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Application of Geophysical Methods in Agriculture

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Abstract: Geophysics is the application of physical quantity measurement techniques to provide information on conditions or features beneath the Earth's surface. The three geophysical methods predominantly used for agricultural purposes are resistivity, electromagnetic induction and ground-penetrating radar. Depth sections and contour maps are two of the most common geophysical data analysis end products .Agricultural application of geophysical methods to investigate the shallow subsurface (within a typical depth range of 0 to 2 m).few application of geophysical method in agriculture are: Soil drainage class mapping, determining clay-pan depth, Estimation of herbicide partition coefficients in soil, Mapping of flood deposited sand depths on farmland, soil nutrient monitoring from manure applications, Quality/efficiency improvement soil surveys, Measurement of micro variability in soil profile horizon depths, Bedrock depth determination in glaciated landscape with thin soil cover, Plant root biomass surveying ,Identification of subsurface flow pathways, Farm field and golf course drainage pipe detection, Soil salinity assessment Delineation of spatial changes in soil properties ,Soil water content determination.

Key words: Geophysical method, application, agriculture, are resistivity, electromagnetic induction, ground-penetrating radar

INTRODUCTION

Geophysics Definitions, Development Chronology, Investigation Scale:

Geophysics can be defined several ways. In the broadest sense, geophysics is the application of physical principles to studies of the Earth (Sheriff, 2002). This general definition of geophysics encompasses a wide range of disciplines, such as hydrology, meteorology, physical oceanography, seismology, tectonophysics, etc. Geophysics, as it is used in this paper, has a much more focused definition. Specifically, geophysics is the application of physical quantity measurement techniques to provide information on conditions or features beneath the Earth's surface. With the exception of borehole geophysical methods and soil probes like a cone penetrometer, these techniques are generally noninvasive, with physical quantities determined from measurements made mostly at or near the ground surface. The geophysical methods employed to obtain subsurface information from surface-based measurements include resistivity, electromagnetic induction,ground-penetrating radar, magnetometry, self-potential, seismic, gravity, radioactivity nuclear magnetic resonance, induced polarization, etc.

Archeological environmental, geotechnical engineering, and hydrological geophysical surveys became more and more common in the latter half of the past century. There was some agricultural research activity in the 1930s and 1940s related to soil moisture measurement with resistivity methods (Edlefsen and Anderson, 1941; Kirkham and Taylor, 1949; McCorkle, 1931), but for the most part, the application of geophysical methods to agriculture did not gain momentum until the 1960s, and to a greater extent in the 1970s, with the use of resistivity methods for soil salinity assessment (Halvorson and Rhodes, 1974; Rhoades and Ingvalson, 1971; Rhoades *et al.*, 1976; Shea and Luthin, 1961).

Geophysical surveys conducted for petroleum, mining, hydrological, environmental, geotechnical engineering, archeological, and agricultural applications vary dramatically in scale with respect to the investigation depth of interest. Most geophysical surveys conducted in the mining industry have an investigation depth of interest that is less than 1 km. A geophysical survey conducted as part of a hydrological investigation to determine groundwater resources usually has an investigation depth no greater than 300 m Geophysical investigation depths for environmental, geotechnical engineering, and archeological applications typically do not exceed 30 m. Agricultural geophysics tends to be heavily focused on a 2m zone directly beneath the

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ground surface, which includes the crop root zone and all, or at least most, of the soil profile With regard to the application of geophysics to agriculture, this extremely shallow 2 m depth of interest is certainly an advantage, in one sense because most geophysical methods have investigation depth capabilities that far exceed 2 m. However, there are complexities associated with agriculture geophysics not typically encountered with the application of geophysical methods to other industries or disciplines. One such complexity involves transient soil temperature and moisture conditions that can appreciably alter the values of measured geophysical quantities over a period of days or even hours. Additionally, physical quantities measured in the soil environment with geophysical methods often exhibit substantial variability over very short horizontal and vertical distances.

