Booklet of Abstracts

Agriculture and geophysics: Illuminating the subsurface!

#agrogeo24

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Monitoring and modelling root-zone processes with geoelectrical methods

Benjamin Mary[1], **Vicente Burchard-Levine**[1], **Miguel Ángel Herrezuelo**[1], and **Héctor Nieto**[1]

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Abstract

Garré et al. (2021) presented a highly positive perspective in their paper, "Geophysics conquering new territories: The rise of 'agrogeophysics'." Considering the opportune timing for fresh brainstorming three years later, our work will focus on how illuminating subsurface root-zone processes, and integration with established pipelines like Evapotranspiration (ET) modeling can enhance farming practices. We first aim to give an overview of the current state of the art with an emphasis on monitoring and modelling root-zone processes with geoelectrical methods within an agricultural context. We will assess and discuss the well adopted electrical resistivity tomography (ERT) with examples illustrating the strengths and limitations of its use at different time and spatial scales (laboratory, mesoscale, field). Our work underscores the importance of using "translators" (pedophysical relationships), to effectively assimilate geoelectrical data into hydrogeophysical models. This raises intriguing questions about the number of puzzle pieces required to unravel the water pathflow from roots to the atmosphere, and encourages future studies to explore the potential for soil to complement with plant physiological observations. In particular, in pursuit of a more holistic understanding, we conclude with a forward-looking perspective, advocating for the integration of root zone soil moisture observations with remote sensing and Earth Observations. This coupling aims to enhance the accuracy of ET estimates, presenting an avenue for future research and advancing the interdisciplinary synergy between geophysics and agricultural sciences.

Keywords ERT, geoelectrical methods, coupled inversion, modeling, pedophysical relationships, evapotranspiration

References

Garré, S., Hyndman, D., Mary, B., & Werban, U. (2021). Geophysics conquering new territories: The rise of "agrogeophysics". *Vadose Zone Journal*, *20*(4). https://doi.org/10.1002/vzj2.20115

Invited Talk

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High-throughput crop root phenotyping through electromagnetic induction method

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Abstract

Crop rooting system, its architecture, and activity, determine the capacity of crop to take up water for growth and yield, underpinning agricultural productivity. Identifying desirable root phenotypes directly in the field would be the short route to help identify and incorporate traits that enhance drought tolerance in breeding programs, and to inform more resilient crop managements. Here we proposed and test a new approach for high-throughput phenotyping crop root growth and activity in the field based on electromagnetic induction (EMI) instrument coupled with a quasi-2D inversion algorithm, and crop canopy sensing technologies. A 3D root activity factor (R) was calculated as a function of crop water use, soil water availability, and an indicator of crop demand. A maximum rooting depth – RD, and a root architecture index– RA was quantified based on the distribution of R with soil depth, in a set of commercial sorghum hybrids (G) grown in contrasting field environments (E), and plant population densities (M). The derived root trait indices from the approach were validated for the presence of roots using field root coring. Results show that the phenotyping approach is able to capture GxExM effects on root traits. The root activity factor is closely related to measured root length density in the field across a wide range of environmental conditions. The RD and RA is related to differences between hybrids in yield, yield components and their stability. We conclude that the proposed high-throughput root phenotyping approach provides a rapid, accurate and cost-efficient option to phenotype crop rooting system in the field and can be a powerful tool to aid breeding phenotype for mean traits of the rooting system.

Keywords EMI, plant roots, phenotyping, 2-D inversion, crop canopy

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Quantitative phenotyping of plant roots using spectral electrical impedance tomography

A rhizotron study on maize and bean crops with optimized measurement design

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Abstract

Root systems are major contributors to plant health, resilience, and ultimately, yield of agricultural crops. Optimizing crop root traits via phenotyping is therefore an important step towards more adaptive and efficient agriculture. Traditional root characterization methods are often labour-intensive and invasive to the soil-root-continuum, thereby limiting high-throughput phenotyping efforts. Here, spectral electrical impedance tomography (sEIT) could help as a non-invasive and cost-efficient alternative, potentially providing 2D or 3D information on root evolution and activity. Electrical impedance measurements on plant roots have been shown to be sensitive to biomass, nutrient status, and even diurnal activity. However, few attempts have been made to employ tomographic algorithms to recover spatially resolved information on root systems. This can be attributed to the technical challenges associated with imaging electrical conduction and polarization information in a plant-based setting, requiring sophisticated instrumentation and analysis practices. In this study, we conducted sEIT measurements on crop roots in a rhizotron container under hydroponic conditions. We present an adopted methodology for the generation of a measurement configuration scheme with optimized spatial resolution characteristics and show its relevance for the correct estimation of root traits. Subsequently, we demonstrate for four different fine root systems (maize, pinto bean, black bean and soy bean) that sEIT is capable of providing spatially resolved information on root biomass and root surface area. Our study showcases that sEIT is a promising, non-invasive tool for the tomographic reconstruction of root traits within root phenotyping trials and can be used as a substitute for traditional root characterization methods.

