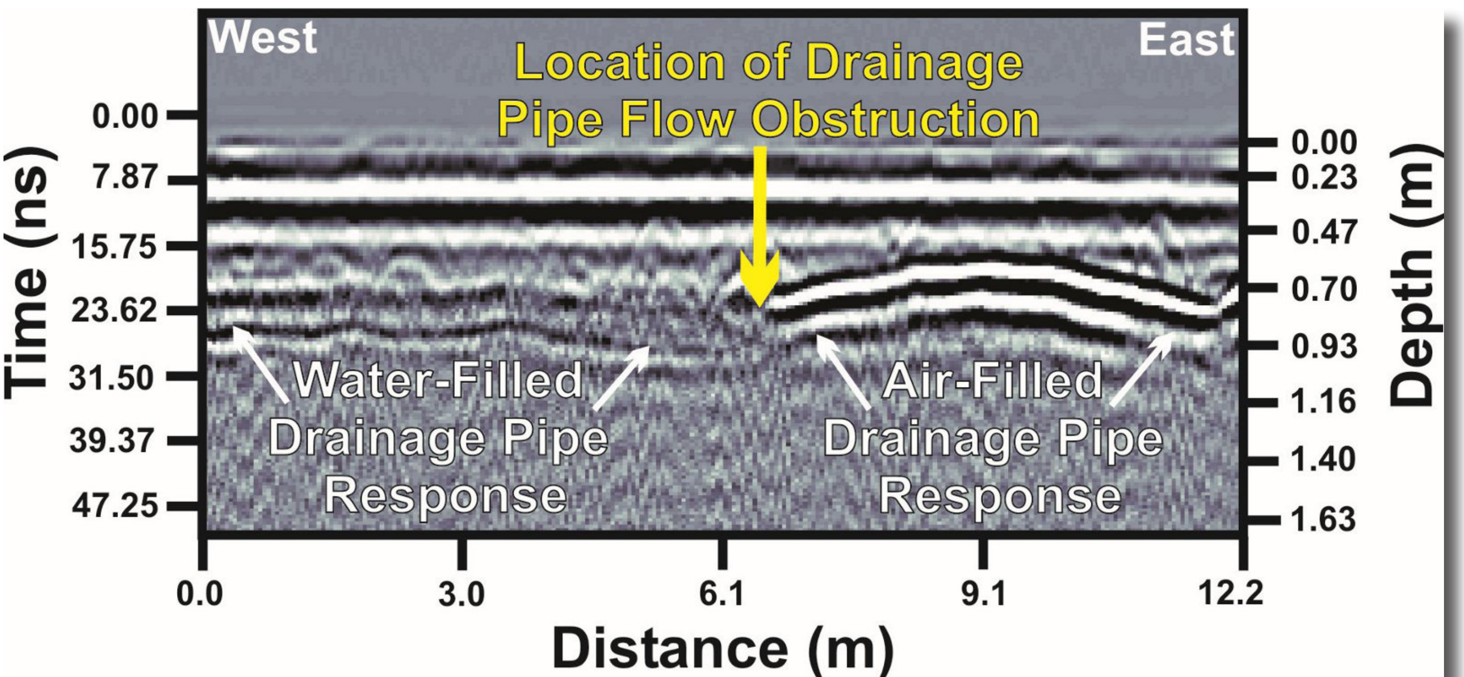

Figure 6. GPR profile oriented along trend of a drain line showing the location of a pipe flow obstruction.

Summary

Studies indicate that ground penetrating radar (GPR) is a potentially important tool for mapping drainage pipe systems beneath both farm fields and golf course greens. For GPR to be successful in this endeavor; site conditions, equipment parameters, field survey set-up, and computer processing steps are important considerations. In addition to mapping drainage pipe systems, GPR, given the right circumstances, is also capable of evaluating drain line functionality by detecting whether pipe flow obstructions are present. Continuing research is focused on integration of GPR with real time kinematic Global Positioning System receivers in order to improve the efficiency of drainage pipe detection GPR surveying. Furthermore, investigations are now being carried out to appraise the impact on the GPR drainage pipe response due to GPR antenna orientation relative to drain line trend.

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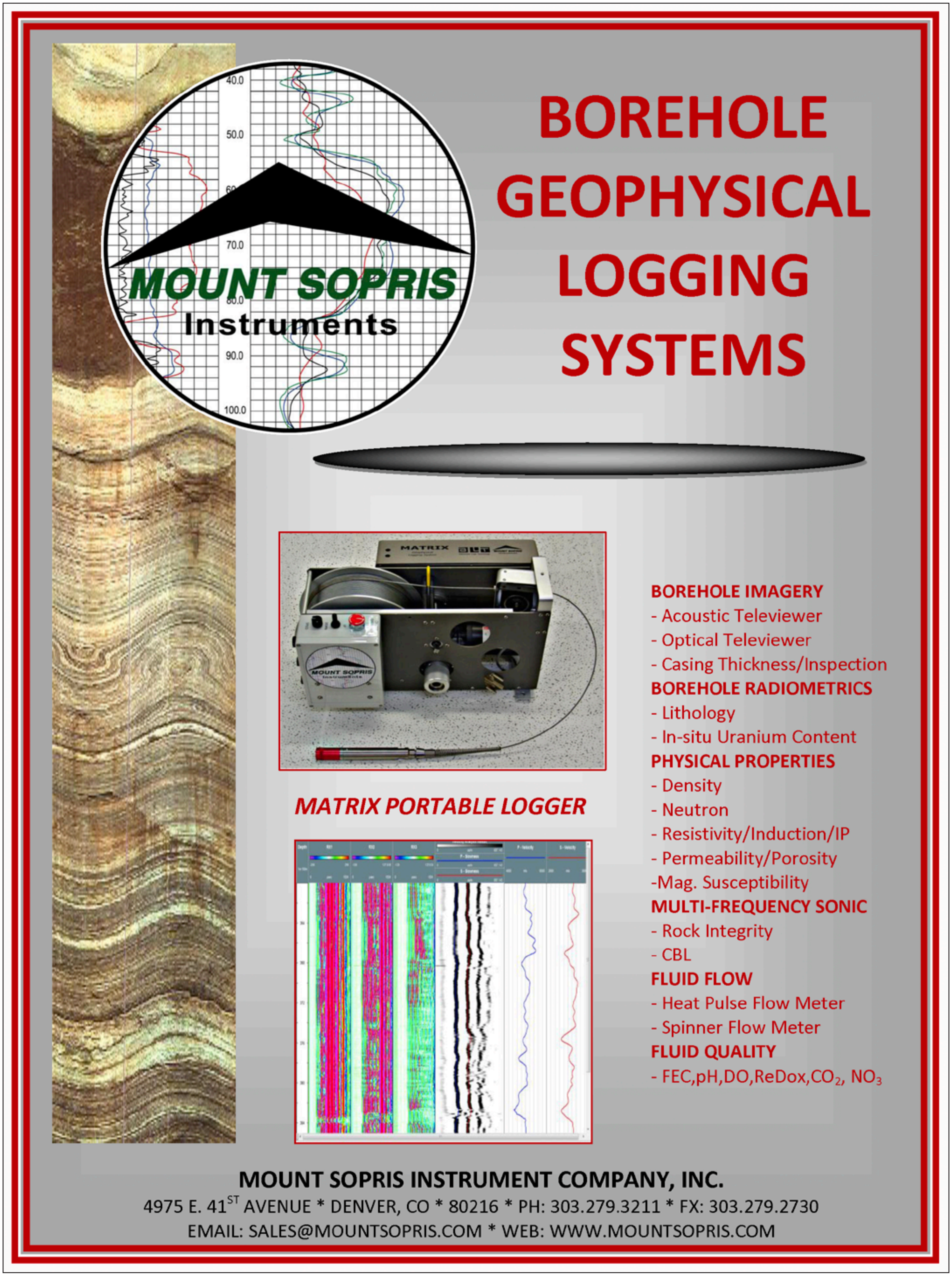
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Using Electromagnetic Induction as a Research Tool to Predict Odor Emissions from Beef Cattle Feedlot Pens

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Introduction

It is estimated that approximately 8.3 x 107 tonnes of manure are produced annually from cattle on feed in the U.S. annually. Greenhouse gases and malodorous compounds are emitted from this accumulated manure; therefore, considerable research has gone into measuring gas emissions from feedlots (Auvermann and others, 2007; Kyoung and others, 2007; Todd and others, 2008). Flux chamber and wind tunnels have been used to estimate emissions at specific points on a feedlot surface (Hudson and others, 2009; Meisinger and others, 2001). However, these techniques are not adequate to predict emissions from large area sources, particularly when there is considerable spatial variability (Cole and others, 2007; Parker and others, 2005, 2008, 2009).

Manure contains sufficient salts to alter the conductivity of the soil to which it is applied. Geophysical techniques have been developed that measure the conductivity of manure accumulated on feedlot pen surface using electromagnetic induction (EMI) (Woodbury and others, 2009) (Figure 1). This technique uses EMI conductivity data with a response surface sampling design to identify sample locations for a calibration set (Lesch and others, 1995a,b). The calibration data are then combined with the EMI survey data to determine an appropriate linear regression model. Recently, Eigenberg and others (2008) successfully adapted these techniques to describe the spatial chloride distribution in a vegetative runoff control system and Woodbury and others (2009) applied similar methods to identify locations of manure buildup on feedlot pen surfaces.

Figure 1. Electromagnetic induction system measuring the spatial manure accumulation on a feedlot surface.

The overall objective of this study was to determine if EMI technology could be used to predict differences in spatial distribution of volatile fatty acids (VFAs) on a feedlot pen. Specific objectives were: (i) use EMI data to direct a response surface sampling design to co-locate sample sites, (ii) incubate samples to develop calibration equations for each pen and volatile compound, (iii) determine overall pen average for each compound, and (iv) determine if diet affected the potential offensiveness basis on differences in VFA type and amounts produced.

Materials and Methods

Eight 30 m x 60 m pens at the U.S. Meat Animal Research Center (USMARC) near Clay Center, NE, were selected for this study. Each pen was stocked with 75 steers for a stocking density of approximately 24 m2 per animal. The steers were fed either a corn-based or a wet distillers grain with solubles (WDGS)-based diet for approximately 215 days. The WDGS is a corn byproduct from the ethanol industry. Pen surfaces are typically cleaned and reconditioned annually during July and August; however, localized accumulated manure was periodically cleaned and removed when needed between annual cleanings. Typical cleaning procedures included scraping and removing accumulated manure and reshaping the central mound.

Specific details on the EMI equipment and techniques used for this study are described by Eigenberg and others (2008) and Woodbury and others (2009). Briefly, a Dualem-1S meter (Dualem Inc., Milton, ON, Canada) was used to collect apparent electrical conductivity (EC_a) data from the feedlot pen. The meter was positioned on a nonmetallic sled and pulled at approximately 1.5 m s^{-1} on 1.5 m intervals across the pen surface. Path spacing was maintained using a Trimble EZ-Guide global positioning system (GPS)/Guidance System (Trimble Navigation Limited, Sunnyvale, CA). The Dualem-1S meter simultaneously records both perpendicular (PRP) and horizontal coplanar (HCP) orientations; however, only the more shallow (depth measured centroid at approximately 0.75 m) penetrating PRP orientation was used for the statistical analysis because of its sensitivity to surface changes. Simultaneously, GPS coordinates of the meter's position within the pen were determined using an AgGPS 332 receiver with OminiSTAR XP correction resulting in 10- to 20 cm accuracy (Trimble Navigation Limited, Sunnyvale, CA). Coordinated GPS and EC_a data were collected at a rate of five samples per second and stored in a Juniper System Allegro (Juniper System, Inc., Logan, UT) data logger. Edge effects from metal fencing were clipped from the EC_a data set before the sampling designs were determined.

Twenty sampling sites per pen were co-located with a selected EC_a value within the pen using the spatial response surface sampling design (RSSD) program contained in USDA–ARS ESAP (ECe Sampling, Assessment, and Prediction) software package (Lesch and others, 2000). These sites were selected to optimize the estimation of the VFA/EC_a calibration equations; and justifications for the procedures are given in Woodbury and others (2009). Samples were collected from a 30cm diameter area to a depth of 5 cm and placed in a 4 L plastic bag.

Once the samples were collected, they were prepared for incubation by placing approximately 350 g of feedlot surface and 700 mL of distilled water in a blender and then mixed to a uniform consistency. The volume of mixed sample was then transferred to 4L glass jars that were covered but not sealed to begin incubations at room temperature to simulate conditions following a rain event. On day 0, 1, 2, and 3, the slurries were stirred and sampled. The sample liquid fraction was analyzed for acetate, propionate, butyrate, valerate, caproate, heptanoate, caprylate, isobutyrate, isovalerate, isocaproate, phenol, cresol, 4-ethylphenol, indole, and skatole. These compounds were grouped into acetate, straight-chained VFAs, branched-chained VFAs, total VFAs, and aromatics. The straight-chained VFAs were composed of propionate, butyrate, valerate, caproate, heptanoate, and caprylate. The branched-chained VFAs were composed of isobutyrate, isovalerate, and isocaproate. Total VFAs were composed of acetate and straight-chained and branch-chained VFAs. The aromatics were composed of phenol, cresol, 4-ethylphenol, indole, and skatole. Discussion for this article will focus only on straight- and branched-chained VFA. A more complete discussion of the results can be found in Woodbury and others (2011).