1.2. Geophysica L Methods Applicable to Agriculture:

Geophysical methods can be classified as passive or active. There is no artificial application of energy with passive geophysical methods. On the other hand, active geophysical methods do require the artificial application of some form of energy. The three geophysical methods predominantly used for agricultural purposes are resistivity, electromagnetic induction, and ground-penetrating radar. we provide shorter descriptions of three additional geophysical methods: magnetrometry (passive), self-potential (passive), and seismic (active), all of which have the potential for substantial future use in agriculture, but at present are being employed sparingly or not at all for agricultural purposes. To provide an introduction, the six geophysical methods resistivity, electromagnetic induction, ground-penetrating radar, magnetometry, self-potential, and seismic—are all concisely defined as follows.

1.2.1. Resistivity Methods:

Resistivity methods measure the electrical resistivity, or its inverse, electrical conductivity, for a bulk volume of soil directly beneath the surface. Resistivity methods basically gather data on the subsurface electric field produced by the artificial application of electric current into the ground. With the conventional resistivity method, an electrical current is supplied between two metal electrode stakes partially inserted at the ground surface, while voltage is concurrently measured between a separate pair of metal electrode stakes also inserted at the surface. The current, voltage, electrode spacing, and electrode configuration are then used to calculate a bulk soil electrical resistivity (or conductivity) value..

1.2.2. Electromagnetic Induction Methods:

Electromagnetic induction methods also measure the electrical conductivity (or resistivity) for a bulk volume of soil directly beneath the surface. An instrument called a ground conductivity meter is commonly employed for relatively shallow electromagnetic induction investigations. In operation, an alternating electrical current is passed through one of two small electric wire coils spaced a set distance apart and housed within the ground conductivity meter that is positioned at, or a short distance above, the ground surface. The applied current produces an electromagnetic field around the "transmitting" coil, with a portion of the electromagnetic field extending into the subsurface.

This electromagnetic field, called the primary field, induces an alternating electrical current within. the ground, in turn producing a secondary electromagnetic field. Part of the secondary field spreads back to the surface and the air above. The second wire coil acts as a receiver measuring the resultant amplitude and phase components of both the primary and secondary fields. The amplitude and phase differences between the primary and resultant fields are then used, along with the intercoil spacing, to calculate an "apparent" value for soil electrical conductivity (or resistivity).

1.2.3. G Round-penetrating Radar Methods:

With the ground-penetrating radar (GPR) method, an electromagnetic radio energy (radar) pulse is directed into the subsurface, followed by measurement of the elapsed time taken by the radar signal as it travels downward from the transmitting antenna, partially reflects off a buried feature, and eventually returns to the surface, where it is picked up by a receiving antenna. Reflections from different depths produce a signal trace, which is a function of radar wave amplitude versus time.

Radar waves that travel along direct and refracted paths through both air and ground from the transmitting antenna to the receiving antenna are also included as part of the signal trace. Antenna frequency, soil moisture conditions, clay content, salinity, and the amount of iron oxide present have a substantial influence on the distance beneath the surface to which the radar signal penetrates. The dielectric constant of a material governs the velocity for the radar signal traveling through that material. Differences in the dielectric constant across a subsurface discontinuity feature control the amount of reflected radar energy, and hence radar wave amplitude, returning to the surface. As an end product, radar signal amplitude data are plotted on depth sections or areal maps to gain insight on below-ground conditions or to provide information on the position and character of a subsurface feature.

1.2.4. Magnetometry Methods:

This geophysical method employs a sensor, called a magnetometer, to measure the strength of the Earth's magnetic field. Anomalies in the Earth's magnetic field indicate the presence of subsurface features. An anomaly is produced when a subsurface feature has a remanent magnetism or magnetic susceptibility that is different from its surroundings. A gradiometer is an instrument setup composed of two magnetometer sensors mounted a set distance apart. Gradiometers are typically used to measure the vertical gradient of the magnetic field, which is not affected by transient magnetic field changes. In comparison to a single magnetometer sensor, the gradiometer has the additional advantage of being better adapted for emphasizing magnetic field anomalies from shallow sources.