Keywords sEIT, plant roots, phenotyping, rhizotron experiment, root biomass, root surface area

Conference Talk

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The first automated ERT belowground field phenotyping installation yields exciting results

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Abstract

Providing enough food for a growing population while preserving natural resources and biodiversity is one of the challenges of the 21st century. A key pathway to maximize yields sustainably is to select and grow crops that are optimally adapted to their environment. Plant performance is determined by characteristics, or 'traits', which are partially genetically determined. Nevertheless, cultivars with the same genome (G) express different appearances or 'phenomes' in different environments (E) and under different management practices (M). Phenotyping the below-ground traits of plants is not straightforward, due to the opaque nature of soil. Non-invasive geophysical techniques to study the root zone have substantially advanced in recent years. Their biggest potential lies in indirect monitoring of water depletion in the root zone, especially in time-lapse mode. We implemented a fully automated electrical resistivity tomography (ERT) monitoring installation at the ILVO Hydras research infrastructure, where belowground phenotyping is combined with above-ground phenotyping with drones and mobile rain-out shelters. In 2023 we conducted a proof-of-concept experiment with 3 soybean varieties. Our first results show that ERT is able to detect belowground difference between varieties. While challenges remain to obtain accurate resistivity distributions and understand error propagation through the data processing pipeline, we obtained an encouraging dataset, from which belowground plant characteristics are derived in space and time. We will present those first results, paving the way for a standardized and automated phenotyping methods based on timelapse ERT measurements.

Keywords ERT, phenotyping, root water uptake, soil moisture, drought

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AGROGEO

Overview of geoelectrical advances for vineyard study: how to provide relevant parameters for the characterization of the physicochemical properties of vineyard soils

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Abstract

As the quality of wine is intricately influenced by the environmental conditions supporting vine growth, a thorough examination of soil and climate parameters becomes imperative. Key soil-related factors impacting vine development, yield, and berry composition include soil water content and soil composition, encompassing geometry and nutrient/mineral distribution. Traditional field-based mapping methods for these influences prove to be both restrictive and costly. Near-surface geophysics emerges as a promising avenue, offering the potential to not only enhance data resolution but also potentially reduce associated costs. Until recently, vineyards primarily utilized geophysical data through apparent electrical resistivity, combined with soil sampling, to establish soil texture maps. Recent advancements in geophysical techniques, tailored to the specific requirements of vineyards, reveal the potential for extracting additional relevant parameters.

This presentation will focus on recent case studies employing geoelectrical methods, namely Electrical Resistivity Tomography (ERT), Induced Polarization (IP), Electromagnetic Induction for Low Induction Number (EMI), and Ground-Penetrating Radar (GPR). The aim of this presentation is to showcase the geoelectrical contributions to soil viticulture characterization, with a specific emphasis on soil water content, soil physico-chemical composition, soil depth, and improved consideration of soil texture definition, accounting for spatial requirements. Each topic will be accompanied by a comprehensive discussion of advantages, limitations, and insightful observations.

Keywords ERT, EMI, IP, GPR, vineyard mapping

Invited Talk

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Electrical resistivity on tree trunks

Modeling assumptions and data interpretation

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Abstract

Electrical resistivity is an increasingly used geophysical method to study the dynamics of sap-flow movements inside trees. Most existing studies that use this method either (1) do not model the 3D geometry or (2) do not account for prior knowledge about the interior structure of trees, such as the sapwood/hardwood separation. Starting with a synthetic modeling study, we show how these assumptions can lead to biased conclusions about the internal processes within trees inferred from electrical resistivity data. Following this, we present a dataset collected on pine trees during an irrigation experiment conducted in the Pfynwald forest (Valais, CH). Six trees are chosen; 2 from a control plot (never irrigated), two from an irrigation-stop plot (irrigated for 10 years and then 10 years without irrigation) and two from an irrigation plot (irrigated for the last 20 years). By combining ground penetrating radar (GPR) reflection imaging around the trunks with tree cores, we propose an approach to constrain the internal structure of sapwood and hardwood across the entire stem. We then use this information as a prior constraint for a 3D inversion of the acquired resistivity data. Our results indicate spatio-temporal resistivity patterns that agree with independent observations about the dynamics of irrigated vs. non-irrigated trees on the site and better explain sap flow measurements on the monitored trees. Our findings offer a new understanding of how geophysical imaging can be used to non-destructively infer the interior processes of trees at increased accuracy.

Keywords ERT, GPR, tree trunk, synthetic experiment, forest experiment

Conference Talk

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Soil-water-plant interactions

An illustrative example from two oak forests in the Swiss Alps

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Abstract

Soil centered quantification and understanding of tree water use in the field is hampered by large root systems and related variability in soil properties affecting the root water uptake. Application of geophysical methods is a promising tool to capture root water uptake at scales representative of vegetation in natural environments. Measurement of sap flow also allows quantification of water uptake in the root zone of trees, but its absolute value is subject to uncertainties due to the several parameters required.