Results

The average straight-chained, branched-chained and total VFA concentrations by pen are presented in Table 1. Pens with cattle fed the corn-based diet produced 60.6 mmol kg^{-1} straight-chained VFAs, significantly more ($P \leq 0.05$) than the 39.0 mmol kg^{-1} produced from pens where cattle were fed the WDGS-based diet. Also, there were significant differences in the total branched-chained VFAs generation ($P = 0.017$) with 4.6 and 6.9 mmol kg^{-1} for the pens with the cattle fed the corn-based and WDGS-based diets, respectively. Total VFA concentrations differed significantly ($P = 0.074$) due to diet. The pens with cattle fed the corn-based diet produced 142.1 mmol kg^{-1} total VFA, whereas the pens with the cattle fed the WDGS-based diet produced only 96.9 mmol kg^{-1} total VFA.

Table 1. Average concentration and standard deviations of acetate, volatile fatty acids (VFA), volatile solids (VS), and other volatiles produced during the 3d in vitro incubation of feedlot soil and manure samples. †

Pen no.	Diet	Total Straight VFA	Total Branched VFA	Total VFA
		mmol kg^{-1}	mmol kg^{-1}	mmol kg^{-1}
217	Corn	76.0 ± 27.8	4.2 ± 1.5	171.6 ± 60.9
218	Corn	48.0 ± 15.3	4.8 ± 2.1	111.6 ± 40.4
223	Corn	75.3 ± 28.1	4.6 ± 2.4	179.2 ± 66.3
224	Corn	42.9 ± 28.5	4.6 ± 2.7	106.0 ± 65.5
Average		60.6a	4.6a	142.1a
219	WDGS	36.4 ± 20.6	6.6 ± 2.3	95.4 ± 48.0
220	WDGS	42.7 ± 24.9	5.9 ± 3.1	75.3 ± 34.4
221	WDGS	40.1 ± 18.0	7.4 ± 2.7	115.8 ± 42.7
222	WDGS	36.6 ± 18.1	7.8 ± 3.6	99.9 ± 45.6
Average		39.0b	6.9b	96.6b
P-value		0.050	0.017	0.074

† Cattle were fed either a corn-based (dry rolled) or wet distillers grain with soluble (WDGS)-based diets.

‡‡ Mean values followed by different letter were significantly different by diet at the $p < 0.1$ level.

In addition to pen concentration averages, calibrated models for each pen and grouped volatile category were used to predict the proportion of the surface area of each pen with VFA concentrations that would exceed specific cutoff levels. Cutoff levels were selected on the basis of experience to represent typical concentrations measured for the volatile categories. Straight-chained VFA distribution had high within-diet variability; however, significant differences were measured between diets for the >55.0 mmol kg^{-1} production cutoff level ($P = 0.040$) (Figure 2). The portion of the pen surface with calculated concentrations >55.0 mmol kg^{-1} was 57.4% for the corn-based diet and 25.0% for the WDGS-based diet. This difference is due to the greater starch content of the manure from cattle fed the corn-based diet producing more straight-chained VFAs than manure from cattle fed the WDGS-based diet.

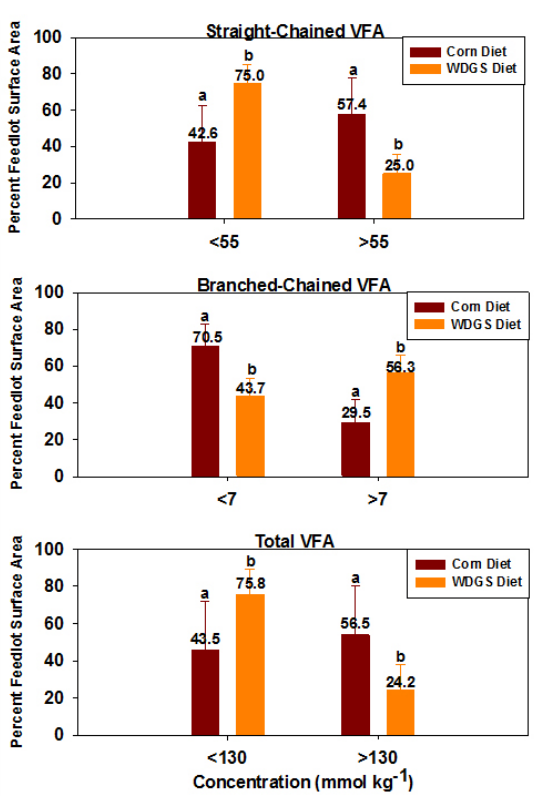

Figure 2. Average percentage of pen surface that is above a specified threshold for straight-, branched-, and total VFA.

Pens with the cattle fed the WDGS-based diet had a greater area generating >7.0 mmol kg^{-1} branched-chained VFAs than the pens with the cattle fed the corn-based diet. Significant differences (P = 0.015) were measured between diets for the <7.0 mmol kg^{-1} concentration ranges (Figure 2). The pens with cattle fed the corn-based diet had 70.5% of the surface area that produced <7.0 mmol kg^{-1}, compared with the 43.7% of pens with the cattle fed the WDGS-based diet. The pens with cattle fed the corn-based diet had a greater area generating <130 mmol kg-1 total VFAs than the pens with the cattle fed the WDGS-based diet, and this difference was significant below the 0.10 level (P = 0.081) (Figure 2). The corn-based diet had only 43.5% of the surface area that produced <130 mmol kg^{-1}, whereas the WDGS-based diet was 75.8%. This difference was probably due to the increase in acetate and straight-chained VFAs for the corn-based diet (even though acetate concentration levels for the two diets cannot be judged to be significantly different).

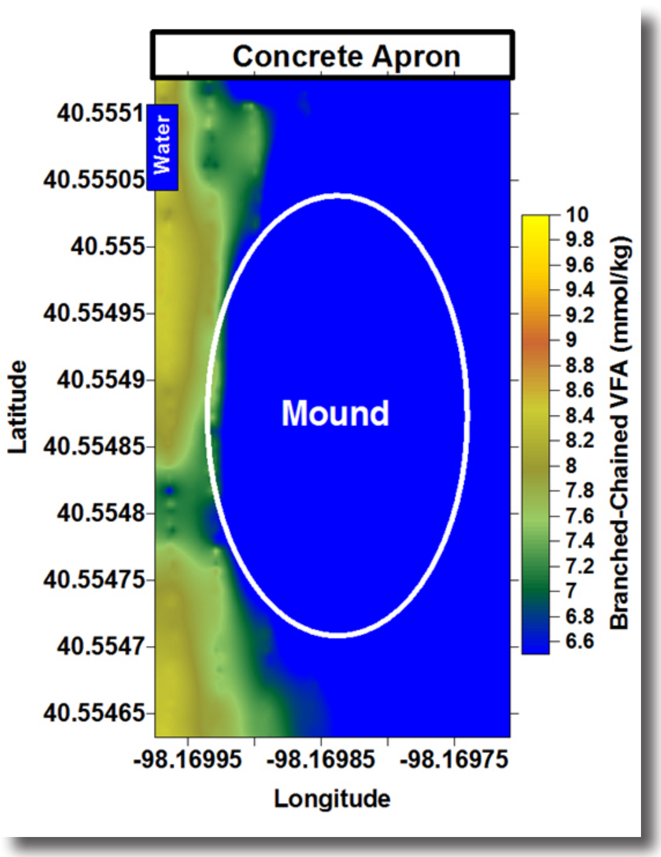

Figure 3. Spatial distribution of branched-chain Volatile Fatty Acids above the 7 mmol kg-1 threshold for pen 218. The area of the pen above the threshold was 26.5%, which was typical for pens with cattle fed a corn-based diet.

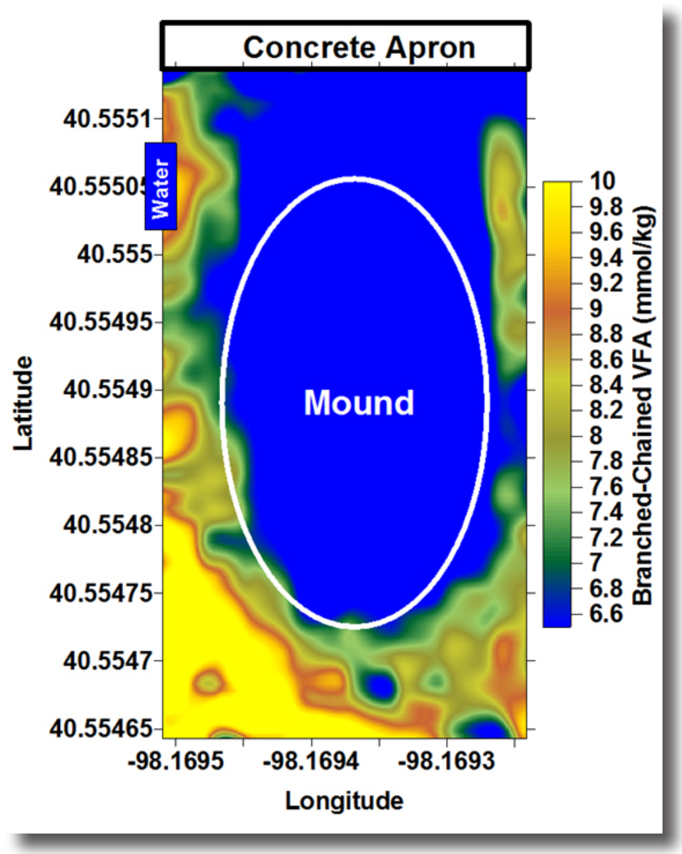

Figure 4. Spatial distribution of branched-chain Volatile Fatty Acids above the 7 mmol kg-1 threshold for pen 219. The area of the pen above the threshold was 42.2%, which was typical for pens with cattle fed a wet distillers grains with solubles-based diet.

Figures 3 and 4 show the predicted branched VFA concentration maps for pens 218 and 219, respectively. Such maps can be created for any volatile category that correlates well with EC_a survey data and in turn used to infer the spatial emission pattern. Figure 3 illustrates that approximately 26.5% of the pen surface area is ≥7 mmol kg^{-1} thresholds for pens with cattle fed corn-based diets. Figure 4 shows approximately 42.2% of the pen surface area is ≥7 mmol kg^{-1} thresholds for pens with cattle fed WDGS-based diets.

Discussion

Manure accumulation can impact the environment in many different ways, such as odor and greenhouse gas emissions, nutrient runoff, as a pathogen source to human food supplies, and as a medium for insect development. Suitably calibrated, EC_a survey data can help researchers better understand the pattern of manure accumulation on a given feedlot surface. This understanding can guide researchers to develop management practices for controlling manure's impact on the environment.

Gases such as NH_3, N_2O, CO_2, and volatile organic compounds associated with malodor emissions from feedlots result from microbial degradation of excreted animal manure. Spatial accumulation of these excreted manure nutrients results in zones within the pen that are much more prone to malodorous emissions. Maps illustrating zones of manure nutrient accumulation could be used to focus pen cleaning efforts. Also, these areas could be cleaned more frequently to remove the organic material and reduce the potential for malodorous emissions. Additionally, these zones could be identified and treated with compounds like thymol to inhibit odor generation during wet periods when removal is not practical (Varel et al., 2006; Varel et al., 2001). The GPS coordinates associated with the mapping technique could be used for the precise application of thymol or other antimicrobial compounds to zones with the highest potential for malodorous emissions. This would reduce malodorous emissions until the manure nutrients could be removed and improve the cost effectiveness of the antimicrobial agent.

Conclusions

No differences were measured in average VS concentration of the accumulated manure due to diet. However, EMI and spatial mapping techniques were a useful tool for understanding manure accumulation patterns and zones for potential odorant emission from the feedlot surface. Using this technology, we were able to determine that the corn-based diet had greater average straight-chained VFA concentrations than the WDGS-based diet. Alternately, the WDGS-based diet had greater branched-chained VFA concentration than the corn-based diet. This finding supports other research indicating the higher starch content found in manure from corn-based diets, particularly dry-rolled corn, tend to produce more straight-chained VFAs. Consequently, the higher protein content in the WDGS-based diet tended to produce greater branch-chained VFA concentrations. Similarly, this technology allowed for the determination that 57.4% of the corn-based diet pen surfaces produced straight-chained VFAs at levels >55 mmol kg-1 ,whereas the WDGS-based diet pens only had 25.0% generation for the same concentration range. The opposite trend was found for the branched-chained VFAs in that the corn-based diet pens had 29.4% of the surface area produce 7 mmol kg_{-1} or greater, whereas the WDGS-based diet had 56.37%. Diets affected the types and amounts of VFAs produced 3 days following a simulated rain event. The WDGS diet appears to produce higher branched-chained VFAs, which can be considered more offensive. Using EMI, combined with spatial techniques as a tool, will enable researchers to better identify and predict odorant generation. This technology will aid in the development of precision management practices for feedlot surfaces that can mitigate environmental contamination from animal feeding operations.

