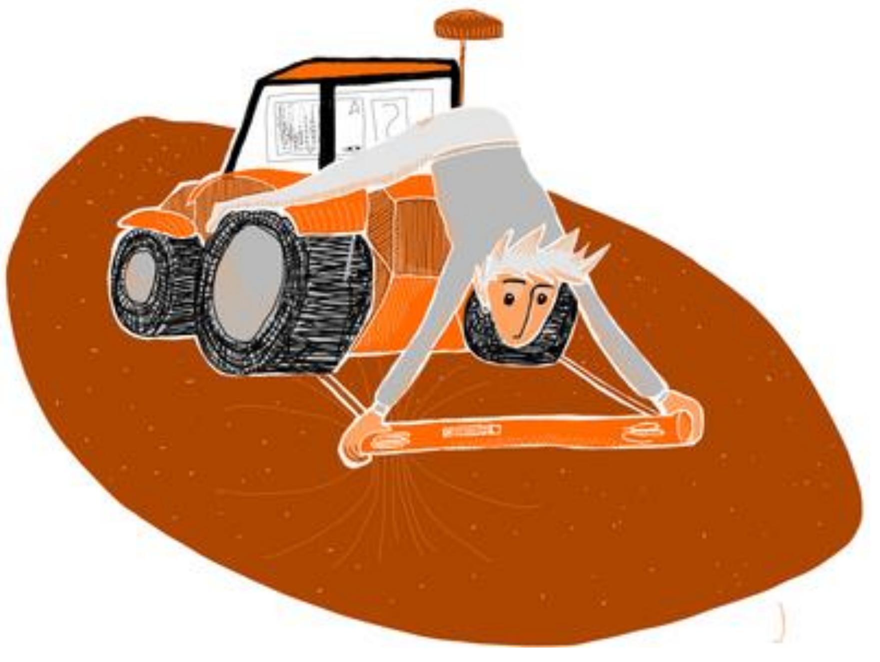
Agriculture and Geophysics: an Electrical Meeting!



Seminar: Friday March 11th, 2022, 8:30 - 18:00

Venue: Palace of the Academies
Stevinzaal and Troonzaal
Palais des Académies
Rue Ducale 1
1000 Brussels, Belgium

Supported by

- Soil Science Society of Belgium (SSSB)
- ENVITAM doctoral school

Meeting agenda

9:00 – 10:00	**Oral Block I: Conveners Ellen Van De Vijver and Christian Von Hebel**
9:00	Evaluating VNIR Spectroscopy, Electromagnetic Induction and Gamma Spectrometry to Predict Soil Properties at Landscape Scale - *Steigerwald et al.*
9:15	Large Scale EMI Survey Linking Electrical Conductivity to Soil Type Properties using Machine Learning Classification Methods - *O'Leary et al.* (invited)
9:30	Using Geophysical Sensors to Map and Improve the Characterization of Peatlands in Denmark - *Adetsu et al.*
9:45	Mapping of Agricultural Subsurface Drainage Systems Using Proximal and Remote Sensors - *Koganti et al.* (invited)

10:00 – 11:00	**Poster session (details on next page)**

11:00 – 12:15	**Oral Block II: Conveners Sarah Garré and Alejandro Romero-Ruiz**
11:00	Sensing of Roots at the Field Scale Using Spectral Electrical Impedance Tomography - *Michels et al.*
11:15	Spectral Induced Polarization Characterization of Artificial Soils with Varying Water Saturation, Salinity and Clay Content - *Iván et al.*
11:30	Electrical Resistivity Tomography as a Monitoring Tool for Rain-Fed Agricultural Hydrodynamics in Southern African Alfisols - *Swift et al.* (invited)
11:45	Cosmic-ray Neutron Sensing in Support of Precision Irrigation or: How a Fairly Simple Question Yields a Puzzling Answer - *Brogi et al.* (invited)
12:00	Electrical Resistivity Tomography Applications for Precision Irrigation Management - *Vanella et al.* (invited)