The objective of this study is to compare ERT and sapflow measurements to assess water use of downy oak at two sites in a drought prone environment. Between April and November, ERT measurements were conducted along two transects of 11.75 m in length to monitor the drying and rewetting of the soil. The resistivity patterns were measured 7 times during the season using 48 electrodes with 0.25 m spacing installed along marked transects (fixed installation and automatic scanning was not possible due to potential damage by animals). With the dipole-dipole arrangement, 906-quadripoles were measured and inverted using RES2DINV. Using Archie's 2nd law with cementation and satu-ration factor values fitted with measured soil water contents we converted resistivity values to water content.

Comparison of sapflow with root water uptake estimated from ERT indicat-ed the same trend, an increase in spring and a decrease in midsummer. Differences in the measurements reflect the different spatial scale and measurement interval of the methods, highlighting their complementarity.

Keywords ERT, tree water use, sap flow, field experiment

Conference Talk

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Evaluating the contribution of spectral induced polarization to understand the geometry of the rhizosphere in agroforestry

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Abstract

Agroforestry, the practice of planting trees on agricultural land, is a sustainable form of agriculture. Trees not only protect the soil from wind erosion, but also improve the water supply, and increase the amount of nutrients and organic matter in the subsurface, which can lead to an increase in the yield. Yet, the impact on the rhizosphere, which are soils influenced by tree roots and associated processes, due to the expansion of the tree root system and their interaction is not fully understood.

In this study, we use the Spectral Induced Polarization (SIP) method, which provides the conductive (conductivity) and capacitive properties (polarization) of the subsurface, to delineate the expansion of tree roots on the edge of agricultural fields. SIP measurements were conducted in a frequency range between 0.1 and 75 Hz at four sites with fruit trees. We collected data with different 2D and 3D electrode configurations, e.g., a circular array and a star-shaped array, to investigate their resolving capabilities, as the detection of roots requires high spatial resolution.

The 2D and 3D inverse models show that the conductivity can be used to delineate the root zone and areas of high water content, while the polarization offers information about areas with high organic matter beneath the roots. Our study demonstrates that the SIP method is able to provide information about the expansion of tree roots and their interaction with soil, which is critical information for the application of agroforestry.

Keywords SIP, tree root system, soil oisture, organic matter, field experiment

Conference Talk

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Geophysical monitoring of the fresh-saline groundwater interface in Belgian polders

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Abstract

Polders are low-lying areas that are constantly drained by a network of ditches and subsurface drains. While the groundwater remains saline water from its seaborn nature, precipitation and effective recharge over the years, created a freshwater lens on top of the saline water. This lens is essential for most conventional crops. However, intensive rainfall events and prolonged summer droughts are becoming more frequent with Climate Change and lead to decreasing freshwater lens thickness, endangering crop yield. Controlled drainage systems that enable regulating the water level in the subsurface drains has the potential to mitigate this issue by imposing a temporary higher water level, hence increasing recharge of the freshwater lens. The dynamics of the fresh/saline water interface throughout the year is therefore key in terms of crops sustainability. To study it, we equipped three fields with multilevel piezometers and 1D resistivity sticks. In addition, electromagnetic induction surveys enabled us to expand the local observations to the entire area (4 ha in total). During 2021, all fields were without controlled drainage and a large increase in salinity was observed with decreasing heads. In 2022, one of the fields was changed to controlled drainage and different dynamics in heads could be observed. However, no effect on the salinity levels could be observed, probably due to the wet summer of 2022. The electromagnetic induction surveys reveal old paleochannels that influence the dynamics of the freshwater lens at the field-scale.

Keywords ERT, EMI, climate-adaptive drainage, salinity monitoring, field experiment, groundwater

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Multi-configuration EMI for large-scale agricultural top- and subsoil characterization

Calibration, inversion and applications

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Abstract

Due to the recent developments of multi-configuration EMI systems consisting of transmitter and multiple receivers in a portable rigid boom, detailed large-scale characterization of the top- and subsoil is nowadays possible. Using Transmitter-Receiver separations ranging from 0.3 m up to 4 m, multiple apparent electrical conductivity (ECa) values are measured for different but overlapping investigation volumes. The measured data can be used in a qualitative way to investigate the spatial ECa patterns/clusters to determine the best locations for soil sampling. Since changes in ECa can be caused by many factors including soil water content, texture, and salinity changes, soil samples need to be used to determine the different top- and subsoil properties that are responsible for the ECa contrasts. In this way, the obtained soil properties can be extrapolated into the obtained clusters resulting in a large-scale top- and subsoil characterisation over several hectares for every square meter. In order to enable a more quantitative use of the data and to obtain a reliable model of the electrical conductivity changes with depth, a calibration of the EMI measurements is required, which can be achieved using soil sampling, independent electrical resistivity tomography (ERT), or vertical electrical sounding (VES) measurements. Here, we give an overview of several agricultural applications, calibration approaches to obtain quantitative ECa values, and inversion results to obtain a quasi-3D image of the top- and subsoil. Especially the subsoil patterns were often responsible for the observed patterns in leaf area index (LAI) and airborne hyperspectral plant performance data.