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The Use of Ground Penetrating Radar for Soil Mapping in Agriculture

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Introduction

The principle of ground penetrating radar (GPR) is based on the measurement of the propagation of electromagnetic waves in the soil. Usually, the applied frequencies lie in the range of MHz to GHz. The propagation of these waves depends on the electromagnetic soil properties:

- The velocity of EM waves depends on relative permittivity, ε_r, and relative magnetic permeability, μ_r.
- The amplitudes of reflected waves are influenced by contrasts in complex electrical permittivity.
- The electrical conductivity affects the wave attenuation and therefore the penetration depth.

Data quality depends on technical parameters of the antenna (frequency, characteristics, shielding, etc.), on soil conditions (electrical conductivity, coupling between antenna and soil) as well as on orientation between the antenna and the investigated structures in the soil. Field work (frequency and arrangement of antenna, time window, stacking, etc.) as well as data processing differ with respect to the field of application. Constant-offset-measurements (COF) are performed to image soil horizons as well as artificial objects like utility and drainage pipes or to study velocity changes for the ground wave caused mainly by changes in soil moisture. Multi-offset measurements (Common midpoint – CMP or wide-angle reflection-refraction – WARR) can be used to estimate the soil moisture on the basis of models correlating velocity of wave propagation and water content. Case studies will illustrate different agricultural applications.

Correlation Between Attenuation and Soil Texture

Two effects may be responsible for the correlation between soil texture and electrical conductivity, both of which have been confirmed by several authors (Rhoades and others, 1999; Lesch and others, 2005; Kühn and others, 2009). On the one hand, the double layer of clay particles increases the bulk electrical conductivity of the soil (Tabbagh and Cosenza, 2006) and on the other hand, the higher water storage capacity of clay results in a higher water content and therefore also in higher conductivity values. Higher conductivity means higher radar signal attenuation and smaller depth of radar signal penetration. Especially in regions with varying soil texture, GPR data are helpful to distinguish between regions with high and low clay content. Data from a test site in the northern part of Germany (Kassow, Mecklenburg-Vorpommern) illustrate this effect. The field is characterized by an undulating topography, and the sandy soil present is low in clay and silt content. Down to 1 m in depth, the mean sand content is about 55% and the mean clay content is 12 %. Field data were collected in summer 2004 when the average water content was 12.3 %.

The conductivity-depth model (Figure 1 a) was achieved with the direct current (DC) resistivity method. The spacing between the electrodes was increased step by step from 0.5 m to 4 meters (Wenner-Array). The variation in conductivity values can be explained by differences in soil texture. Soil samples were sieved in the laboratory. The numbers in the circles at the top of Figure 1a give the mean content of the particle size fraction < 20 µm. Increasing contents in clay and silt correlate with an exponential decay of electrical resistivity. The correlation between particle size distribution and electrical resistivity was improved when not only clay but also silt was considered. The GPR-dataset was recorded with 100 MHz-antennas and an offset of 2 m (Figure 1b). The differences in penetration depth and the correlation compared to the conductivity model are evident. To quantify this correlation, the sum of amplitudes was calculated for each trace. In Figure 2a, the variation of the subsurface resistivity (apparent resistivity rhoa and modeled resistivity rho for the first layer) as well as the variation of the summarized radar amplitudes are given. The time window of 200 ns was chosen to integrate information of the depth penetration. The trend is similar also for other trace lengths. The amplitudes decrease with increasing electrical conductivities as a combination of both datasets (Figure 2b).

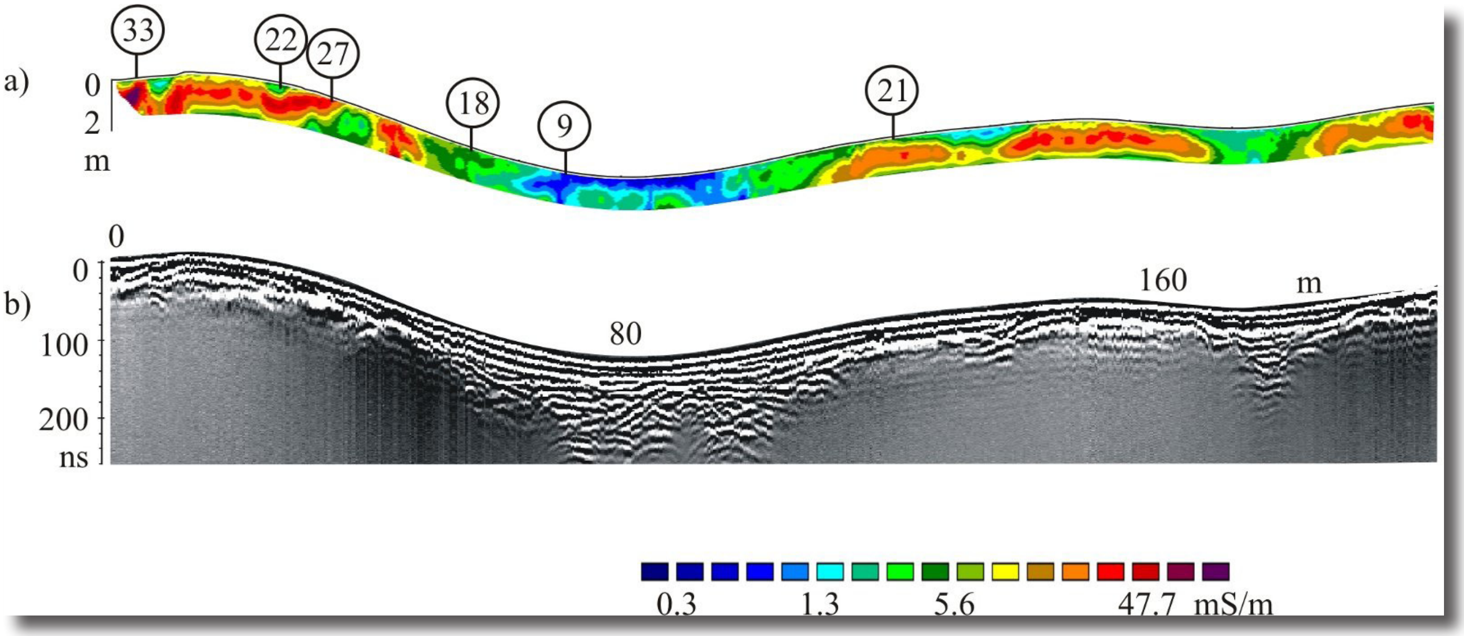

Figure 1. Comparison of (a) a conductivity model derived from DC- (direct current) method with (b) a GPR-section measured with 100 MHz-antenna using 2 m offset between antennas. The numbers in the circles give the mean value of fine material for the upper meter.

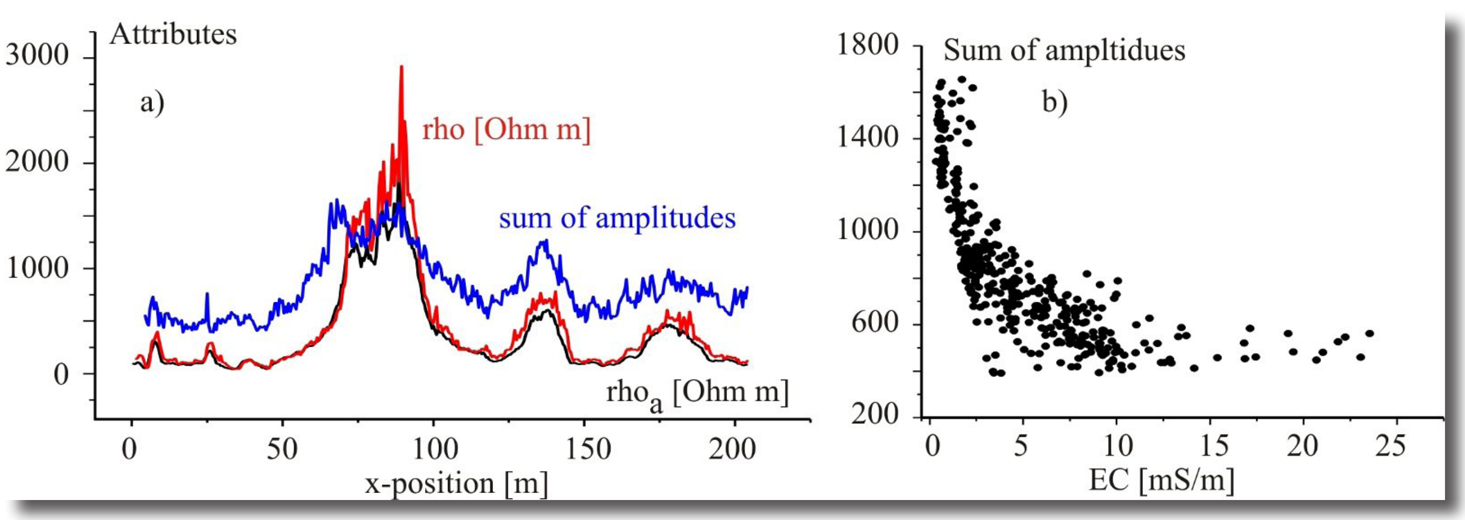

Figure 2. Attribute analysis of geophysical data; (a) trend of apparent (rhoa) and modeled (rho) resistivity and sum of GPR amplitudes within a time window of 200 ns and (b) cross-plot between sum of amplitudes and electrical conductivity.

Soil Horizons

For low conductive soils, GPR measurements can be used to image structures in the subsoil. This was studied in detail at a 200 m long profile in Grossbeeren (50 km south of Berlin, Germany), where several structures with a well defined geometry were artificially embedded in a sandy soil. Conductivity data as well as GPR data were collected and evaluated. Here, only the embedded loam body will be discussed. The differences in soil texture (Table 1) generate conductivity contrasts which can be measured by electrical methods.

Table 1. Soil texture for the 'Grossbeeren' test site.

	Particle size fraction [%]						
Particle size [mm]	0.63 – 2.0	0.2 – 0.63	0.063 – 0.2	0.02 – 0.063	0.0063 – 0.02	0.002 – 0.0063	< 0002
Sand	8.8	54.9	22.8	4.1	3.6	3.1	2.7
Loam	3.1	21	28.9	13.1	13.1	12.4	8.4

All standard resistivity method configurations (Wenner, Dipole-Dipole, Schlumberger and also equatorial dipole-dipole) were able to outline the loam body. However, the sharpness of the image differs depending on the geometry of the electrodes. In Figure 3c, results only from the Wenner-configuration are shown. For comparison, the position and the 2-dimensional geometry of the loam body (5 m extension in the third dimension) are given in Figure 3a.

The soil stratification as well as the relief of soil horizons can also be imaged with GPR, if changes in the permittivity generate reflections. The 200 MHz-GPR section (Figure 3b) shows a lot of structures and the interpretation of the reflection pattern required some additional information. Trenches have provided insight into the soil heterogeneity. Homogeneous areas have an extent of only a few meters. The reflector at about 40 ns may be caused by significantly increasing water content at a depth between 1.5 and 2 m, known from small additional bore holes. The transition between the well known loam body and the surrounding sand is clearly visible. Inclination and depth of the lower horizon can be estimated.

Utility and Drainage Pipes

GPR is not only used to locate utility pipes and agricultural drainage pipes (Holden and others, 2002; Allred and others, 2005), but also to study their conveyance functionality (Allred and others, 2010). Böniger and Tronicke (2010) varied the symmetry of the antenna and studied the polarization to characterize the pipe material. Difficulties in data interpretation are described in literature as well (Holden and others, 2002). The small diameters of the object pipes result in the well known reflection hyperbola pattern for these items if the GPR profile is oriented perpendicular to the utility or drainage pipes. However, other narrow, restricted reflectors in the surrounding soil will generate a similar GPR response pattern. To overcome these difficulties in interpretation, time slice maps of a set of 2-dimensional GPR-measurements may be constructed. A case study illustrates the potential of this method. At a relative small field in Grossbeeren (Germany), measurements with 500 MHz-antenna GPR system were done with 0.5 m line spacing. The processed time slice maps for two time windows are given in Figure 4.

The upper slice (Figure 4a) is dominated by a linear object which represents a water pipe at about 0.5 m depth, slightly increasing from west to east. From the lower slice it can be seen that the field was partly drained in former time. This region was part of a sewage farm where drainage pipes were installed in a depth between 1 and 1.5 m more than 100 years ago. These drainage pipes beneath the water pipe can be seen within a time window of 18 – 28 ns (Figure 4b). The NE-SW-orientated drainage pipes end in the middle of the field at a main collector pipe.