1.2.5. Self-potential Methods:

Self-potential methods collect information on a naturally occurring electric field associated with nonartificial electric currents moving through the ground. Unlike resistivity methods, no electric power source is required. Naturally occurring electric potential gradients can arise a number of different ways, including the subsurface flow of water containing dissolved ions, spatial concentration differences of dissolved ions present in subsurface waters, and electrochemical interactions between mineral ore bodies and dissolved ions in subsurface waters. Self-potential methods are fairly simple operationally. All that is required to obtain information on a natural electric field below ground is the voltage measurement between two nonpolarizing electrodes placed or inserted at the ground surface.

1.2.6. Seismic Methods:

Seismic methods employ explosive, impact, vibratory and acoustic energy sources to introduce elastic (or seismic) waves into the ground. These seismic waves are essentially elastic vibrations that propagate through soil and rock materials. The seismic waves are timed as they travel through the subsurface from the source to the sensors, called "geophones." The energy source is positioned at the surface or at a shallow depth. Geophones are typically inserted at the ground surface. Seismic waves move through the subsurface from source to geophone along a variety of direct, refracted, and reflected travel paths. The velocity of a seismic wave as it travels through a material is determined by the density and elastic properties for that particular material. Differences in the density and elastic properties across a subsurface discontinuity feature control the amount of reflected or refracted seismic energy, and hence the seismic wave amplitudes returning to the surface. Information on the timed arrivals and amplitudes of the direct, refracted, and reflected seismic waves measured by the geophones are then used to gain insight on below-ground conditions or to locate and characterize subsurface features.

1.3. Aspects of Agricultural Geophysics Data Collection and Analysis:

1.3.1. Selecting the Proper Geophysical Method:

A clear goal must be defined in the initial planning stage of a geophysical survey regarding the soil condition or subsurface feature information that needs to be acquired. In order to choose the proper geophysical method for monitoring changing soil conditions, consideration must first be given to the different physical properties responded to by the various geophysical methods and then whether any of these physical properties are influenced by the soil condition of interest. Delineating a subsurface feature with geophysics requires there to be a contrast between the feature and its surroundings with respect to some physical property responded to by a geophysical method. To summarize the geophysical method selected must respond to a physical property that is in turn affected by temporal changes in soil conditions or the spatial patterns of subsurface features; otherwise, useful information cannot be obtained on these soil conditions or subsurface features of interest. For example, soil cation exchange capacity (CEC) will often have a substantial impact on soil electrical conductivity (or resistivity); therefore, resistivity or electromagnetic induction methods that measure soil electrical conductivity may be useful for delineating spatial patterns in CEC. On the other hand magnetometry methods respond to anomalies in remanent magnetism or magnetic susceptibility properties that are not likely to be affected by CEC, and consequently, magnetometry methods would not be a good choice for delineating spatial patterns in CEC.

1.3.2. Investigation Depth and Feature Resolution Issues:

Once a geophysical method is chosen, there are usually options with respect to the equipment and its setup. The investigation depth required and the size of the feature to be detected is two important issues that should be taken into account when deciding on the equipment to use and its setup. There is normally a trade-off between the investigation depth and the minimum size a feature must have to be detected. Finding a large, deeply buried object or a small, shallow object with geophysical methods is much easier than locating a small, deeply buried object. One potential example is the use of GPR to locate buried plastic or clay tile agricultural drainage pipe. The radar signal penetration depth and minimum size at which an object can be detected are both inversely related to GPR antenna frequency. Low-frequency GPR antennas are better for locating larger deeply buried objects, and high-frequency GPR antennas are more applicable for small, shallow objects.