Keywords EMI, mapping, clustering, apparent electrical conductivity, calibration, inversion

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AGROGEO

Assessing the suitability of ground-penetrating radar for peat imaging

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Abstract

Peatland conservation and restoration are prominent in slowing global warming. A thorough comprehension of peat inventory, especially the thickness, bulk density, water table levels, and geological setting, is necessary to plan and initiate rewetting strategies and to calculate emission savings. The conventional mapping methods involving push probes and boreholes are not only cost- and labor-intensive, but they also provide only localized measurements. Among the geophysical sensors, while electromagnetic induction (EMI) and gamma-ray spectrometry have proven to be suitable for mapping specific attributes, ground penetrating radar (GPR) is seen as the industry's standard recommendation. However, the success rate can be highly variable in reality depending on the peatland type, and ignoring this can lead to the waste of numerous resources.

To demonstrate this, in this study, we compare GPR survey transects performed on two different peatland types (a bog vs. a fen) with two different antenna center frequencies (i.e., 160 MHz and 450 MHz). Electrical resistivity tomography was also performed along the same transects to complement and guide our interpretation. Our results suggest that while GPR surveys are suitable in rain-fed oligotrophic bogs, less to no success rate can be anticipated in minerotrophic fens. Forward modeling using gprMax is also shown to substantiate these findings. Thus, knowledge of the peatland type constitutes crucial information for sensor selection. If in doubt, we recommend performing on-the-go EMI surveys before initiating GPR surveys, as electrical conductivity might be sufficient on its own for peatland characterization. Moreover, EMI is also useful for predicting GPR performances.

Keywords GPR, ERT, peat, mapping, thickness, bulk density, water table, modelling, field experiment

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Delineation of organic carbon pools in subsoils through electrical methods

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Abstract

The spectral induced polarization (SIP) method has emerged as a suitable method in Biogeophysics due to its sensitivity to the geometry and the geochemical properties of the pore-space, the presence of bacteria, biofilms and other membranes such as roots. Recent laboratory studies have proposed the use of SIP measurements to monitor the activity of roots and plants as they observed a relation between the activity and the polarization response. However, field-scale SIP measurements for the investigation of processes in the rhizosphere are still rare. Moreover, there are no investigations regarding the contribution of the soil organic carbon (SOC) to the electrical response in the rhizosphere yet. Here, I present evidence on the link between SIP response and SOC from field measurements in different sites conducted in both organic and mineral soils. Our results show that SIP images can be used to further understand in-situ root activity at the field-scale. Additionally, I discuss challenges in the collection of high quality SIP datasets.

Keywords SIP, rhizosphere processes, soil organic carbon, field experiment

Invited Talk

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AGROGEO

Potential of GPR in of Agro-Geophysics: Mapping and monitoring soil variables in different settings

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Abstract

In the last decade, ground penetrating radar (GPR) has been applied to a wide range of different settings to minimal invasively investigate the subsurface to enhance sustainable agricultural, e.g., responsible use of natural resources. Compared to other geophysical methods, GPR can provide permittivity and electrical conductivity information at a high resolution in the field. Additionally, GPR can characterize subsurface structures and has as a great link to soil water content (SWC). This talk provides an overview of current applications of crosshole and surface GPR to investigate the soil-root continuum, monitor SWC in agricultural fields, and to characterize effects on the soil related to agricultural management including nitrate applications and the use of cover crops. Thereby, controlled plot and field trials, such as the minirhizotron facilities and the bare-field site in Selhausen, are crucial to validate research findings. Using crosshole GPR at the minirhizotron facilities allowed monitoring variations in the permittivity hence SWC during the crop growing season for different treatments and depths between 0.2 and 1.2 m. These variations were then linked to variabilities in root volume fractions acquired from root images of maize obtained in the same rhizotubes as the GPR data. At the bare-field site and controlled field trials, we conducted time-lapse surface GPR and other geophysical methods to measure the impact of fertilizer and tillage on the GPR signals. Overall, GPR has shown potential to map and monitor variations in the subsurface variables related to SWC or differences in the agricultural management.

Keywords GPR, permittivity, electrical conductivity, soil moisture, crosshole, surface, field experiment

Invited Talk

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Continuous resistivity profiling using Geophilus system for efficient characterization of soil properties

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Abstract

TONIA project aims to enhance agricultural efficiency by precisely assessing soil electrical resistivity within fields. The research targets optimal water and fertilizer allocation to address varied soil needs, ensuring improved yields and environmental sustainability. The GEOPHILUS ELECTRICUS system introduces an innovative approach using rolling electrodes to map soil electrical resistivity. It measures amplitude and phase data at five different depths, reaching 1.5 meters, providing crucial insights into subsurface structures.