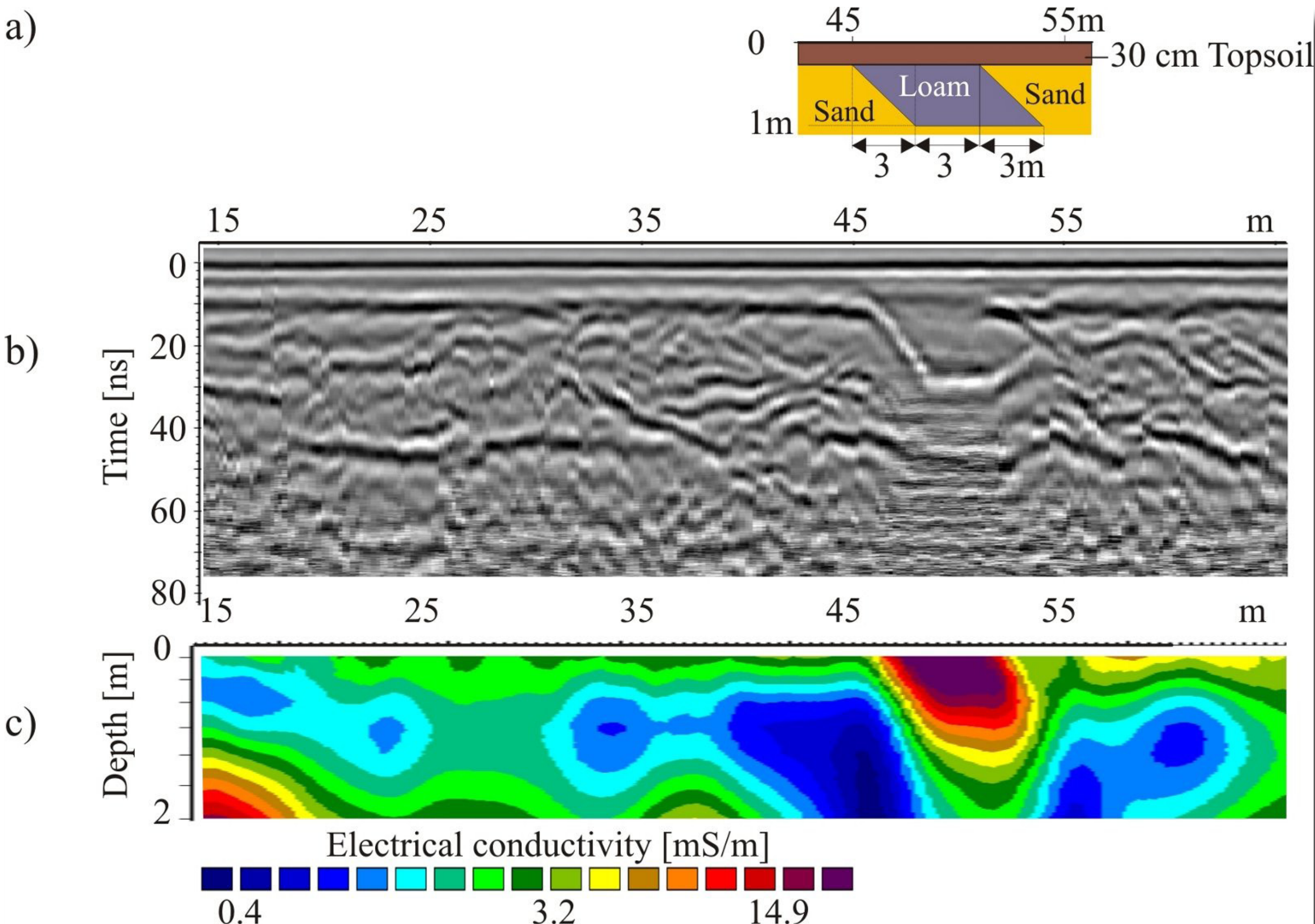

Figure 3. Geophysical image of a loam body within sand – test site in Grossberen (Germany); (a) sketch of the known structure, (b) GPR section measured with a 200 MHz antenna, and (c) conductivity section.

Soil Moisture

The relation between velocity of electromagnetic wave propagation and permittivity, and further the high permittivity of water compared with solid soil components result in methods to estimate soil moisture from GPR just as from time domain reflectometry (TDR) data. Ground waves (Sperl and others, 1997; Berkthold and others, 1998; Grote and others., 2010) as well as reflected waves (Graves and others, 1996; Loeffler and others, 2004) can be used. A new method is based not on velocity or amplitudes but on the peak frequency. Benedetto (2010) demonstrated that the peak frequency provides information on the soil moisture too.

CMP and WARR data allow estimating water content at discrete positions. If data does not contain any reflection, only the ground wave can provide water content information for the topsoil. The depth of highest sensitivity depends on the radar signal wavelength. Simulation experiments from Sperl (1999)

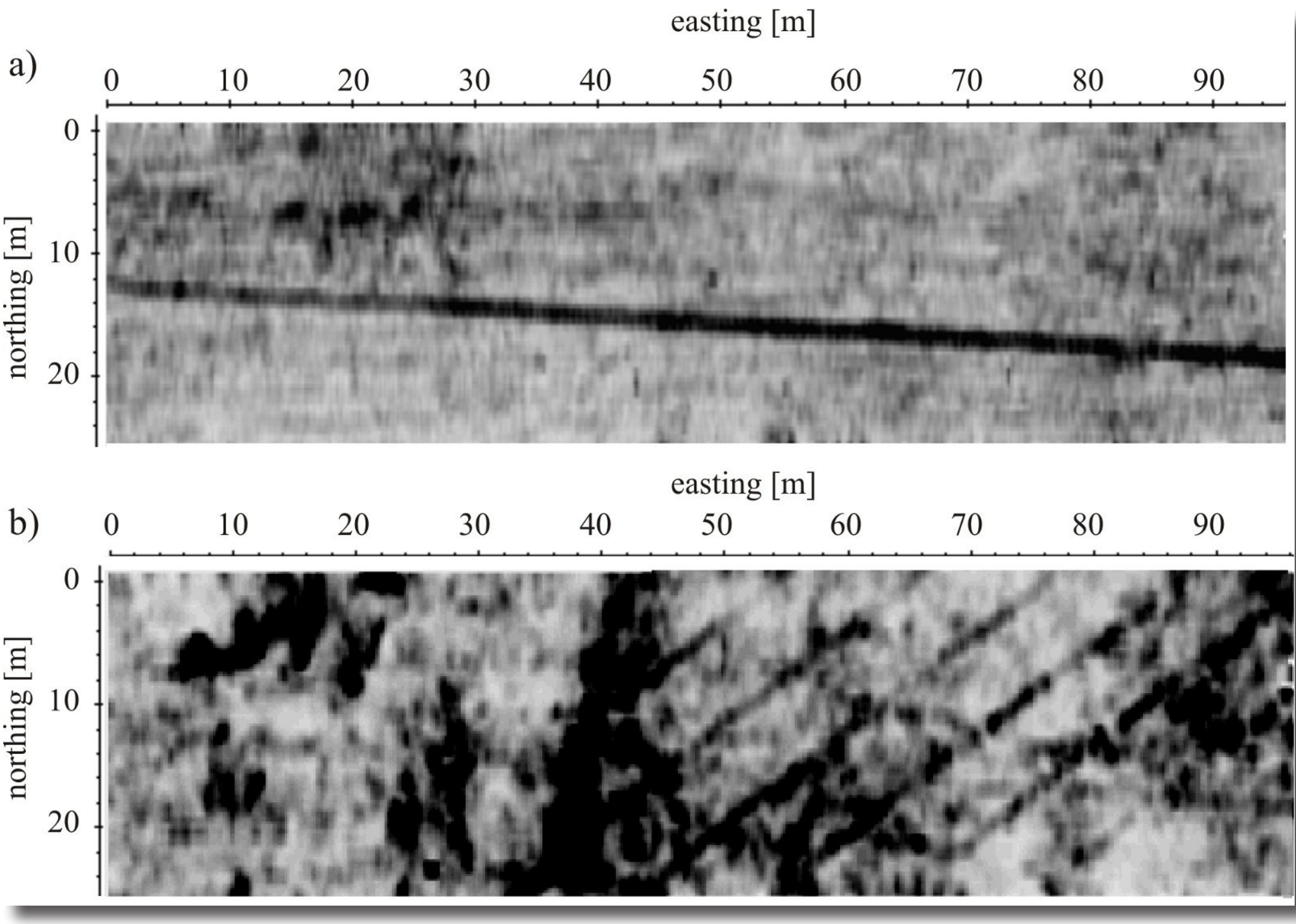

Figure 4. GPR - time slice maps at the test site in Grossbeeren, Germany; (a) time window 4 – 12 ns and (b) time window 18 – 28 ns.

have resulted in 0.26 m depth for a 35 MHz antenna and 0.11 m depth for a 130 MHz antenna. Figure 5 gives an example for a sandy soil in Germany (Bornim, Brandenburg). GPR data were recorded at several positions in spring and in summer. Soil samples were taken to estimate soil moisture gravimetrically. As expected, the wave velocity is much higher (0.13 m/ns) under dry soil (soil moisture 5.7%) conditions (Figure 5b) than for a wet soil (Figure 5a). In Figure 5c, the results (red points) are compared with the empirical relationship which was given by Topp and others (1980) (black solid line).

Working with constant offset (COF) data, the ground wave can also be used to image spatial changes in subsurface water content. However, it is more difficult to interpret lateral variations of wave pattern. Near surface horizons can produce a superposition of ground wave and reflected waves (Figure 5b). Therefore, lateral changes in first arrivals can be caused by velocity variations as well a by layered structures. A combination of COF and CMP measurements may be helpful to optimize the offset between antennas in the field and later to improve the identification of the ground wave. Even though the amplitudes decrease rapidly with increasing antenna separation, greater offsets and therefore greater time shifts allow better ground wave identification. The multi-channel technique will minimize erroneous wave identification in future.

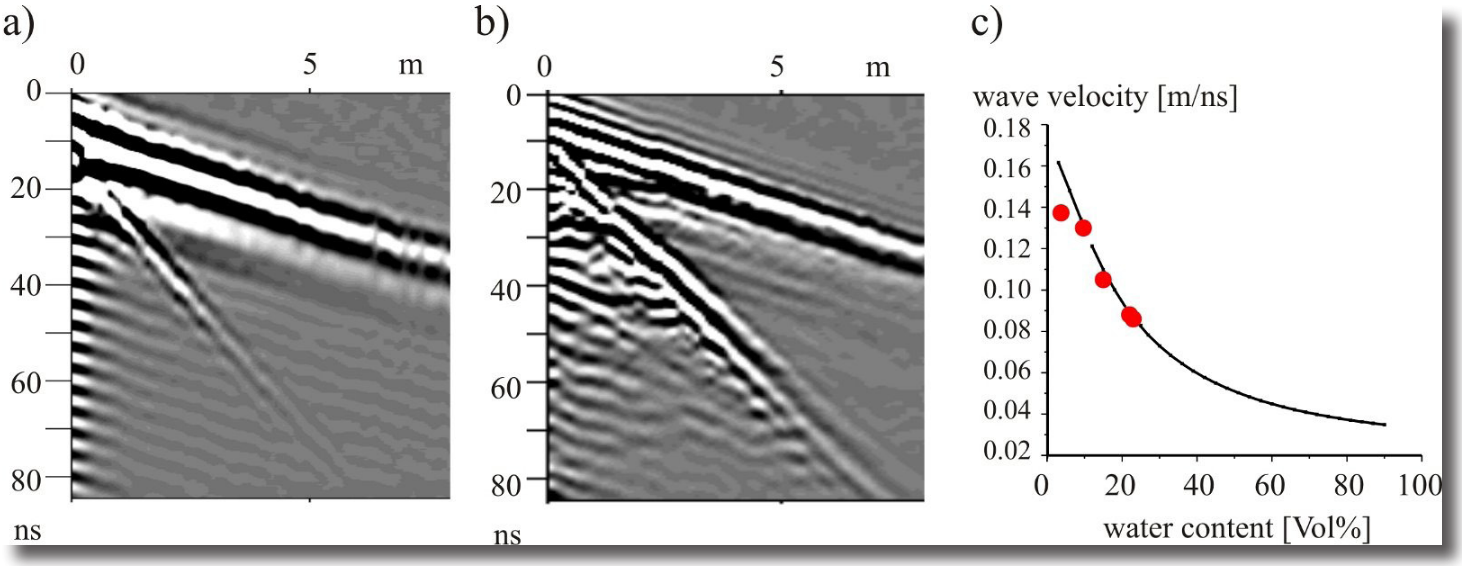

Figure 5. Variety of CMP-data at several positions in Bornim (Germany); (a) measurements for a wet sand (water content 22 %, velocity = 0.09 m/ns), (b) data under dry conditions (water content 5.7 %, velocity 0.13 m/ns), and (c) relationship between wave velocity and volumetric water content.

Conclusions

Multiple application fields of GPR measurements were demonstrated. Specific soil conditions and capable parameter choices both in the field and for data processing can affect the results. The amount of data controls the reliability as well. The spatial resolution depends significantly on frequency and on line and trace spacing. Even though GPR method can be used to investigate agricultural fields, the method cannot be standardized in all parameters but needs geophysical understanding.

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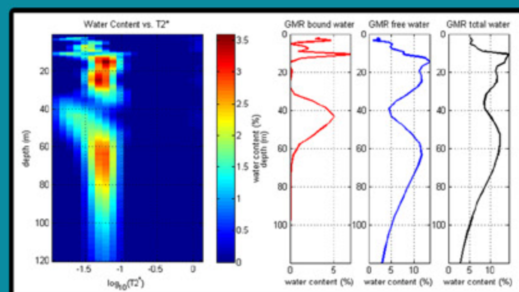

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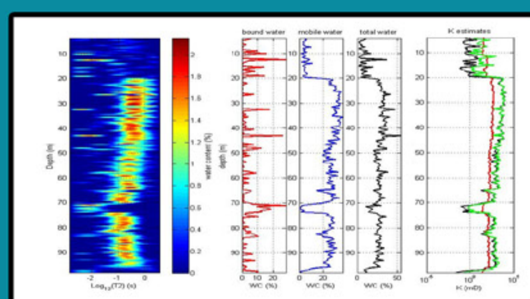

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CALL FOR PAPERS

Geophysics for Levee Safety

Special Issue of the Journal of Environmental and Engineering Geophysics

The Journal of Environmental and Engineering Geophysics (JEEG) announces a Call for Papers for a special issue on geophysics for levee safety. The Levee Safety issue is scheduled for publication in March 2012. The special issue editor is Dr. Maureen K. Corcoran, U.S. Army Engineer Research and Development Center. Sponsorship of this issue is still open.