13:00 – 16:30	**Hackathon (details on next page)**

Meeting agenda

10:00 – 10:45	**Posters**
	Joint Inversion Approach for Soil Compaction Characterization - *Carrera et al.*
	Modeling Soil Structure Spatio-Temporal Dynamics and Geophysical Signatures of Compacted Soils - *Romero-Ruiz et al.*
	EMI Characterization In Mountain Catchments: Multi-Frequency versus Multi-Coil Inversion Using EMagPy - *Blanchy et al.*
	The Potential of Geophysics for Field Phenotyping - *Garré et al.*

13:00 – 18:00	Interactive session hackathon Conveners Guillaume Blanchy and Benjamin Mary
	Start: a quick overview of CAGS
	Phase 1: Idea generation to answer the challenges
	Phase 2: Idea development
	Phase 3: Idea implementation
	Phase 4: pitch of team results to an expert panel and the public
16:30 – 18:00	Teams pitch their work

Evaluating VNIR Spectroscopy, Electromagnetic Induction and Gamma Spectrometry to Predict Soil Properties at Landscape Scale

Sophie Steigerwald[1]*, Ulrike Werban[1], Marco Pohle[1], Thorsten Behrens[2], and Felix Thomas[1]
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Soils are the foundation of agricultural production. To maintain it farmers and decision-makers need to know the state of our soils. This requires suitable indicators at a suitable scale and resolution. A key indicator for soil health is Soil organic matter and other soil properties like nitrogen or clay content can refine the picture even more.

In digital soil mapping a variety of sensors are available to derive input data for the actual mapping process. In general sensor choice depends on target variable and site characteristics but no clear recommendations exist. Therefore, we carried out a landscape scale study on agricultural land in the Northwestern German plain with three sensor types to better understand in which scenarios they are reasonable to use. On-site measurements were carried out using gamma spectrometry and electromagnetic induction (EMI). Soil samples were collected and VNIR spectra were captured in the laboratory using a Vis and a NIR MEMS sensor.

The approach of the analysis is explorative: For the spectral data a range of soil properties (C, N, pH, clay and silt) is screened for model performance. Preliminary results show that NIR data can predict C and clay with reasonable accuracy. Secondly correlation of spectral, gamma ray and EMI data should be studied and lastly models should be boosted with gamma ray and EMI data. This will help to study the correlation of different sensor data types and contextualize our findings with environmental covariates of the study site to derive recommendations for sensor choice.

Large Scale EMI Survey Linking Electrical Conductivity to Soil Type Properties using Machine Learning Classification Methods

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Traditionally mapping of soil properties, soil type and soil condition has been done by in-situ augur or core samples. This method is slow, costly, and subjective depending on the experience of the operator and the requirements of the survey. Often these sample locations are randomly selected, or limited to 1 per unit area, from within a site which may not fully represent the spatial variability of the soil property of interest. Furthermore, it is difficult to create maps from point samples as boundaries are rarely sampled and must be inferred.

A CMD Mini-Explorer 6L instrument has been used to survey a farm (circa. 32 hectares) in the summer of 2021. This instrument provides 6 layers of apparent conductivity measurements reaching a depth of approx. 2.5m. These six 1m x 1m gridded maps of electrical conductivity act as input to a machine learning and GIS based analysis. In this case, we attempt to link these data layers to a national soil classification scheme using surveyed in-situ augur points where the soil classifications present are well understood. We use modern machine learning methods to identify the pattern of layered electrical conductivity associated with each soil classification present at an auger site. This pattern can then be used to predict the soil class in other areas on the farm resulting in a high-resolution map of soil type across the farm which could be used for precision agriculture applications such as fertilizer management, crop rotation or drainage planning.