The primary objective involves processing resistivity data measured by GEOPHILUS system and conducting 1D inversions for them. The methodology begins with meticulous data preprocessing and line detection algorithms, leading to successful inversions across various lines. These models offer essential understandings of the farm's geophysical features. Multiple data processing algorithms were used for the original data, and the results for individual algorithms and combined algorithms were compared.

Key findings involve successful 1D inversions yielding multiple resistivity models across various lines. Overall, TONIA project establishes a robust framework for processing electrical resistivity data, facilitating reliable subsurface modeling for agricultural enhancement.

Keywords ERT, soil mapping, field experiment, 1-D inversion

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AGROGEO

Drone-borne Ground-Penetrating Radar for Digital Soil Mapping

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Abstract

Characterizing soil hydrogeophysical properties has always been a vital task in various fields, including hydrology, meteorology, environmental sciences, and agriculture. Our studies collectively demonstrate the potential of drone-borne Ground Penetrating Radar (GPR) for high-resolution mapping of soil moisture and electrical conductivity at the field scale. We explore its application in precision agriculture and environmental monitoring. These studies aim to showcase the potential, benefits, and limitations of GPR for soil characterization at the field scale and provide insights into the factors influencing GPR measurements and inversion.

The drone-borne GPR system for soil moisture mapping comprises a handheld vector network analyzer, a hybrid horn-dipole antenna, a GPS unit, a microcomputer, and a smartphone for remote control. Soil moisture and electrical conductivity are determined through full-wave inverse modeling based on the full-wave radar equation and Green's functions for multilayered media. In the case of electrical conductivity characterization, we observe that the soil surface reflection coefficient becomes highly sensitive to electrical conductivity and less sensitive to permittivity when the frequency is relatively low, typically in the range of 15-45 MHz. This phenomenon is demonstrated and analyzed through numerical experiments.

To validate our findings, we conducted field experiments and analyzed soil moisture and conductivity maps by comparing them with topographical conditions and results from electromagnetic induction (EMI) surveys. Furthermore, we investigated the effects of incidence angles and soil surface roughness on the inverse estimates. The former can be minimized or mitigated by using a less directive antenna or by considering the angles during calibration. The latter issue can be addressed by employing lower frequencies, depending on the prevailing roughness conditions.

Keywords GPR, drone, soil moisture, electrical conductivity, full-wave inverse modeling, numerical and field experiments

Invited Talk

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Validation of a new soil bulk density sensor

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Abstract

Soil compaction and bulk density are key soil properties, affecting the contribution of soil health to soil services like crop production, water retention and purification, and carbon sequestration. However, the standard measurement with rings is labor-intensive and expensive. To overcome classic limitations of soil density measurements we propose the use of a portable gamma sensor to measure bulk density in situ. A validation was performed in two locations, on sandy clay loam and sand soil in the Netherlands, both with large within field variation in subsoil compaction. In both fields ten soil pits were dug, where in every soil pit 3 profiles with the RhoC soil density meter were sampled. In addition, 3 profiles with undisturbed soil cores in rings were taken at every 10 cm depth, up until 60 cm depth. In total, 180 rings and 180 RhoC samples were taken per field. We will discuss the uncertainty of the RhoC method with respect to the uncertainty due to heterogeneity in the field. This novel technique allows the quantitative assessment of bulk density in the field at various depths. This measurement is essential for rapid and accurate soil compaction assessment and soil organic carbon stocks calculation. The acquisition of this data for land managers, advisors, and (national) soil monitoring is indispensable for the sustainable management of soils for the provision of ecosystem services, such as requested in the proposal EU Directive on Soil Monitoring and Resilience.

Keywords gamma-ray, soil compaction, bulk density, sensor development

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Drone-borne Gamma-Ray Spectrometry to Map Natural Radionuclide Concentrations and Detect Changes in Soil Moisture

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Abstract

In regions where water scarcity is a pressing concern, soil moisture measurement is essential for optimized irrigation. This study explores the potential of drone-borne gamma-ray spectrometry as a cost-effective method for mapping soil moisture levels and detecting their temporal changes. Traditional methods for assessing soil moisture are often limited to point measurements, which may not accurately reflect the overall moisture content of larger agricultural fields. Addressing this challenge, our research, in collaboration with the International Atomic Energy Agency (IAEA), integrates airborne and stationary gamma-ray spectrometry for large-scale soil moisture mapping. The study compares data from six drone-borne gamma-ray spectrometry measurements, a quad measurement, readings from a stationary gamma Soil Moisture Sensor (gSMS) (Veeke et al., 2020), and a capacity soil moisture sensor. These measurements were conducted over three years in the same field near Onstwedde, Groningen (NL). This study aims to validate the spatial and temporal coherence of drone-borne gamma-ray spectrometry in mapping and monitoring soil moisture. Our results demonstrate a strong correlation between drone-borne gamma-ray spectrometry results, gSMS readings, and capacity soil moisture sensor. This confirms the effectiveness of drone-borne gamma-ray spectrometry in soil moisture assessment.

