Keynote Presentation

Agricultural Geophysics: Past/Present Accomplishments and Future Advancements

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Abstract

Geophysical methods have become an increasingly valuable tool for application within a variety of agroecosystems. Agricultural geophysics measurements are obtained at a wide range of scales and often exhibit significant variability both temporally and spatially. The three geophysical methods predominantly employed for agriculture, both past and present, are resistivity, electromagnetic induction, and ground penetrating radar. Likely future advancements in agricultural geophysics, to name a few, may include greater employment of geophysical methods that have not traditionally been applied to agriculture; construction of multi-sensor geophysical equipment platforms, perhaps integrated with agricultural machinery; and development of agricultural geophysics expert system computer software.

Keywords: agroecosystems, geophysics, resistivity, electromagnetic induction, ground penetrating radar.

Introduction

Valuable applications of geophysical methods have been found within a number of different 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.). The scale for geophysical applications to agriculture can be extremely small, on the order of centimeters, 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 et al., 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 et al., 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). To some extent, this shallow 2 m depth of interest is an advantage, since many geophysical methods presently available have investigation depth capabilities exceeding 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 (EC_a) measured using resistivity and electromagnetic induction (EMI) 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 EC_a over the same timeframe. Moisture conditions also govern the soil relative permittivity (or dielectric content); thereby impacting ground penetrating radar (GPR) results obtained within agroecosystem settings. Measured EC_a 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 EC_a, if they vary temporally at all, do so at a much slower rate, and included in this category are 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 changes over very short horizontal and vertical distances. For soils without salinity or nutrient build-up concerns, it has been noted that although average EC_a values for an agricultural field may vary with changes in soil temperature and moisture, the EC_a 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 EC_a spatial patterns were governed predominantly by the spatial variations in the more stable soil properties (Banton et al., 1997; Lund et al., 1999; Farahani & Buchleiter, 2004; Farahani et al., 2005; Allred et al., 2005a; Allred et al., 2006). In many cases, EC_a is a quantitative proxy for a single soil property such as for salinity within some irrigated agricultural areas of California (Rhoades & Ingvalson, 1971; Lesch et al., 1992); but conversely, there are also agricultural areas in which a complex relationship exists between EC_a and several soil properties (Johnson et al., 2001; Allred et al., 2005a; Carroll & Oliver, 2005; Allred et al., 2009).

Geophysical Methods Commonly Employed 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 but discrete soil electrical conductivity (EC_a) measurements. The location for each EC_a measurement is determined accurately by GPS. Consequently, these resistivity systems, with their fast EC_a measurement rates and integrated GPS receivers, are capable of surveying large farm fields in a relatively short period of time. Figure 1 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 et al., 2006), but these systems have not yet been extensively employed for this purpose.

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 EC_a 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 EC_a 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 EC_a measurements. As with the previously described resistivity systems, the proper EMI ground conductivity meter integrated with a GPS receiver is capable of relatively quick EC_a mapping over large farm fields. Although primarily used to map EC_a, ground conductivity meters can also be used to measure magnetic susceptibility, a property that has been demonstrated useful for delineating hydric soils via direct measurement with magnetic susceptibility meters (Grimley & Vepraskas, 2000; Grimley et al., 2008; Wang et al., 2008). Two examples of ground conductivity meters commonly used for agricultural applications are shown in Figure 2.

Figure 1. 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.

Figure 2. 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).

The GPR systems utilized within agroecosystem settings typically employ antennas with center frequencies in the range of 100 MHz to 1.5 GHz (Figure 3). 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 et al. (2008) provide further discussion of the different geophysical methods that can be used for agriculture.

Figure 3. Example of GPR system (Sensors & Software Inc., Noggin^{plus} with 250 MHz antennas - Mississauga, Ontario, Canada) being used to map buried agricultural drainage pipes.

Past and Present Accomplishments 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 (EC_a) 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 & Luthin, 1961; Roades & Ingvalson, 1971; Halvorson & Rhodes, 1974; Rhoades et al., 1976). Through the use of resistivity methods, and now EMI methods, geophysical EC_a 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 et al., 1999; George & Woodgate, 2002; Beirwirth & 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 et al., 1986; Collins & Doolittle, 1987; Doolittle, 1987; Schellentrager et al., 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, EC_a mapping with resistivity and EMI methods became an increasingly important precision farming tool. Mapping of EC_a 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 EC_a 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.

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, EMI, and GPR methods; however, research is now also being conducted on possible agricultural uses for other geophysical methods, such as magnetometry, self-potential, and seismic (Lu et al., 2004; Maineult et al., 2004; Rogers et al., 2005; Rogers et al., 2006; Lu & Sabatier; 2009). 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 (Butnor et al., 2001; Butnor et al., 2003), high value crops (Konstantinovic et al., 2007; Konstantinovic et al., 2008), animal waste management (Eigenberg et al., 2002; Eigenberg et al., 2010), soil hydrologic characterizations (Grote et al., 2003; Grote et al., 2010), buried infrastructure location/assessment (Allred et al., 2004; Allred et al., 2005b; Allred et al., 2005c), etc.

Five Probable Future Advancements in Agricultural Geophysics

1) Geophysical methods not traditionally employed in the past for agricultural purposes will find more significant use in the future. The geophysical methods most 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. Furthermore, airborne electromagnetic induction (EMI) surveys will find greater use for watershed scale agricultural investigations.

2) 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.

3) 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 ground penetrating radar (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.

4) There is likely to be a substantial increase beyond present levels in the use of inverse modelling, enhanced data visualization, and expert system computer software to analyze and even automatically interpret agricultural geophysics data.

5) 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.

Conclusions

Geophysical methods can be an important tool for application within a variety of agroecosystem settings. Agricultural geophysics measurements are obtained at a wide range of scales and often exhibit significant variability both temporally and spatially. 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) greater employment of geophysical methods that have not traditionally been applied to agriculture; (2) integration of geophysical equipment with real-time kinematic Global Positioning System (RTK-GPS) receivers; (3) construction of multi-sensor geophysical equipment platforms; (4) increased use of inverse modelling, enhanced data visualization, and expert system computer software to analyze and interpret agricultural geophysics data; and (5) 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.

Author’s Note

The use of manufacturer names are provided for informational purposes only and do not imply endorsement by the author or the USDA – Agricultural Research Service.

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