Using Geophysical Sensors to Map and Improve the Characterization of Peatlands in Denmark

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Natural peatlands represent important ecosystems. Global peat coverage is estimated at 3% out of the total land area, where one-third of global soil carbon (C) is contained. Additionally, the capability of peatlands to either sequester (sink) or release C (source) to the atmosphere renders them important under a changing climate. However, historical, and current anthropogenic alterations such as their excavation for fuel, and drainage for agriculture have resulted in the reduction of global peatland coverage. Following national commitments to reduce the Danish CO2 emissions by 70% in 2030 has made it necessary to rewet the majority of Danish agricultural peatlands and hence, map and quantify CO2 emissions from peatlands. To achieve this, characterization of the present status and extent of peatlands in Demark warrants the acquisition of detailed information of peat properties mainly thickness, density, and type. Nevertheless, the conventional approach for surveying peatlands is not only laborious, time-consuming and invasive but may result in large measurement uncertainties due to the obstruction of probes by artefacts like buried drainage pipes. Geophysical sensors may provide a rapid, cost-effective and non-invasive means for improved mapping and characterization of peatlands. Here, we present preliminary results from a selected peatland in Denmark where we combine gamma radiometric and electromagnetic induction techniques to augment the manually measured thickness at a few discrete locations to map peat thickness. The three-dimensional characterization of peat extent will improve our knowledge on C stock and facilitate policy advising to decide on different management scenarios to prevent their further decline.

Mapping of Agricultural Subsurface Drainage Systems Using Proximal and Remote Sensors

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Installation of agricultural subsurface drainage systems is a widely adopted practice to lower the water table, improve the timeliness of field operations and mitigate soil salinization for increasing crop yields. Though they provide many agronomic, economic, and environmental benefits, the drainage pipes act as shortened pathways for solute transport and increase the eutrophication risk of the surface water bodies; thereby affecting the aquatic ecosystem. Hence, knowledge of the location of these installations is important for hydrological modeling to plan effective mitigation strategies. In addition, it is also crucial for initiating repairs or for the periodical reinstallation of drain lines. Nevertheless, this information is often poorly documented or non-existing. The conventional methods for drainage mapping are labor-intensive, time-consuming, and invasive, thus carrying an added risk of severing the drainage pipes. Non-destructive soil and crop sensing techniques might provide an effective alternative solution. In this study, we tested ground-penetrating radar (working in both time and frequency domains), a novel vector magnetic gradiometer, and unmanned aerial vehicles equipped with visible, multispectral, and thermal infrared cameras at study sites in Denmark and Midwest USA. Amongst the proximal sensors, ground-penetrating radar proved mainly successful when the average soil electrical conductivity was less than 20 mS/m. Amongst the different cameras, thermal imagery proved superior given the relative humidity was lower than 60%. Hence, the complementary use of both techniques is optimal for efficient mapping of the drainage systems. Further, guidelines were proposed on suitable timing for their deployment to maximize the success rate.

Sensing of Winterwheat Root-systems at the Field Scale Using Spectral Electrical Impedance Tomography

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Spectral electrical impedance tomography (sEIT) is a geoelectrical, non-invasive method that is used in geophysical applications to derive information about the subsurface complex electrical resistivity. Using an alternating current at a broad frequency range, the method does not only give insight about the conductive properties of the investigated material, but also measures the capacitive behavior, therefore capturing the polarizability of the subsurface.

Past research suggests that root systems do show polarization processes at cell-cell and cell-soil-interfaces that can be captured by sEIT. In the presented work, a permanent sEIT measurement-system was installed at a winterwheat field and continuous measurements were performed with the aim to monitor the root growth during a whole vegetation period in spring and summer of 2021. Remote control of the device and automatic data transfer to the university server was realized to perform quality checks on the data during the measurement period and allow fixing of the system in case of failure.

The collected data was analyzed with regard to the temporal evolution of the spectral behavior of the complex resistivity and results suggest that sEIT is able to capture root growth processes and possibly even the activity of the root system in the subsurface. However, environmental influences can disturb the correct interpretation of the sEIT responses in terms of root extent and activity and need to be recorded as complementary data to prevent analysis errors.