Therefore a GPR unit with 100 MHz transmitting and receiving antennas might work well at finding a 30cm diameter drainage pipe 2 m beneath the surface in a clay soil, and a GPR unit with 250 MHz transmitting and receiving antennas is likely capable of finding a 10 cm diameter drainage pipe 0.5m beneath the surface in a clay soil. But, finding a 10 cm diameter drainage pipe 2 m beneath the surface in a clay soil is probably an extremely difficult undertaking regardless of the GPR antenna Frequency employed An important implication with respect to the issues of investigation depth and feature resolution (detection(is to use equipment with the proper setup that provides an investigation depth similar to the investigation depth of interest.

1.3.4. Analysis of Geophysical Data:

Depth sections and contour maps are two of the most common geophysical data analysis end products.Two-dimensional depth sections characterize the distribution of some geophysically measured property beneath a measurement transect along the surface. Different geophysical methods employ different computer processing steps to produce these depth sections. Contour maps are typically used to show the horizontal spatial pattern of some geophysically measured property. Various spatial interpolation algorithms are employed by the computer software used to generate these contour maps. Where there is a choice, careful consideration is needed in selecting the interpolation algorithm so as not to introduce features on the contour map that do not truly exist or to remove features that are actually present Rather than focusing just on a single geophysical data set at a time, the integration of several geophysical data sets along with other spatial information is an approach that can potentially improve agricultural data interpretation for a particular farm site. Integration of multiple geophysical and nongeophysical spatial data sets is accomplished using a geographic information system GIS. A GIS is a powerful data analysis tool that is just beginning to find widespread use in agricultural geophysics.

1.4. Potential Agricultural Uses for Geophysical Methods:

Past research indicates a wide range of potential uses for the three geophysical methods predominantly employed in agriculture (resistivity, electromagnetic induction, and ground-penetrating radar .Table 1.1 serves to emphasize the variety of possible applications by listing just a few of the numerous ways that these three geophysical methods can provide valuable information for agriculture purposes.

1.5. Agricultural Geophysics Outlook:

New developments in the overall discipline of geophysics are ongoing, with innovative methods equipment, and field procedures continuing to be introduced. The same is particularly true for agricultural geophysics. Many concepts being tested and initiated at present will eventually become commonplace for agricultural geophysics. In this regard, the following is a list summarizing the probable future trends (some previously mentioned) for agricultural geophysics

1. New agricultural applications will continue to be discovered for the geophysical methods already used in agriculture (resistivity, electromagnetic induction, and GPR)
2. Geophysical methods not traditionally employed in the past for agricultural purposes will find significant use in the future. The geophysical methods likely to make inroads into agriculture include magnetometry, self-potential, and seismic. Agricultural opportunities for other geophysical methods, such as nuclear magnetic resonance, induced polarization, and seismoelectric, may also exist.
3. The incorporation of GPS receivers will become the norm, especially with regard to realtime kinematic (RTK) GPS, which will allow geophysical measurement positions to be determined with horizontal and vertical accuracies of a few centimeters or less. 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. For reference, the physical properties responded to by the different geophysical methods are reviewed in Table 1.2

5. Multiple geophysical data sets integrated and analyzed together along with other geospatial information can provide agricultural insight not available when analyzing each geophysical data set separately. Geostatistical analysis techniques can be especially useful in this regard. GISs are particularly well adapted for integration and geostatistical analysis of multiple geophysical and nongeophysical spatial data sets. Consequently, GIS will play a greater role in the analysis of geophysical data collected in agricultural settings.
6. Expert system computer software and learning-capable computer software incorporating neural networks will be developed for specific agricultural applications to automatically analyze and interpret geophysical data
7. Tomographic procedures will be employed to obtain geophysical data in agricultural settings When the situation is warranted. It is usually not possible to conduct geophysical surveys in an agricultural 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 to be determined without actually having to obtain geophysical measurements inside the field.
8. The application of geophysical methods to agriculture will eventually become a well-Recognized subdiscipline of geophysics, at which time it may become appropriate to use the contracted term “agrigeophysics” instead of the longer term “agricultural geophysics".