Papers describing the successful use of one or more geophysical surveys to understand engineering issues of concern for levee safety risk assessment and/or remediation are sought. The issues can include woody vegetation assessment, foundation and/or embankment property measurements, fault analyses for earthquake hazard potential, basin studies to better understand hydrological risks, or other safety concerns. Preference will be given for papers with supporting information to substantiate the geophysical models. International contributions are encouraged. The final special issue can only accommodate a maximum of seven or eight papers, but all accepted papers will be considered for publication in other JEEG issues.

Papers can be submitted through the JEEG submission site, http://jeeg.allentrack.net. Indicate in the cover letter that the paper is for consideration in the Levee Safety special issue. The deadline for submissions is February 28, 2011.

Questions may be directed to:

Special Issue Editor—Maureen K. Corcoran, Maureen.K.Corcoran@usace.army.mil
JEEG Editor—Janet Simms, Janet.E.Simms@usace.army.mil

Funding Available for Environmental R&D

Application Deadlines: January 6, 2011 (non-federal sector) and March 10, 2011 (federal sector)

ARLINGTON, VA, October 28, 2010 - The Department of Defense's (DoD) Strategic Environmental Research and Development Program (SERDP) is seeking to fund environmental research and development proposals. SERDP is DoD's environmental science and technology program, planned and executed in partnership with DOE and EPA, with participation by numerous other federal and non-federal organizations. The Program invests across the broad spectrum of basic and applied research, as well as advanced development. The development and application of innovative environmental technologies will reduce the costs, environmental risks, and time required to resolve environmental problems while, at the same time, enhancing and sustaining military readiness.

Proposals responding to focused Statements of Need (SON) in the following areas are requested:

- Environmental Restoration - Research and technologies for the characterization, risk assessment, remediation, and management of contaminants in soil, sediments, and water.
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- Resource Conservation and Climate Change - Research that advances DoD's management of its natural and cultural resources and improves understanding of climate change impacts.
- Weapons Systems and Platforms - Research and technologies to reduce, control, and understand the sources of waste and emissions in the manufacturing, maintenance, and use of weapons systems and platforms.

Proposals responding to the Fiscal Year (FY) 2012 SONs will be selected through a competitive process. Separate solicitations are available to federal and non-federal proposers. The SONs and detailed instructions for federal and private sector proposers are available on the SERDP web site at *http://www.serdp-estcp.org/Funding-Opportunities/SERDP-Solicitations*.

The Core SERDP Solicitation provides funding in varying amounts for multi-year projects. For the Core Solicitation, PRE-PROPOSALS FROM THE NON-FEDERAL SECTOR ARE DUE BY THURSDAY, JANUARY 6, 2011. PROPOSALS FROM THE FEDERAL SECTOR ARE DUE BY THURSDAY, MARCH 10, 2011.

SERDP also will be funding environmental research and development through the SERDP Exploratory Development (SEED) Solicitation. The SEED Solicitation is designed to provide a limited amount of funding (not to exceed $150,000) for projects up to one year in duration to investigate innovative approaches that entail high technical risk or require supporting data to provide proof of concept. ALL SEED PROPOSALS ARE DUE BY THURSDAY, MARCH 10, 2011.

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AND

Join us in person for the Partners in Environmental Technology Technical Symposium & Workshop, November 30 - December 2, 2010, in Washington, DC, where SERDP and ESTCP Director Dr. Jeffrey Marqusee will present a Funding Opportunities Briefing and Q&A session on Thursday, December 2, 2010 at 12:15 p.m. EST. This presentation will offer valuable information for those who are interested in SERDP and ESTCP funding opportunities as well as answer questions about the funding process, proposal submission, and the current FY 2012 SERDP solicitation and upcoming FY 2012 ESTCP solicitation. To learn more about the Symposium or to register for this event, visit *http://www.serdp-estcp.org/symposium*.

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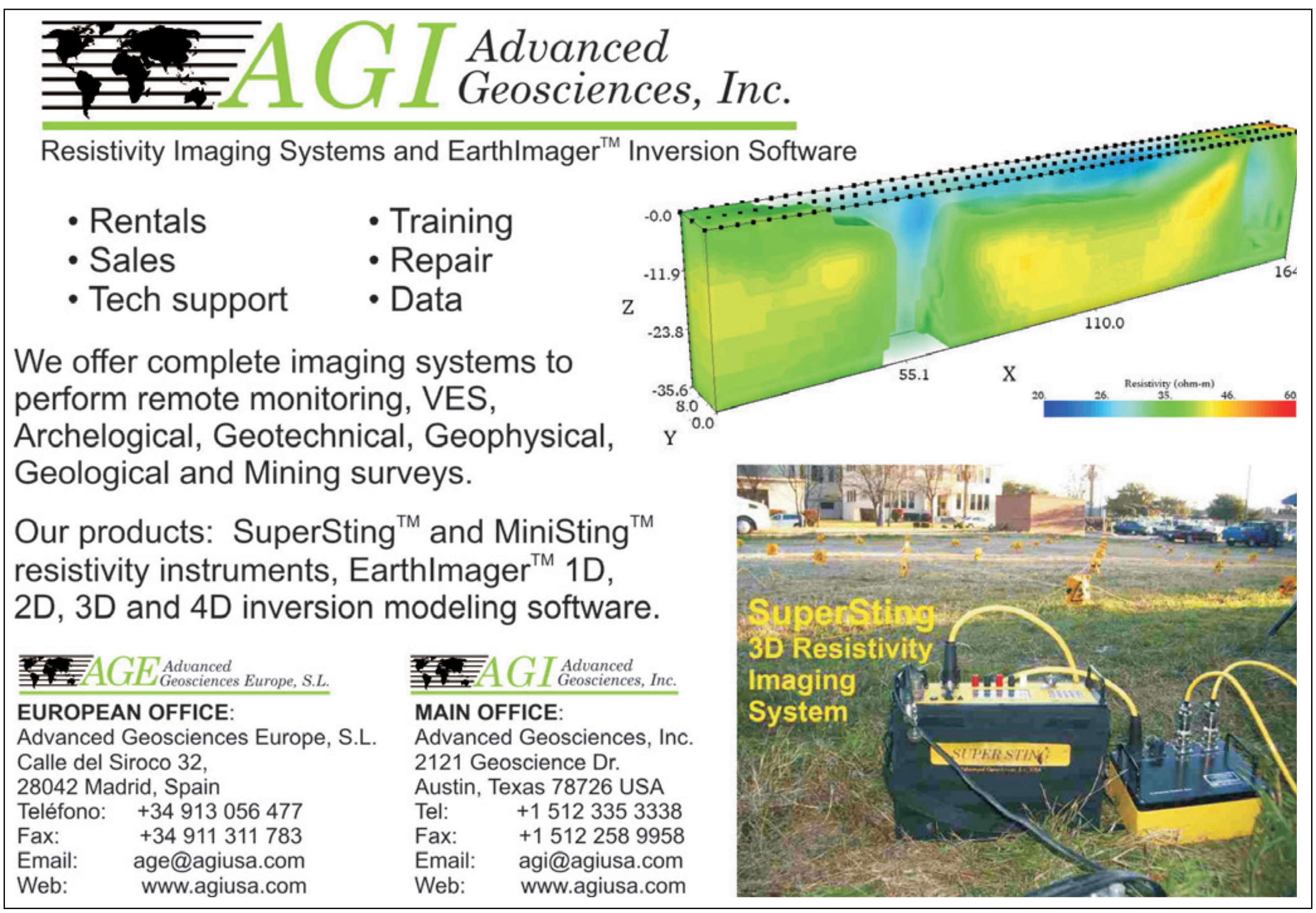
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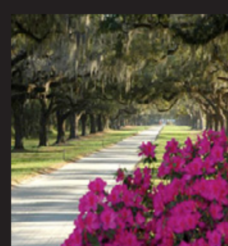
Access the web site for full program listings and details. Conference registration opening soon.



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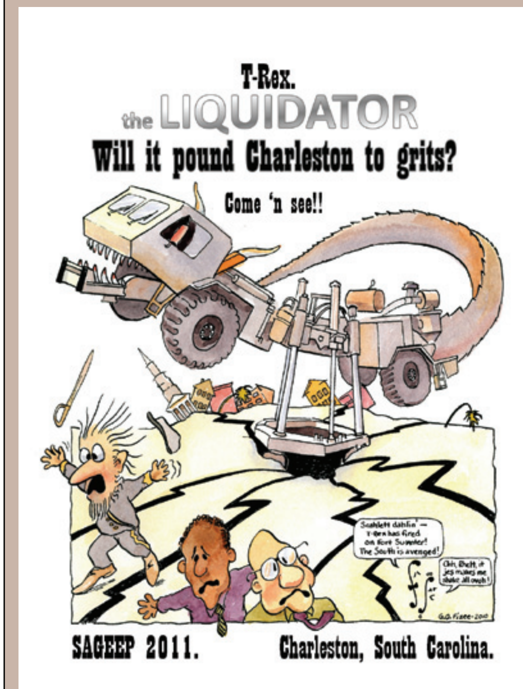

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WORKSHOPS

- Advances in Near-surface Electromagnetic Induction Geophysics, Mark Everett
- Application of Geophysical Technologies to Agroecosystems, Barry Allred

SHORT COURSES

- Surface Waves Are for Everyone (Active and Passive MASW), Julian Ivanov
- Advanced Surface Wave (MASW) Methods, Julian Ivanov
- Application of Time-Domain Electromagnetics to Ground-Water Studies, David Fitterman
- Magnetic Resonance for Groundwater Investigations: Physical Principles and Applications, Jean-Francois Girard, Anatoli Legchenko, and Jean Bernard
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Visit http://www.eegs.org/sageep to register for the workshop and/or the conference.

Workshop Overview

Geophysical methods have become an increasingly important tool for agricultural landscape management. The workshop covers past developments, present utilization, and future trends of geophysical techniques within agroecosystem topic areas that include soil salinity measurement, assessment of spatial variations of soil properties, precision farming, forestry research, watershed scale mapping, turfgrass investigations, and considerations for data collection/analysis.

This unique workshop, which ends with a panel discussion focused on future developments, is expected to be highly informative as it brings together the leading authorities on applications of geophysical methods within agroecosystems.

For More Information:
Barry Allred
Barry.Allred@ars.usda.gov
614-292-9806

Historic
Charleston, SC

Agenda

8:30 – 9:10 Agricultural Geophysics: Methods Employed, Past Success, and Current Trends
Barry Allred, *USDA – ARS*

9:10 – 9:50 Soil Salinity Monitoring and Mapping
Dennis Corwin, *USDA – ARS*

9:50 - 10:10 **Break**

10:10 - 10:50 Use of Geophysical Methods for Characterization of Soil Spatial Variability
Jim Doolittle, *USDA – NRCS*

10:50 - 11:30 Incorporation of Geophysical Data for Precision Farming
Hamid Farahani*, USDA - NRCS*
Dennis Corwin, *USDA – ARS*

11:30 - 1:00 **Lunch**

1:00 - 1:30 Forest Environment Applications
John Butnor*, USDA - Forest Service*

1:30 - 2:00 Agricultural Geophysics at Watershed Scales
Bruce Smith*, U.S. Geological Survey*

2:00 - 2:30 Turfgrass Geophysical Surveying (golf courses, athletic fields, etc…)
Robert Freeland*, University of Tennessee*

2:30 – 2:50 **Break**

2:50 – 3:30 Considerations for Planning an Agricultural Geophysics Survey, Collecting Data, and Interpreting Results
Ty Ferré*, University of Arizona*

3:30 – 4:30 Panel Discussion and Wrap up "Future Development of Agricultural Geophysics"
Moderator, ***Rick Taylor****, DUALEM, Inc.*

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Correction: Advance pricing is $295 until February 3rd

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NovCare 2011 - Workshop on Novel Methods for Subsurface Characterization and Monitoring: From Theory to Practice

May 9-11, 2011, Ocean Edge Resort, Brewster, MA

As societal concerns over sustainability of groundwater resources mount, and to address pressing issues of groundwater quality and quantity, the environmental research community increasingly finds itself in need of investigation methods that have high accuracy and resolution across a range of spatial and temporal scales. Ideally, such methods should be able to identify, quantify, and parameterize relevant physical and biochemical processes through space and time.

In recent years, several new technologies have been developed for cost-effective, minimal-disturbance, and high-resolution subsurface characterization and monitoring. Most of these methods, however, are not yet widespread. To share insights and knowledge, and to identify key areas for future research and development we announce a workshop to bring together interested stakeholders from a broad range of areas, including research, technology development, consultancy, and government.