Spectral Induced Polarization Characterization of Artificial Soils with Varying Water Saturation, Salinity and Clay Content

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The structure and function of dryland agricultural and natural ecosystems is dramatically determined by water availability. Geoelectrical methods provide a suite of tools to image the subsurface and monitor its water dynamics. However, describing the combined effect of soil water content, salinity and soil composition remains a challenging issue. Recent studies demonstrated the sensitivity of the IP method to water content (Breede et al. 2012, Kremer et al. 2016), to clay content (Osterman et al. 2019) and salinity (Grunat 2013, Mendieta et al. 2021). Grunat (2013) noted that the quadrature conductivity is weakly dependent on the pore fluid salinity, thus, it might be used to separate between pore water salinity and water content. Here, in a laboratory experiment series, we conducted spectral measurements on small sample holders to observe under controlled conditions how the IP response is affected by water saturation and salinity. Sand-clay mixtures were created from very fine-coarse sand and clay powder (Ca-montmorillonite) which were mixed during multiple dry-wet mixing cycles with gradually growing clay content (0-8 %). The decreasing water content was obtained by air injection with growing pressure (0,05-2,5 bar). As a second phase, the salinity was increased (up to the pore water electrical conductivity of 7000 µS/cm). Regression analysis is carried out on the obtained dataset to calibrate the sensitivity of the complex resistivity to the changing parameters at different frequencies. Based on the preliminary results, the method shows the potential for the construction of a pedophysical model, allowing the field application for water content monitoring in arid areas.

Electrical Resistivity Tomography as a Monitoring Tool for Rain-Fed Agricultural Hydrodynamics in Southern African Alfisols

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Assessment of the dependency of crops on soil water content necessitates a detailed understanding of soil hydrodynamics. Rapid changes in soil moisture coupled with spatial heterogeneities mean it is critical to monitor these processes in high resolution, both spatial and temporal. Geophysical techniques - and Electrical Resistivity Tomography (ERT) in particular - are ideally suited to providing required spatial information, contributing additional information when compared with point sensors alone. Recent developments in ERT monitoring mean that we are now able to collect data at the rate required to enable us to image these often rapidly-evolving processes.

We use geoelectrical monitoring data, collected using PRIME - the low-cost, low-power, ERT monitoring instrument developed by the British Geological Survey - to better understand the hydrodynamic regimes associated with two agricultural techniques in southern Africa. By utilising long time series of frequent ERT measurements, combined with a high density of point sensors, and additional lab measurements, we have been able to study the differences between conservation agriculture and conventional agriculture in Alfisols at observatories in Malawi, Zambia, and Zimbabwe.

We investigate the differences in hydrodynamic characteristics between the two agricultural techniques, but also study the spatial variability of the geoelectrical response of soils with similar water contents by utilising the high quantity of co-located point sensors. In addition to this, we explore the problems around scaling ERT data between small sized laboratory samples, and field data collected from the three observatories.

Cosmic-ray Neutron Sensing in Support of Precision Irrigation or: How a Fairly Simple Question Yields a Puzzling Answer

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The agricultural sector is increasingly reliant on water availability, especially given expected increase of agricultural droughts related to climate change. Thus, improved soil moisture (SM) monitoring tools are needed to support more efficient water management strategies such as precision irrigation. A novel and non-invasive method is cosmic-ray neutron sensing (CRNS). It is characterized by a large footprint (~240m) and relies on the negative correlation between fast neutrons originating from cosmic radiation and SM. Despite promising results in the monitoring of SM dynamics and patterns, only a few studies explored the use of CRNS for irrigation management. In this study, two apple orchards of ~1.2 ha located in the Pinios Hydrological Observatory (Greece) were provided with CRNS probes. These were supported by extensive monitoring of SM and climate data in the context of the H2020 ATLAS project. In capturing irrigation events, the agreement between the CRNS and the validation measurements depended largely on a) the timing of irrigation, b) the CRNS calibration strategy, c) precipitation, and d) the management of the surrounding fields. In parallel, we performed neutron transport simulations of multiple scenarios with variable irrigated area and soil moisture by using the URANOS model. This allowed the study of how the surrounding environment influences the effectiveness of a CRNS sensor when its footprint is larger than the area of interest. This combination of simulations and experiments is providing key insights on how CRNS methods can move from a proof o concept to a relevant tool in actual precision irrigation scenarios.

Electrical Resistivity Tomography Applications for Precision Irrigation Management

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Geophysical monitoring based on direct current methods can help to explore the soil water content variability at the soil-plant interface aiming at providing useful insights for supporting the precision irrigation management.

