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SPECIAL SECTION: AGROGEOPHYSICS: GEOPHYSICS TO INVESTIGATE SOIL–PLANT–ATMOSPHERE INTERACTIONS & SUPPORT AGRICULTURAL MANAGEMENT

Geophysics conquering new territories: The rise of "agrogeophysics"

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Abstract

Agriculture is facing immense challenges. We have to produce enough food while safe-guarding the environment for future generations. This results in the need to use less water and fertilizer, and to harness soil quality. Key to achieving this goal is improving the understanding of processes and interactions governing the soil–plant–atmosphere continuum of agricultural ecosystems. Geophysical tools have great potential to better characterize and quantify these processes noninvasively from the plot to landscape scale. Nevertheless, a number of challenges remain for geophysical results to be better exploited by different scientific communities and by decision-makers. In this special section, we explore ongoing research in the relatively new field of agrogeophysics, and we provide an overview of potential applications and highlight future research needs.

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Abbreviations: EC_a, soil apparent electrical conductivity; EMI, electromagnetic induction; ERT, electrical resistivity tomography.

Soil degradation continues to aggravate in many parts of the world (Bai et al., 2008). Surface sealing, compaction, and salinization can be attributed to a large extent to poor management of soils and water and have a tremendous impact on agricultural productivity. Soil is an essential natural resource to grow our food. It should be managed in such a way that it maintains its integrity as a complex and highly structured entity, composed of mineral particles, organic matter, air, water, and living organisms. Approaches to the improved management of soils, and sustainable agriculture in general, include those that (a) reduce nutrient losses by adapted timing and slow-release properties, (b) capitalize on natural resources and circular farming and/or precision farming, (c) apply efficient irrigation techniques and scheduling, and (d) select more efficient crops (e.g., by phenotyping from laboratory to field).

Geophysics has several strengths to create added value in providing an answer to these challenges. Due to its noninvasive nature, near-surface geophysical methods support the investigation of soil properties, characteristics and variables (Romero-Ruiz et al., 2018). High-resolution two- and three-dimensional mapping and monitoring opens up extensive options to tackle inherent heterogeneity and complex dynamics of soil and cropping systems. Therefore, geophysical techniques are likely to become future essential tools for sustainable management in agro-food systems together with remote-sensing techniques.

Nevertheless, challenges to use geophysics for agricultural applications remain. Even though geophysical results are sensitive to key characteristics and state variables of agroecosystems such as soil moisture, clay content, porosity, or salinity, a transfer function has to be established for quantitative interpretation. These transfer functions often represent nonlinear relationships as well as interactions between variables that lead to a site- and/or time-specific and ambiguous character and a continued need for in situ calibration (Tso et al., 2019). Inversion algorithms are necessary to fully exploit three-dimensional information content of geophysical data. This adds uncertainty to the estimates by smoothness and other constraints. Furthermore, varying sensitivity volumes of several geophysical methods combined with the multiscale nature of patterns, heterogeneity, and anisotropic behavior of cropped soils remains a challenge to fully exploit the potential of geophysical techniques for agriculture.

This special issue contains papers that apply geophysical techniques in exciting agricultural contexts and highlights potential and remaining challenges.

A first exciting emerging research field is the use of geophysical techniques to characterize root systems, including their density, architecture, and growth. Whereas ground-penetrating radar has been used to identify the location of large, woody roots, electrical techniques to study a broad range of root systems have been used with varying success.

Core Ideas

- Geophysical techniques are future tools for sustainable management of water and nutrients in agroecosystems.
- Spatial electromagnetic data help to characterize large areas and to understand underlying processes.
- Geophysical characterization offers insights in processes driving the soil–plant–atmosphere continuum.
- Geophysics to characterize root properties and processes is a growing interdisciplinary research topic.

The review article "Sensing the electrical properties of roots: A review: by Ehosioke et al. (2020) provides an overview of the different techniques available, their advantages and limitations, and the remaining knowledge gaps to successfully use electrical techniques to characterize root systems in space and time.

Illustration by Sarah Garré.

Geophysics was first discovered as a reconnaissance tool, also in agriculture. In the 2000s, the field of proximal soil sensing evolved quickly from qualitative to quantitative mapping tool (McBratney et al., 2003; Minasny et al., 2013). Nevertheless, time-lapse geophysical techniques, repeating the same measurements over time in a system, have much more potential to underpin and manage the dynamics of agricultural systems and how agricultural practices might affect them. In their paper "Time-lapse geophysical assessment of agricultural practices on soil moisture dynamics," Blanchy et al. (2020) discuss the use and potential of geophysics in several agricultural case studies. They advocate the use of electrical resistivity tomography (ERT) and electromagnetic induction

(EMI) to monitor the effects of different agricultural practices (cover crops, compaction, irrigation, tillage, and fertilization), which can influence water retention in soils and crop yields.