The three-day workshop, sponsored by the Army Research Office, will provide a rare opportunity for participants to explore, experience, and discuss the latest science on subsurface characterization and monitoring. Workshop activities include plenary and poster sessions with invited and selected speakers, a social event, and a field trip to the famous Cape Cod Tracer studies on Otis Air Force Base. At this site, vendors will be on hand to present field demonstrations of their latest technologies.

Thematic areas for the conference are: subsurface transport monitoring, contaminant remediation, stream-aquifer interactions, and watershed characterization. Relevant technologies include: direct-push characterization tools, surface and borehole geophysics, adaptive & wireless sensor networks, geotechnical methods and sonic drilling, novel sensing devices, and tracer and other hydraulic testing methods.

Logistics

The workshop will be held at the Ocean Edge Resort, located on Cape Cod, MA, with easy access from Boston and close to the proposed demonstration site on Otis Air Force Base. Accommodation for attendees will be at the conference facilities.

A first call for abstracts will be distributed in November, 2010. More information can be found on http://www.novcare.org.

Organizing committee:

- Drs. David Hyndman, Remke van Dam - Michigan State University
- Drs. Jim Butler, Geoff Bohling – Kansas Geological Survey, Univ. of Kansas
- Drs. Peter Dietrich, Georg Teutsch – Helmholtz Center for Env. Research (UFZ)
- Dr. Carsten Leven – University of Tuebingen
- Dr. Kamini Singha – Penn State University


Second GLOBAL WORKSHOP ON
Proximal Soil Sensing
(Formerly known as Global Workshop on High Resolution Digital Soil Sensing and Mapping)
www.friglobalevents.com/pss
MONTREAL 2011
Dates:
May 15-19, 2011
Venue:
Leacock Building, McGill University, Downtown Montreal, Canada
Format:
Similar to the First Global Workshop on High Resolution Digital Soil Sensing and Mapping held in Sydney, Australia in February 2008.
Focus:
Proximal soil sensor development, equipment, applications, calibrations, signal processing, sensor data fusion, inference systems, (geo)statistical analyses.
INTERNATIONAL UNION OF SOIL SCIENCES
Working Group on Proximal Soil Sensing (WG-PSS):
Chair: Raphael Viscarra Rossel, Raphael.Viscarra-Rossel@csiro.au
Vice-chair: Viacheslav Adamchuk, Viacheslav.Adamchuk@mcgill.ca

The 10th SEGJ International Symposium
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November 20-22, 2011（Tentative）
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Abstract deadline: May 31, 2011 (tentative)

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3. EM/GPR Imaging Technologies
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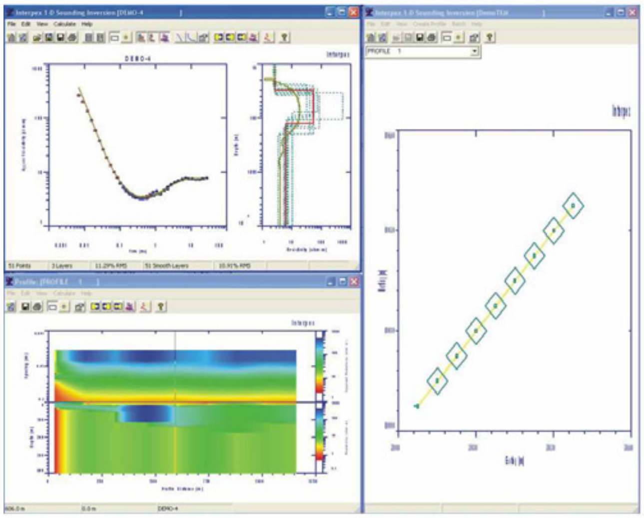
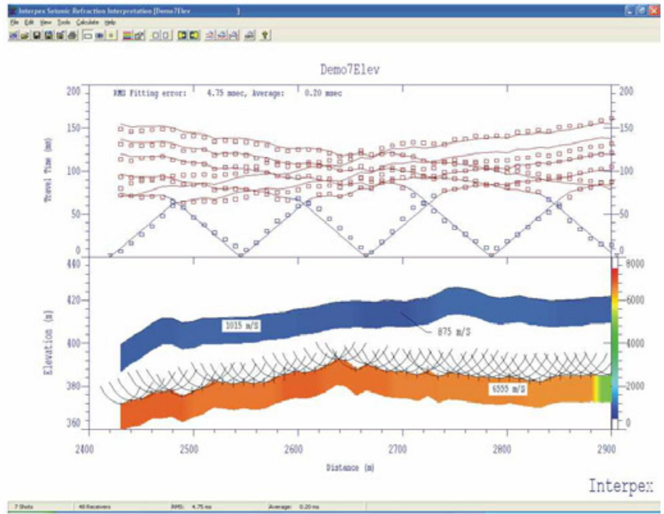

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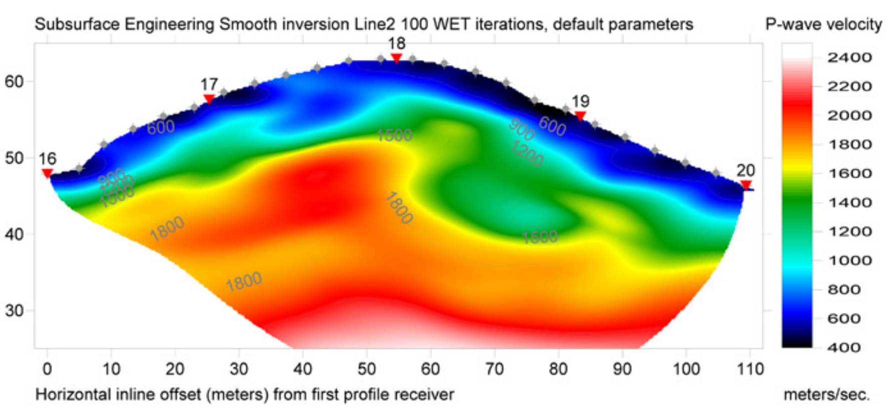

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FastTIMES presents articles about commercial products for use in near geophysics investigations. Corporate sponsors are invited to send the editors descriptions of new products for possible inclusion in future issues.

LandMapper ERM-02: Handheld Meter for Near-Surface Electrical Geophysical Surveys

Larisa Golovko, Anatoly Pozdnyakov, and Antonina Pozdnyakova, Landviser, LLC, League City, TX (www.landviser.com)

On-the-go sensors, designed to measure soil electrical resistivity (ER) or electrical conductivity (EC) are vital for faster non-destructive soil mapping in precision agriculture, civil and environmental engineering, archaeology and other near-surface applications. Compared with electromagnetic methods and ground penetrating radar, methods of EC/ER measured with direct current and a four-electrode probe have fewer limitations and were successfully applied on clayish and saline soils as well as on highly resistive sandy soils, such as Alfisols and Spodosols. However, commercially available contact devices, which utilize a four-electrode principle, are bulky, very expensive, and can be used only on fallow fields. Multi-electrode ER-imaging systems applied in deep geophysical explorations are heavy, cumbersome and their use is usually cost-prohibited in many near-surface applications, such as forestry, archaeology, environmental site assessment and cleanup, and in agricultural surveys on farms growing perennial horticultural crops, vegetables, or turf-grass. In such applications there is a need for an accurate, portable, low-cost device to quickly check resistivity of the ground on-a-spot, especially on the sites non-accessible to heavy machinery.

LandMapper ERM-01

To address those applications, Landviser, LLC developed and commercialized the first model of LandMapper ERM-01 in 2004, which was able to measure electrical resistivity with central-symmetric four-electrode probes of Shlumberger and Wenner configurations to the depth of five meters. The device became popular among agricultural researchers in USA and Europe, and was tested for fast mapping and monitoring of agricultural and horticultural lands (Pozdnyakova and others, 2004; Paillet and others, 2010; Duncan and others, 2008). LandMapper is portable, fast, accurate, compact, safe, and affordable. It uses fully customized, interchangeable, and easily constructed four-electrode probes, which make it highly versatile for many applications, ranging from ER measurements in the laboratory and soil test pits to non-destructive field mapping of soil layers at 0-5 m depth (Figure 1).

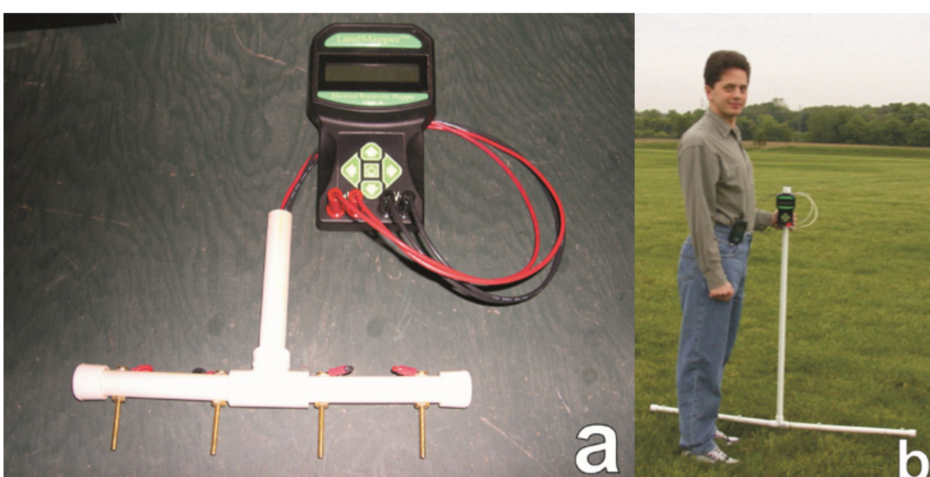

Figure 1: LandMapper ERM-01 device with; (a) a soil pit probe and (b) typical setting for soil mapping application.

LandMapper ERM-02 – Three Parameter Geophysical Device

The newest model, LandMapper ERM-02, can automatically output EC or ER, accepts four-electrode probes of any configuration, including dipole-dipole and rectangular probes, reaches down to 10 m depth in most soils, and stores up to 999 resistivity values in non-volatile memory. Also, ERM-02 model can be used to measure natural electrical potentials in soils, plants, and other media with two non-polarizing electrodes (Figures 2 and 3). Comparison of features between ERM-01 and ERM-02 models is shown in Table 1. Technical specifications of a current model is presented in Table 2.

Figure 2: LandMapper ERM-02 hand-held device for measuring electrical resistivity, conductivity, and self-potential. (Manufactured by Landviser, LLC).

The accuracy of electrical resistivity measurements with LandMapper was tested by Landviser, LLC and by USGS and USDA labs alongside with Sting (AGI, Inc.) and AE-72 (analog Russian standard resistivity meter for deep geophysical sounding). Difference between equipment had not exceeded 2% in a wide range of resistivities. Being essentially direct current contact resistivity meter with high internal impedance, LandMapper can measure

Figure 3: Correct placement of electrodes when measuring electrical potential difference between soils and plants with LandMapper ERM-02.

ER in an extensive range from 0.1 to 106 Ohm m (Table 2) with automatic adjustment to the range of apparent resistivity in the studied media. LandMapper is being featured in 2nd edition of Solid Earth Encyclopedia as accurate and ultra-light field resistivity meter (M.H. Loke and others, in press).

Table 1: Comparison of LandMapper ERM-01 and ERM-02 models

Feature	LandMapper ERM-01	LandMapper ERM-02
Electrical Resistivity, Ohm m	YES	YES
Electrical Conductivity, Sm	Post-process	YES, direct readout
Natural Electrical Potential	NO	YES
Central-symmetric 4-electrode probes (Wenner, Schlumberger)	YES	YES
Universal 4-electrode probes (dipole-dipole, square, etc.)	NO	YES
Max depth	5 m	10 m
Measurements in the lab	YES	YES
Measurements in the soil pit	YES	YES
Stores 1000 data points for download to PC	YES	YES
Responds to commands from PC in interactive regime	NO	YES

Table 2: Technical specifications of LandMapper ERM-02

Range of measurements	ER= 0.1-1E^{5} Ohm.m
	EC= 1E^{-6} - 10 Sm^{-1}
	EP= -1 to +1 V (Δ 0.01 mV)
User-selectable ER/EC/EP modes of measurement Automatically adjusts electrical resistivity/conductivity/potential ranges to provide best measurement accuracy Error of measurements is typically less than 1%	
User-defined K (geometrical coefficient)	01 up to 999
Quantity of changeable K-coefficients	9
Quantity of data storage locations	999
Range of operation temperatures	from - 10 up to + 40 °C or 14 to 100 °F
Air humidity, no more than	85.00%
Weight of the device, no more	250 g or 8 oz
Current of consumption, no more	70 mA
Output voltage, no more	5 V
Measurements comparable with DC methods, frequency	125 Hz
Computer connection	serial port

Seven-Step Approach for Complete Resistivity Survey of Farmland with LandMapper

Despite numerous EC-mapping case studies conducted in many countries, only a few studies have demonstrated a complex approach to electrical geophysical site survey. In most studies only one technique of EC-mapping, either EM, GPR, or four-electrode method was employed. This is understandable since most commercially available EC/ER measuring equipment operate in limited range of resistivities and depths (1-2 manufacturer-set depths are typical). Purchasing different equipment for each application to measure EC/ER at multiple depths/scales quickly raises the cost of such surveys above the budget of most agricultural, environmental or archeological survey firms and agencies as typical commercially available geophysical devices cost more than $10,000 per unit. But, LandMapper ERM-02 costs less than $2,500. Four-electrode probes are custom-made to any specific depth from a few cm to 10 meters and cost less than $100 each. To further decrease the cost of such a system user can make their own probes from materials available in any hardware store.