Keywords Gamma-ray spectrometry, soil moisture, drone, stationary, field experiment

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Geoelectric joint inversion: a novel approach for grape vineyards investigation

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Abstract

This study focuses on a joint inversion approach within an agronomic framework, involving the inversion of 3D electrical conductivity data from the galvanic contact resistivity (GCR) method and 2D data from the capacitively-coupled resistivity (CCR). By minimizing misfit in model parameters, the joint inversion process enhances data-fitting in terms of resolution and accuracy of subsurface models within the inversion theory framework. The method integrates data pertaining to the same petrophysical property, mitigating ambiguity arising from variable survey sensitivities to distinct properties. The joint inversion algorithm was executed on a shared model parameterized with an irregular 3D mesh, and the optimization objective function was defined as the weighted misfit of the two datasets. Datasets were acquired in a red Sangiovese grape vineyard ("Tenuta il Poggione" - Montalcino, Siena, Italy), covering a 200 m² area. Employing a 3D GCR configuration for maximum resolution perpendicular to the vineyard rows and 2D CCR sections along the rows, the study explores up to a 5-meter depth, encompassing the entire vineyard's root system. We compare the results from the joint inversion method against those obtained from individual GCR and CCR inversions, with the primary objective of characterizing the geopedological properties more accurately. This study demonstrates the enhanced effectiveness and precision of the joint inversion method when applied to geoelectrical data in agrogeophysical investigations.

Keywords GCR, CCR, joint inversion, field experiment, plant roots

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Imaging water flow and solute transport at unsaturated soils using physics-informed neural networks trained with geo-electrical data

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Abstract

Monitoring water flow and solute transport in unsaturated soils is essential for agriculture. Traditional modeling approaches are challenging since they require well-defined boundaries and initial conditions. Machine learning (ML) techniques have gained considerable attention in imaging subsurface flow and transport. Nevertheless, conventional ML methods require vast data, which is extremely limited in most subsurface applications. Physics-informed neural networks (PINNs) have recently been developed to learn and solve forward and inverse problems constrained to partial differential equations. Unlike traditional ML techniques, PINNs are confined to physics and do not require" big" data for training. In this work, we adopted the PINNs approach to image two-dimensional water flow and solute transport during a drip irrigation event and the following redistribution stage with limited knowledge of the initial and boundary conditions. We used five time-lapse geo-electrical measurements obtained with 59 electrodes placed at the surface. The PINNs system contained two coupled feed-forward neural networks describing the spatiotemporal distribution of both water content and pore-water salinity. Numerical simulations conducted with Hydrus 2D/3D were used as benchmarks to examine the suitability of the described approach. The trained PINNs system provided the spatiotemporal distribution of both state variables with high accuracy. It also reproduced the initial conditions and separated the “measured” electrical signal into its two components. Moreover, the geo-electrical tomograms were significantly improved compared to the ones obtained with classical inversion of the raw geo-electrical data.

Keywords geo-electrical methods, machine learning, Physics-informed neural network, water flow, solute transport, field experiment

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Advances in Bayesian inversion methodologies with high potential value in agrogeophysics

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Abstract

In agrogeophysics, geophysical data are used to gain understanding about soil properties, states and processes. The geophysical properties that the measurements respond to are best treated as latent variables and targeted inversion methods should focus on characterizing the actual quantities of interest. Using examples in near-surface geophysics, I will demonstrate how the correlated pseudo-marginal method can be used for this purpose and how meaningful approximations can be obtained, at a much lower cost, by a linearized Gaussian approximation. Since soil systems are complex and data are insufficient, there is often a need to perform uncertainty quantification, but such techniques are computationally expensive. I will showcase some of our recent work using surrogate modeling and variational methods to speed up Bayesian inversion methods. I will conclude with a short outlook on the use of deep learning in the context of agrogeophysics.

Keywords Bayesian inversion, pseudo-marginal method, uncertainty quantification, surrogate modeling, variational methods

Invited Talk

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AGROGEO

3D soil moisture dynamics within a tree root system monitored using OhmPi, an open-source, open-hardware resistivity meter

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Abstract

In recent years geoelectrical imaging, and monitoring in particular, has become more popular to illuminate hydrological processes in the shallow subsurface. In this context, the accessibility of geophysical equipment is key to expanding the use of geophysical monitoring, and to developing novel, versatile acquisition strategies. While the robustness and practicality of commercial geophysical equipments can't be denied, they sometimes suffer from a lack of versatility for designing dedicated monitoring applications. Their cost may also be prohibitive in some contexts, such as for humanitarian applications or to equip a large number of sites.