In the article "Time-lapse mapping of crop and tillage interactions with soil water using electromagnetic induction," Brown et al. (2021) show that the different crops monitored with EMI were the main drivers of the soil apparent electrical conductivity (EC_a) patterns. This happens through the effect of root water uptake on soil moisture. Tillage effects were not significant in their study. This points out that it is essential to monitor the soil–plant system as a whole to understand the complexity of its interactions.

In "Hydrodynamic characterization of soil compaction using integrated electrical resistivity and X-ray tomography," Cimpoiaşu et al. (2021) focus on the urgent need to develop fast techniques to characterize and monitor soil compaction. They used the combined capabilities of small-scale X-ray tomography and larger scale ERT tomograms to investigate the effect of different levels of compaction on soil hydrodynamic functioning.

Kuhl et al. (2021) use soil water content from time domain reflectometry and electrical resistivity measurements to support a broadly applicable and novel coupled hydrogeophysical approach in their article "Root water uptake of biofuel crops revealed by coupled electrical resistivity and soil water content measurements." They estimate root growth and root water uptake distribution properties, along with heterogeneous soil properties below nonirrigated biofuel crops in a field setting across three growing seasons in the humid temperate climate of southwestern Michigan (USA).

Although the mapping potential of geophysical techniques is not new and is probably amongst the first commonly used geophysics-based applications in agriculture, considerable steps have been made recently to use these data in agricultural decision-making processes and to obtain quantitative spatial information about variables of interest.

In their article "Toward high-resolution agronomic soil information and management zones delineated by ground-based electromagnetic induction and aerial drone data," von Hebel et al. (2021) focus on the integration of soil EC_a maps generated using a classical EMI survey with time-lapse aerial data to generate management zones at the size of agricultural machinery. They show that the information content in aerial data is highly time dependent and that for the analyzed case studies, no added value was observed when aerial data were added to the EMI data to delineate management zone. This underpins the importance of including spatially distributed soil information in crop data interpretation to manage agricultural systems.

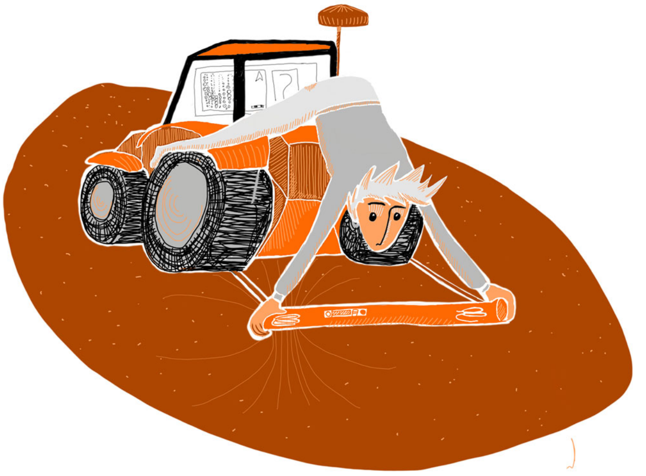

Illustration by Sarah Garré.

Romero-Ruiz et al. (2021) report how seismic signatures can reveal persistence of soil compaction at the management scale. In their article "Seismic signatures reveal persistence of soil compaction," they introduce a pedophysical model to interpret macroscopic seismic properties and apply it on monitoring data from a compacted field site, showing that seismic data can be used to identify zones with chronic compaction problems.

Many initiatives call for land management practices raising soil organic carbon as a mitigation measure for climate change and as a pathway to improve soil structure and soil functioning. Nevertheless, clear guidelines on how to map and monitor C sequestration are missing. Longo et al. (2020) describe in "Soil apparent electrical conductivity-directed sampling design for advancing soil characterization in agricultural fields" how EC_a–directed sampling can help construct a meaningful experimental design for deep soil organic C stock estimation under contrasting agronomic management practices.

Rentschler et al. (2020) focused on how geophysical techniques can also provide information on the vertical distribution of soil organic carbon and soil moisture with their paper "3D mapping of soil organic carbon content and soil moisture with electrical conductivity data and machine learning." They used machine learning models combining depth-related data from multiple EMI sensors and a gamma-ray spectrometer to gain insights into horizontal and vertical variability of soil organic C and soil moisture with relatively low error.

The variety of studies submitted to this special section shows that agrogeophysics has enormous potential to capitalize on. We hope that this collection offers a small window on how agrogeophysics can contribute to a better and more sustainable management of agricultural soils.

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AUTHOR CONTRIBUTIONS

S. Garré: Conceptualization, Project administration, Supervision, Visualization, Writing-original draft, Writing-review & editing; D. Hyndman: Writing-original draft, Writing-review & editing; B. Mary: Writing-original draft, Writing-review & editing; U. Werban: Writing-original draft, Writing-review & editing.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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