Table 1.1: Potential Agricultural Applications for Resistivity, Electromagnetic Induction, and Ground-Penetrating Radar Methods

Geophysical Method	Agricultural Application	Literature Source
Resistivity	Soil drainage class mapping	Kravchenko *et al.*, 2002
Electromagnetic induction	Determining clay-pan depth	Doolittle *et al*., 1994
Electromagnetic induction	Estimation of herbicide partition coefficients in soil	Jaynes *et al.*, 1995a
Electromagnetic induction	Mapping of flood deposited sand depths on farmland adjacent to the Missouri River	Kitchen *et al*., 1996
Electromagnetic induction	Soil nutrient monitoring from manure applications	Eigenberg and Nienaber, 1998
Ground-penetrating radar	Quality/efficiency improvement and updating of U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/ NRCS) soil surveys	Doolittle, 1987; Schellentrager *et al*., 1988
Ground-penetrating radar	Measurement of microvariability in soil profile horizon depths	Collins and Doolittle, 1987
Ground-penetrating radar	Bedrock depth determination in glaciated landscape with thin soil cover	Collins *et al*., 1989
Ground-penetrating radar	Plant root biomass surveying Butnor *et al*., 2003;	Konstantinovic *et al*., 2007; Wockel, *et al*., 2006
Ground-penetrating radar	Identification of subsurface flow pathways	Freeland *et al*., 2006; Gish *et al*., 2002
Ground-penetrating radar	Farm field and golf course drainage pipe detection	Allred *et al*., 2005a; Boniak *et al*., 2002;Chow and Rees, 1989
Resistivity and electromagnetic induction	Soil salinity assessment	Doolittle *et al*., 2001; Hendrickx *et al*., 1992; Rhoades and Ingvalson, 1971; Rhoades *et al*., 1989; Shea and Luthin, 1961.
Resistivity and electromagnetic induction	Delineation of spatial changes in soil properties	Allred *et al*., 2005b; Banton *et al*., 1997; Carroll and Oliver, 2005; Johnson *et.al*.,2001; Lund *et. al*., 1999
Resistivity, electromagnetic induction, and ground-penetrating radar	Soil water content determination	Grote *at al*., 2003; Huisman *et al*., 2003; Kirkham and Taylor, 1949; Lunt *et al*.,2005; McCorkle, 1931; Sheets and Hendrickx, 1995

Ta ble 1.2: Physical Properties Responded to by Geophysical Methods

Geophysical Method	Physical Property
Resistivity	Electrical resistivity (or electrical conductivity)
Electromagnetic induction	Electrical conductivity (or electrical resistivity)
Ground-penetrating radar	Dielectric constant and electrical conductivity
Magnetometry	Magnetic susceptibility and remanent magnetism
Self-potential	Electric potential gradient
Seismic	Density and elastic moduli (bulk modulus, shear modulus, etc.)

1.6. Conclusion:

The three geophysical methods predominantly used for agricultural purposes are resistivity, electromagnetic induction and ground-penetrating radar. Depth sections and contour maps are two of the most common geophysical data analysis end products. Agricultural application of geophysical methods to investigate the shallow subsurface (within a typical depth range of 0 to 2 m). New developments in the overall discipline of geophysics are ongoing, with innovative methods equipment, and field procedures continuing to be introduced.

The same is particularly true for agricultural geophysics. Many concepts being tested and initiated at present will eventually become Commonplace for agricultural geophysics. The follow list serves to emphasize the variety of possible applications by listing just a Few of the numerous ways that these three geophysical methods can provide valuable information for agriculture purposes:Soil drainage class mapping , determining clay-pan depth , Estimation of herbicide partition coefficients in soil, Mapping of flood deposited sand depths on farmland, soil nutrient monitoring from manure applications, Quality/efficiency improvement soil surveys, Measurement of micro variability in soil profile horizon depths Bedrock depth determination in glaciated landscape with thin soil cover, Plant root biomass surveying ,Identification of subsurface flow pathways, Farm field and golf course drainage pipe detection, Soil salinity assessment Delineation of spatial changes in soil properties ,Soil water content determination.

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