In an attempt to tackle these issues, the OhmPi project was initiated to provide an alternative open-source, open-hardware resistivity meter to the community, which main purpose is an enhanced acquisition flexibility. Relying on low-cost components and devices, and using a low-power injection module (0-50V), OhmPi is specifically designed for small-scale field experiments. Developed as an open-source project, new collaborations are warmly welcomed.

We will present early results of a test monitoring of soil-plant interactions in a forested area at the Rochefort Cave Observatory (Belgium). It comprises 6 months of 3D daily measurements on 64 electrodes installed in a 40x60 cm grid covering a 6.0 x 1.8 m surface area centred on a young beech tree. This dataset allows us to investigate changes in resistivity associated with locally variable moisture content associated with the tree activity. While this example doesn't strictly lie in an agricultural context, it illustrates the applicability and transferability of OhmPi to similar agro-geophysical applications.

Keywords ERT, instrumentation, open-source, tree roots, forest experiment

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AGROGEO

Modeling the electrical polarization response of 1D radially symmetric rhizosphere processes in the plant-soil continuum

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Abstract

Various interactions of root systems in soils are influencing the complex electrical signature of spectral induced polarization (SIP) measurements. This non-invasive method applies a frequency dependent injection current to the soil near the roots to derive information about the plant's physiological state in the soil-root continuum. In an alternating current field, cells and cell membranes are polarized due to electrical double layers formed by the electrical surface properties of membranes. Nutrient dynamics and translocation processes in the root system modify the electrical properties and the polarization response of the root surface and vice versa.

Developing a one dimensional electrical structural-functional soil-root model, taking into account soil water flux, solute dynamics, as well as soil textural and mineralogical characteristics, improves the interpretation of SIP signals and the understanding of rhizosphere processes. By applying different soil parameters in a simulation study, we quantify the impact of nutrient uptake, pH regulation, and root exudate ion in the rhizosphere.

We identified the alkalinization of the rhizosphere with the absorption of nitrate and equilibrating H+ ions by the root as one key influencing factor on the electrical response. The resulting ion gradient, also affected by plant nutrient uptake, influences the imaginary part of the complex conductivity in SIP signals. This outcome enhances our comprehension of the structural-functional dynamics within the soil-plant continuum for modeling electrical signals and provides valuable insights into the relationships between plant-soil conditions and complex electrical conductivity behavior.

Keywords SIP, soil-root model, polarization mechanisms, rhizosphere

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Soil characterization through FDEM in heterogenous fields: a practical workflow evaluation

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Abstract

Quantitative characterization of soil properties across agricultural fields using geophysical techniques as Frequency Domain Electromagnetic Induction (FDEM) has a central role on Agrogeophysics. As a method, FDEM enables evaluating spatiotemporal variations in apparent electrical conductivity (ECa), which is influenced by a range of soil characteristics. Despite its potential, the transformation of FDEM-sensor data into accurate soil property information faces several challenges. These include compensating for systematic errors, and EC data inversion. Lastly, translating soil EC data into a target soil property using deterministic (pedophysical) models and stochastic (field-specific) relationships can suffer of inaccuracy, especially in fields with heterogeneous soils. To evaluate the impact of these limitations and explore the potential for FDEM-based soil property quantification, we collected FDEM data at two heterogeneous test sites. A first site with large variations in clay content, a second with saline groundwater. Sampling was conducted at 15 locations per site, at two depths (topsoil and subsoil) alongside soil probe EC measurements. Additionally, an ERT profile was collected at each site for FDEM data calibration. Regardless of FDEM data calibration and corrections, stochastic modelling showed relative good predictions of volumetric water content, bulk density, clay content, cation exchange capacity, and water EC; while sampling depth resulted a relevant parameter for stochastic predictions. Deterministic modelling performance was generally poor when comparing observed and predicted water content using inverted EC. While underscoring the need for adaptive pedophysical models, the results highlight the importance of accurate FDEM data collection and processing in deterministic approaches.

Keywords EMI, FDEM, apparent electrical conductivity, soil properties, pedophysical model, field data

Poster Presentation

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Use of electromagnetic induction and remote sensing datasets to characterize spatial variability in soil properties for sustainable farming

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Abstract

Within-field soil variability significantly influences water and nutrients availability, which in turn affects crop growth and yield. A comprehensive understanding of soil characteristics is thus necessary in sustainable agriculture, which demands both above and below-surface soil sensing. Commonly used sensing methods include electromagnetic induction (EMI) mapping and remote sensing of the normalized difference vegetation index (NDVI). Previous studies have harnessed EMI data to characterize the impact of soil heterogeneity on crop production, utilizing classification techniques in combination with soil maps and remote sensing data. However, there is further potential in combining proximal sensing, remote sensing, and yield maps in a fully integrated manner. This combination may result in the delineation of agricultural management zones that can account for a more holistic range of factors that affect crop development. This study focuses on a 70-hectare field of the PatchCrop living lab in Tempelberg, Brandenburg. EMI measurements were performed with two systems recording nine different coil separations that provide information on different subsurface depth ranges. Three field campaigns between August 2022 and 2023 have been conducted. The analysis presented here is focused on the 2019 growing season, where 19 NDVI images obtained from high-resolution PlanetScope satellite were available. In addition, historical yield maps from 2011 to 2019 are available. In this study, we used unsupervised classification approaches to derive more holistic management zones using a combination of NDVI maps and normalized EMI maps. The results of clustering are compared with yield maps to assess the efficacy of the derived management zones.