The following is a complete 7-step methodology of ER-mapping and vertical electrical sounding to aid in agro-reclamation mapping. The detail description of this approach can be found in Kokoreva and others (2007) and Golovko and Pozdnyakov (2009). All the proposed measurements of soil electrical parameters both in the field and laboratory can be carried out with only one hand-held device LandMapper ERM-02 and interchangeable probes.

1. Study available soil maps and landscape of the survey area and select locations for a few complete vertical electrical soundings (VES down to 5-10 m).
2. VES of major soils on the territory of survey.
3. Electrical mapping of the territory with 2-5 four-electrode probes sensing specific key depths selected after VES interpretation.
4. Preparation of electrical survey maps in GIS.
5. Selection of key soil pits on the territory of survey based on electrical maps and measurement of electrical parameters on the walls of soil pits. Collection of soil samples from the layers with contrasting electrical parameters.
6. Measurements of electrical parameters and soil chemical/physical properties of samples in laboratory.
7. Transformation and interpretation of field soil survey with the support of laboratory tests and pedotransfer functions.

Applications of this 7-step approach are illustrated below in the case of mapping an intensively cultivated potato field near Moscow. Maps of electrical resistivity at four layers were prepared with Surfer and ArcMap software (Figure 4) in step 4. Next, 10 soil pits were dug out on the survey field in places exhibited the most contrast in electrical resistivity between soil horizons. Electrical resistivity and other soil properties were measured in soil samples collected from characteristic soil horizons in step 5. Exponential relationships between ER and clay content, filtration coefficient, field capacity and field soil moisture were obtained in step 6 (Figure 5). Electrical soil properties influencing density of mobile electrical charges are exponentially related to apparent soil electrical resistivity according to Boltzmans' Law (Pozdnyakov and Pozdnyakova, 2002; Pozdnyakova, 1999; Pozdnyakov and others, 1996; Pozdnyakov and others, 2006) Finally, using obtained exponential relationships, the field ER maps were transformed into maps of soil physical properties in step 7. Figure 6 shows map of clay content for 480 cm depth. Result of the study was map of redistribution of water and nutrients within the field, which was used by farmer as an aid for site-specific fertilizer applications.

Measuring Electrical Potentials with LandMapper ERM-02

Electrical geophysical methods are classified as methods measuring natural electrical potentials of the ground without introducing additional electrical field and methods utilizing artificial electrical or electromagnetic fields to measure soil electrical parameters. Method of self-potential (SP) measures the naturally existing electrical potentials in soils and "bio-potentials" in plants, which are important in agriculture. Despite growing popularity of electrical resistivity/conductivity methods in agriculture, the method of self-potential is rarely used. The SP method is based on measuring the natural potential differences, which generally exist between any two points in the soil or plant. In addition to measuring ER/EC with four-electrode arrays, LandMapper ERM-02 also allow non-invasively measured natural electrical potentials in soils or between soils and plants, which are very small (μV magnitude) and mostly referred as "noise" potentials in conventional geophysics.

In soil studies, researchers are especially interested in the measurement of such "noise" electrical potentials created in soils due to soil-forming process and water/ion movements. The electrical potentials in soils, clays, marls, and other water-saturated and unsaturated sediments can be explained by

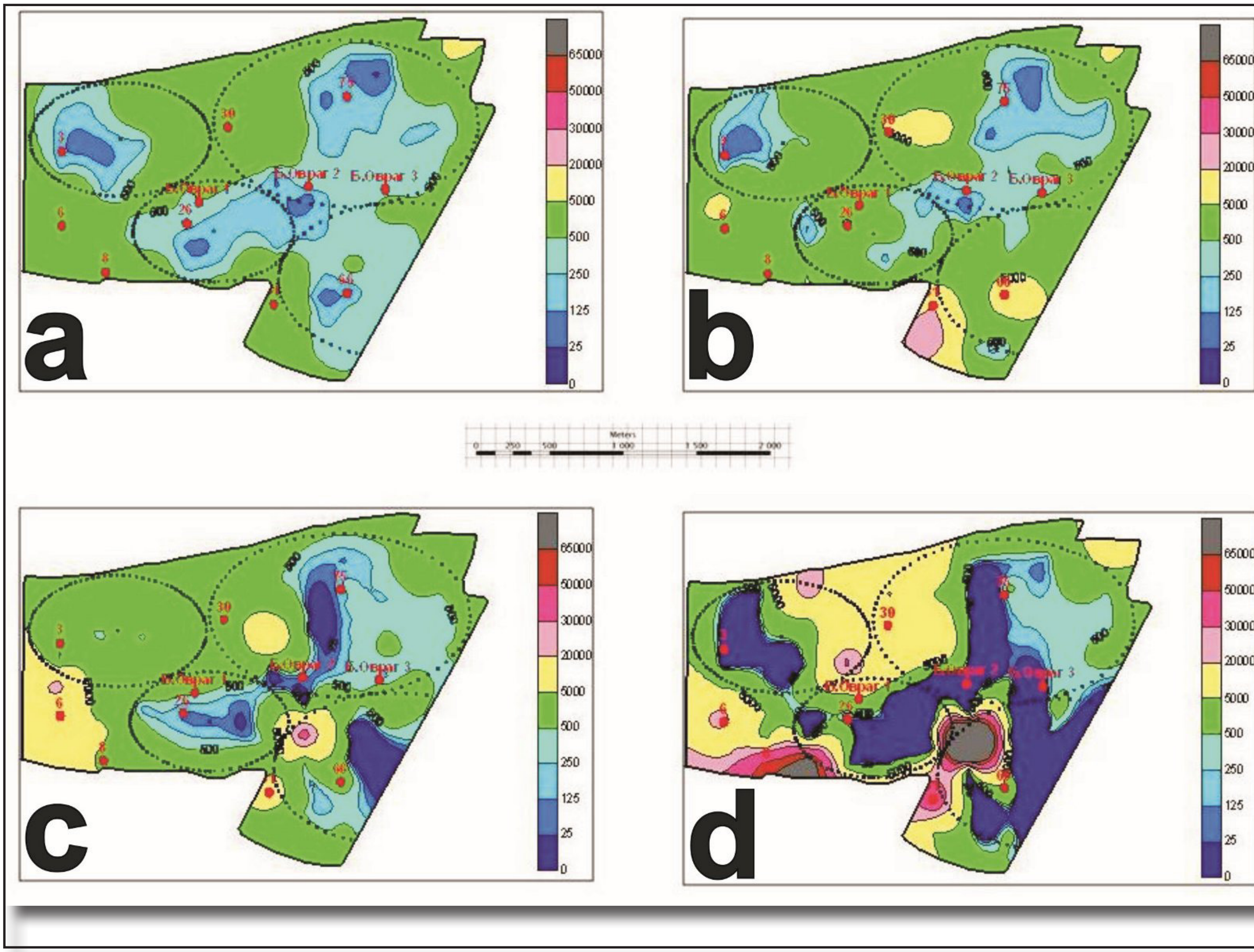

Figure 4: Maps of electrical resistivity (ER); (a) 10 cm (b), 30 cm (c) 60 cm (c), and (d) 480 cm.

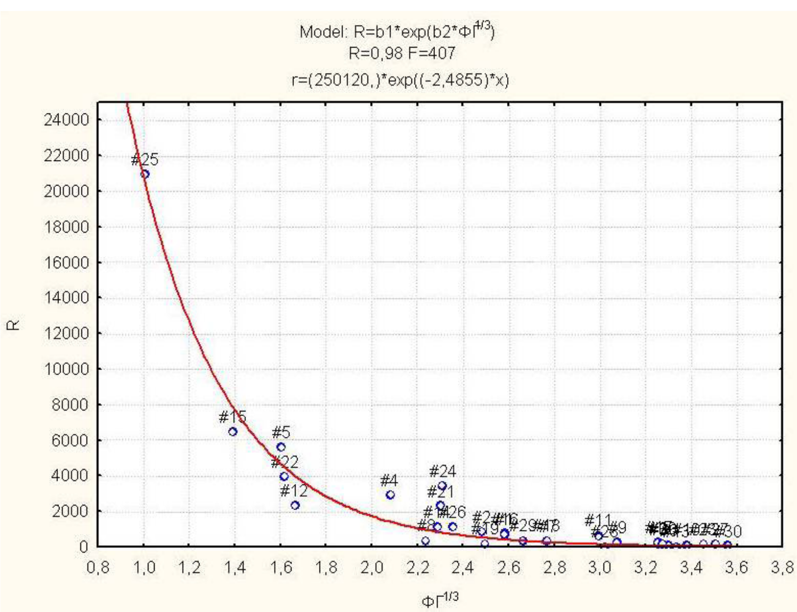

Figure 5: Exponential relationship between field ER and clay content of soil samples from different soil horizons.

such phenomena as ionic layers, electro-filtration, pH differences, and electro-osmosis. Soil-forming processes can create electrically variable horizons in soil profiles, thus electrical potential differences measured between soil horizons can be used to study soil forming processes and soil genesis.

Another possible environmental and engineering application of self-potential method is to study subsurface water movement. Measurements of electro-filtration potentials or streaming potentials have been used to detect water leakage spots on the submerged slopes of earth dams (Corwin, 1990). Method of self-potential in addition to EC mapping and vertical electrical sounding/imaging (VES) can aid in archaeological and civil engineering projects (Pozdnyakova and others, 2001).

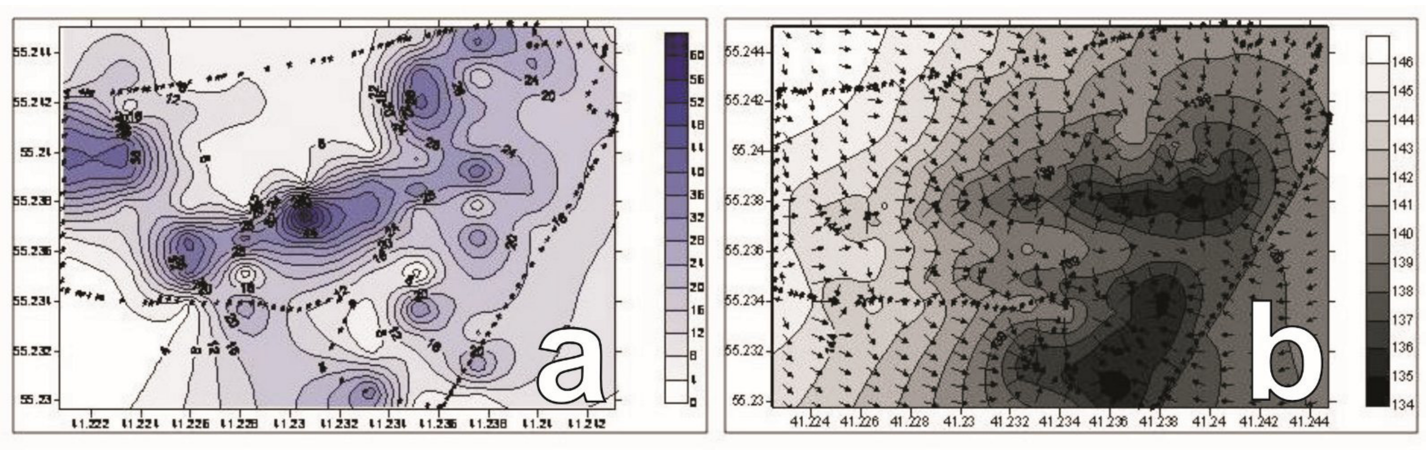

Figure 6: Maps of soil physical properties at 480 cm depth created with non-destructive geophysical ER mapping; (a) clay content map and (b) map of redistribution of water and nutrients in landscape.

Special Instrumentation for Soil SP Method

LandMapper ERM-02, in addition to electrical conductivity and resistivity measurements also allows non-invasively measure natural electrical potentials in soils and plants when two special non-polarizing electrodes are connected to MN terminals (Figure 3).

Potentials generated by subsurface environmental sources are lower than those induced by mineral and geothermal anomalies and often associated with high noise polarization level (Corwin, 1990). Therefore, the use of non-polarizing electrodes is mandatory when the SP method is applied in soil and environmental studies. The non-polarizing electrode consists of a metal element immersed in a solution of salt of the same metal with a porous membrane between the solution and the soil (Corwin and Butler, 1989). Because of easy breakage of the membrane and leakage of the solution we adopted firm non-polarizing electrodes (carbon cores from the exhausted electrical cells) to develop non-polarizing electrodes for soil studies (Pozdnyakov, 2001). In addition, low-polarizable and non-polarizable electrodes used in medical studies (available from In-Vivo Metrics, CA) were successfully used on soils/plants in the field and laboratory. For soils with high potential differences between horizons gold-plated electrodes can be used. For seasonal monitoring in plant physiology we recommend high quality solid sintered Ag-AgCl sensor electrodes (Figure 7). Those silver-silver chloride electrodes are very stable and performance is exceptionally reproducible. Should the electrode surface become damaged or contaminated, a new surface can be exposed with sandpaper to restore the electrode's original performance.