Keywords electromagnetic induction, normalized difference vegetation index

Poster Presentation

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Linking electromagnetic induction data to soil properties at field scales aided by neural network clustering

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Abstract

The mapping of soil properties, such as soil texture, at the field scale is important in the context of national agricultural planning/policy and precision agriculture. Electromagnetic Induction (EMI) surveys are commonly used to measure soil apparent electrical conductivity and can provide valuable insights into such subsurface properties. Multi-receiver or multi-frequency instruments provide a vertical distribution of apparent conductivity beneath the instrument, while the mobility of such instruments allows for spatial coverage. Clustering is the grouping together of similar multi-dimensional data, such as the processed EMI data over a field. A neural network clustering process, where the number of clusters can be objectively determined, results in a set of one-dimensional apparent electrical conductivity cluster centers, which are representative of the entire three-dimensional dataset. These cluster centers are used to guide inversions of apparent conductivity data to give an estimate of the true electrical conductivity distribution at a site. The method is applied to two sites and the results demonstrate a correlation between (true) electrical conductivity with sampled soil texture which is superior to correlations where no clustering is included. The method has the potential to be developed further, with the aim of improving the prediction of soil properties at cluster scale, such as texture, from EMI data. A particularly important conclusion from this initial study is that EMI data should be acquired prior to a focused soil sampling campaign to calibrate the electrical conductivity – soil property correlations.

Keywords EMI, mapping, soil texture, clustering, machine learning, field experiment

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Monitoring soil compaction during a controlled irrigation experiment using multiple hydrogeophysical data

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Abstract

Characterizing the spatio-temporal dynamics of water flow in compacted soils poses a significant scientific challenge. Indeed, soil compaction resulting from inappropriate agricultural practices impacts not only the ecological functions of the soil, but also decreases the water-use efficiency of plants by reducing porosity and increasing water loss through superficial runoff and enhanced evaporation. Recognizing these issues in parallel to the demands to mitigate water quantity in irrigated farming underscores the major socio-economic impacts and the importance of addressing soil compaction for sustainable water management in agriculture.

Here we present a controlled infiltration test on a site with different levels of experimental compaction, which was monitored using both electrical resistivity tomography (ERT, 2d and 3d) and frequency domain reflectometry (FDR) sensors. Furthermore, we want to show how a well-designed ERT measurement scheme which fully exploits borehole and surface electrodes can improve the information quality conveyed by the acquired datasets and, coupled with an accurate error analysis, processing and timelapse-inversion, could delineate distinct infiltration fronts with respect to the soil compaction level. To infer the key system parameters controlling the irrigation infiltration, observations will be fused into a coupled hydrolo-geophysical model using a surface-subsurface water flow scheme.

Keywords ERT, soil compaction, plant water use, field experiment, coupled inversion

Poster Presentation

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Agrogeophysical modelling of managed grasslands

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Abstract

Geophysical methods help understanding soil processes and properties at management scales beyond what is possible with traditional monitoring techniques such as soil sampling. In managed grasslands, geophysical methods can assist for field-scale characterization of soil compaction patterns produced by grazing animals affecting soil structure, soil water and nitrogen dynamics (impacted by cattle urination). However, the application of geophysical methods is typically focused on soil bulk properties or moisture mapping and further assessment of soil functioning is often uninvestigated. In this study, we explore how integrated modelling of grazing patterns, soil structure dynamics, soil processes and related electromagnetic induction (EMI) data may provide valuable insights of nitrous oxide (N_2O) emissions in managed grasslands. This is achieved by using EMI data to constrain soil structure dynamics in an agroecosystem modelling framework, ultimately allowing to make predictions of key soil functions. This approach was tested using EMI data and management information from a dairy farm in central Ireland. The EMI data suggests that N_2O emissions from compacted zones (occupying about 3-25% of the total area of the studied paddocks) are 2.5 higher than those from non-compacted zones. This is consistent with profile-scale studies reported in the literature for compacted grasslands. Linking agricultural management and geophysical data (through agroecosystem modelling) may offer new means for large-scale and long-term testing and monitoring of the environmental impacts of management for different agricultural systems.

Keywords EMI, mapping, soil compaction, soil functioning, N2O emissions, agroecosystem modeling, field experiment

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