To measure small electrical potential differences in soils accurately, in addition to non-polarizing electrodes, the measuring device should be modified and as such should have isolated connectors and high internal impedance. Most leading geophysical resistivity instruments, such as ABEM SAS, Syskal, and Sting provide such connections, but coupling electrodes are bulky, leaky and generally not useable in plant/soil studies. LandMapper ERM-02 has self-potential measuring capability with easy coupling to medical-grade non-polarizing electrodes. Detail description of SP method with LandMapper ERM-02 and case studies were presented by Golovko (2010). The technique was tested in a few case studies, summary of which is provided below.

Figure 7: Solid-state Ag-AgCl non-polarizing electrodes manufactured by In-Vivo Metrics, CA.

Electrical Potential Differences Between Soil Horizons

The natural electrical potentials (stationary and fluctuating) in soils were studied by our group for last 40 years and the results were summarized and presented on 17th World Congress of Soil Science (Pozdnyakov andmPozdnyakova, 2002). The largest electrical potential differences were observed between soil horizons drastically different in physical and chemical properties. In most soils topsoil has higher electrical potentials than subsoil. The highest potential difference between soil horizons reported for Spodosols (40-60 mV), decreasing to 20-40 mV in Alfisoils and to ~20 mV in Mollisols, and even lower in Aridisols. Probably, the higher potential difference in Spodosols and Alfisols profiles guides growth of woody plants with well developed root system spreading deep into the subsoil. Natural electrical potential differences between soil horizons facilitate root growth. Those differences also form in uniform soil profiles under consistent vertical or horizontal water fluxes. Lysimeter studies on uniform soil column confirm that negative potential gradient forms downwards after intensive infiltration.

Electrical Potential Differences in Topsoil

Maps of electrical potentials in topsoil help to reveal the micro-environments for plant growth and correspond to plant biomes in natural ecosystems (Pozdnyakov, 2008). Electrical resistivity (ER) or conductivity (EC) maps are generally similar to the maps of self-potentials, but using combination of those methods brings more information about infiltration and subsurface water fluxes and aid in search for clogged drainage pipes and reclamation planning (Bedmar and Araguás, 2002; Pozdnyakova and others, 2001).

Electrical Potential Differences Between Plants and Topsoil

Many soil properties influencing plant growth and yield can be identified and mapped with electrical geophysical methods, which explains recent advances in electrical conductivity method application in precision agriculture. Moreover, our recent studies have shown that soil electrical potentials influence plant growth directly and electrical geophysical methods can be used to monitor plant health (Fedotov and Pozdnyakov, 2001). The biopotentials or micro electrical potentials of the plant tissues and their effect on plant growth have been studied by plant physiologists for quite some time. However, practically no research has been conducted on natural electrical potentials between soil and a growing plant, or “macropotentials” of the plants.

Recently, we advanced to measure and research the natural electrical potentials between soil and growing plants (Pozdnyakov and others, 2006). Natural electrical potentials between soils of major genetic types and more than 100 species of native and cultural plants of Ukraine, Russia, and Philippines in different growing conditions have been studied in 2003-2005. The electrical potential difference between soil and a plant was always negative. This difference was highest during spring and for young plants in summer, and decreased in the fall when plants in Russia are ready for dormancy. Tropical plants showed higher potential differences than plants of temperate climate. The potentials for all plants decreased in a row flower-leaf-stem. Electrical potential of herbaceous plants are directly related with the leaf area and the highest potentials were observed for burdock, cow-parsnip, and young banana palms. More research is underway for establishing relationships between natural electrical potentials/ resistivity of plants/soils and plant's water stress (Terehova and others, 2007).

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Veris P4000: A 4-Sensor Hydraulic Probe for Agricultural Research

Eric D. Lund, Veris Technologies Inc., Salina, KS, USA (www.veristech.com)

Soil sensing is a rapidly developing field of soil science. Soil electrical conductivity (EC) geophysical mapping of agricultural soils was commercialized in the mid-1990's and has been widely adopted in precision agriculture during the past decade. EC has been found to correlate well with soil texture and salinity. Optical measurements of soil in the visible and near-infrared (Vis-NIR) range have been studied for the past 40 years, and commercial in situ Vis-NIR sensors have recently been introduced. Optical measurements are influenced primarily by soil carbon, nitrogen and water. Soil penetrometers have been in use for nearly 100 years, being used primarily to assess soil density. Never before have these sensors been combined into one probe. Veris Technologies, the leader in proximal soil sensing, has developed and commercialized a probe that accomplishes that feat. The Veris P4000 Vis-NIR-EC-Force probe is part of a heavy-duty hydraulic platform that also performs core sampling (Figure 1).

Figure 1: Veris P4000 4-Sensor Probe.

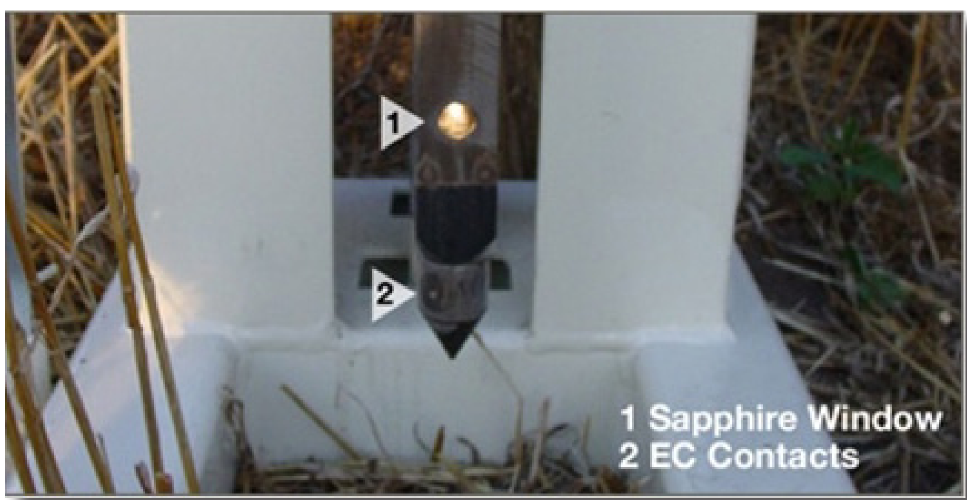
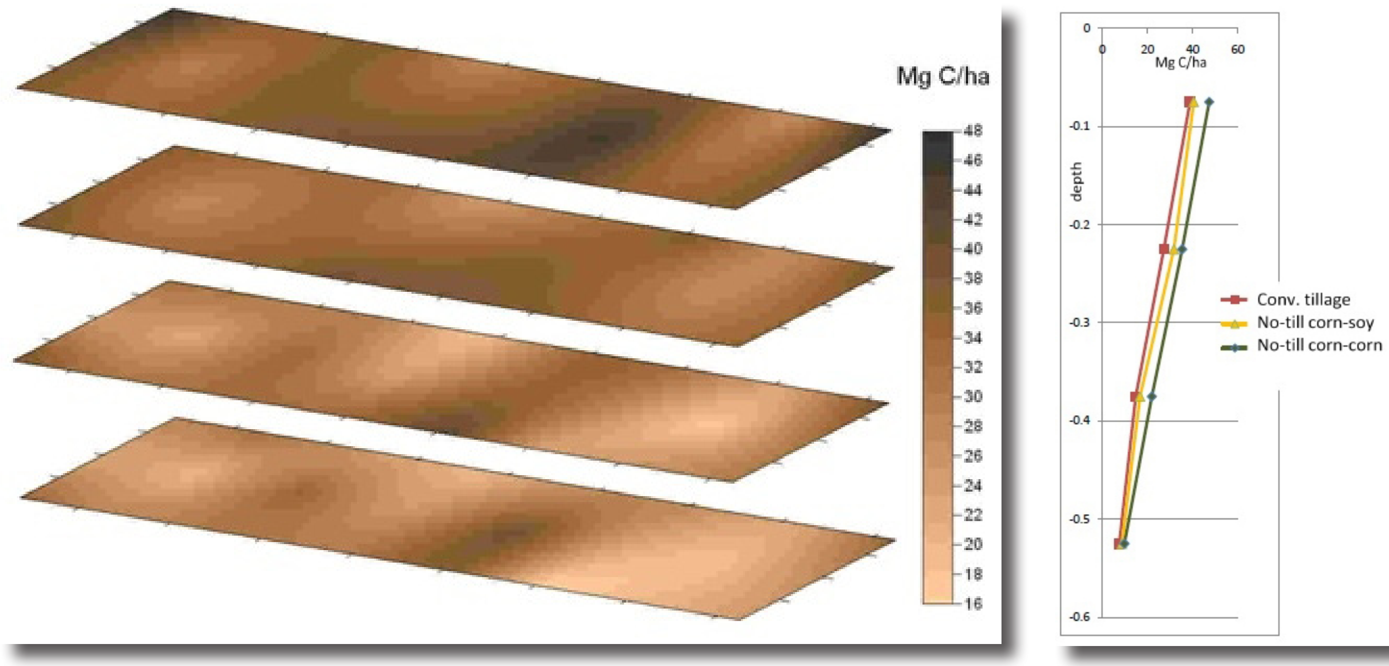


Figure 2: Probe window for Vis-NIR measurements and dipole EC cone tip.

The P4000 sensor suite provides an extensive dataset of soil profile information to a depth of 40" (102 cm). The Vis-NIR spectrometers collect optical measurements through the sapphire window on the side of the probe as it moves into the soil profile (Figure 2). These spectrometers are the same as those on Veris Vis-NIR on-the-go shank system—allowing for expansion of the system to map field and profile variability. At the bottom of the probe is a cone-tip with soil EC contacts—for collecting dipole EC data (Figure 2). A load cell measures the insertion force required to push the probe into the soil. The heavy-duty sensor probe is constructed of 1” (2.54 cm) diameter probe rod. All readings are geo-referenced and depth is recorded in centimeter increments. This sensor combination has been used to measure profile soil carbon and bulk density in research and in carbon inventorying (Figures 3 and 4).



Figures 3 and 4: Estimates of profile carbon: 0-15, 15-30, 30-45, and 45-60 cm.

The Veris P4000 probe utilizes sampling tools and technology made famous by Veris Technologies’ sister company Geoprobe®, the worldwide leader in direct-push systems for deep soil sampling. Standard coring equipment is a 0-35” (89 cm) sampler with 2” OD (5 cm). A complete line of cutting shoes, liners, and other options are available. P4000 can be configured as a tractor-mounted or truck-bed skid mount. Both feature 54” (137 cm) stroke cylinders, hydraulic side-shift, convenient controls, and heavy-duty construction. The rack-and-pinion hydraulic side-shift provides lateral motion, and the extend cylinder moves the probe forward or backward—all controlled by accessible lever controls, making it easy to collect cores adjacent to sensor probe locations. Hydraulic rotation, anchoring, and hammer options are available.

This new technology package has the potential for a wide-range of soil research initiatives. With the assistance of reconnaissance maps from geophysical sensors such as soil electrical conductivity, the P4000 has shown promising calibrations to various soil properties, including carbon. The ability to investigate the soil profile with sensors significantly increases both the quantity and quality of soil information.

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Instructions: Please complete this order form and fax or mail the form to the EEGS office listed above. Payment must accompany the form or materials will not be shipped. Faxing a copy of a check does not constitute payment and the order will be held until payment is received. Purchase orders will be held until payment is received. If you have questions regarding any of the items, please contact the EEGS Office. Thank you for your order!

Merchandise Order Information:

ITEM DESCRIPTION	QTY	T-SHIRT COLOR WHITE/GRAY	MEMBER RATE	NON-MEMBER RATE	TOTAL
EEGS Mug			$10	$10	Sold Out
T-shirt (Medium)			$10	$10	Sold Out
T-shirt (Large)			$10	$10	Sold Out
T-shirt (X-Large)			$10	$10	
T-shirt (XX-Large)			$10	$10	Sold Out
EEGS Lapel Pin			$3	$3	

SUBTOTAL – MERCHANDISE ORDERED:

TOTAL ORDER:

SUBTOTAL – Merchandise Ordered:	
STATE SALES TAX: (If order will be delivered in Colorado – add 3.7000%):	
CITY SALES TAX: (If order will be delivered in the City of Denver – add an additional 3.5000%):	
SHIPPING AND HANDLING (US - $7; Canada/Mexico - $15; All other countries - $40):	

GRAND TOTAL:

Payment Information:

☐ Check #: ______________________ (Payable to EEGS)

☐ Purchase Order: ______________________
(Shipment will be made upon receipt of payment.)

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Card Number: _______________________ Cardholder Name (Print): ___________________________

Exp. Date: ___________________________ Signature: ____

Three easy ways to order:
Fax to: 303.820.3844
Internet: www.eegs.org
Mail to: EEGS
1720 S. Bellaire St., #110
Denver, CO 80222-4303

THANK YOU FOR YOUR ORDER!

Order Return Policy: Returns for credit must be accompanied by invoice or invoice information (invoice number, date, and purchase price). Materials must be in saleable condition. Out-of-print titles are not accepted 180 days after order. No returns for credit will be accepted which were not purchased directly from EEGS. Return shipment costs will be borne by the shipper. Returned orders carry a 10% restocking fee to cover administrative costs unless waived by

EEGS/Forms/Merchandise Order Form/2010 Prices and details on this form are as accurate as possible, but are subject to change without notice.