The general purpose of this contribution is to promote the potential of integrating geo-electrical imaging with multiple sources of ancillary data (from stem water potential to point-based soil moisture information) for capturing and characterizing the soil-water dynamics that are active within the soil-plant-atmosphere continuum of agricultural system under different soil type/management and irrigation strategies.

Real case study applications based on the use of electrical resistivity imaging (ERI, or electrical resistivity tomography, ERT) techniques under micro-irrigated heterogeneous crops (almond and citrus orchards), located in similar semi-arid Mediterranean climate conditions, will be discussed. Specifically, the preliminary findings from two case studies conducted in almond orchards, located in California (USA) and characterized by site-specific soil conditions, also treated with organic soil amendments; and a case study carried out in a citrus orchard supplied by micro-irrigation systems under different level of water deficit application will be showed (Vanella et al. 2021).

Joint Inversion Approach for Soil Compaction Characterization

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Soil compaction due to modern agricultural machinery weight and repeated tillage operations is one of the major threats to arable lands. Compaction adversely affects soil quality and ecosystem, resulting in significant ecological and economic damage to farmers and society, even because of its persistent nature. Traditional methods for soil structure characterization are limited by both their own destructive and punctual nature. Therefore, the purpose of this work was to explore the potentiality to combine different non-destructive geophysical techniques with a joint inversion approach to study the complexity of the soil structure as related to soil compaction. The experiment was conducted on a silt-loam arable land belonging to 'Lucio Toniolo' Padova University experimental farm. Electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) soundings were coupled to characterize the subsoil structure and estimate, in a non-invasive way, the liquid water and air fractions in compacted and non-compacted systems. The joint inversion of ERT and SRT dataset involved a representative pedophysical model allowing to quantitatively estimate the volume of soil affected by compaction. To evaluate the reliability of the obtained results, geophysical data were compared with traditional direct measurements of soil volumetric water content, bulk density and penetration resistance. Preliminary results showed that the proposed pedophysical joint inversion (PedJI) appears a promising tool for spatio-temporal evaluation of soil structure evolution.

Modeling Soil Structure Spatio-Temporal Dynamics and Geophysical Signatures of Compacted Soils

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Soil compaction is a form of soil degradation that adversely impacts soil mechanical and hydraulic properties, and is often linked to increases in greenhouse gases (GHG) emissions. However, we lack a quantitative understanding of the extent and environmental impacts of soil compaction. This is partly due to gaps in knowledge of spatial and temporal dynamics of soil properties in compacted soils. To address this challenge, we propose a framework that accounts for soil structural dynamics in soil-process modeling and predicts the associated geophysical signatures. We used this framework to discuss environmental impacts of soil compaction by animal treading and illustrate potential ways of monitoring grassland systems with geophysical methods. We modeled random movement of cattle in a confined area and used a rheology model based on Bingham's law to infer compaction-induced changes in soil bulk density and saturated hydraulic conductivity. This compaction model was integrated in an agro-ecosystems model to simulate compaction impacts in soil moisture dynamics, plant growth and GHG emissions. The simulated soil moistures were fed to pedophysical models to predict electrical resistivity and seismic properties at selected states (e.g., dry vs wet). In agreement with literature values, we predict a decrease in electrical resistivity of 10% and an increase of P-wave velocity of 15% in highly compacted zones. Similarly, compacted zones present an increase of up to 60% in N20 emissions and a reduction of 15% in yield. This modeling framework may help assessing the environmental impact of soil compaction, improve our monitoring capabilities and suggest management strategies for ameliorating this impact.

EMI Characterization in Mountain Catchments: Multi-Frequency versus Multi-Coil Inversion Using EMagPy

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Advanced modeling of hydrological processes in mountain catchments requires accurate characterization of the shallow subsurface, and in particular the depth to the soil/bedrock interface. Frequency domain electromagnetic induction (EMI) methods are well suited to this challenge as they have short acquisition times and do not require direct coupling with the ground; hence being highly productive. Moreover, EMI inversion is increasingly used to quantitatively resolve both lateral and vertical changes. These quantitative models can then be used to inform several properties relevant for hydrological modelling.

In this work the open-source software EMagPy is used to compare between EMI data collected with a multi-coil device (i.e., a single frequency device with multiple receiver coils) and a multi-frequency device (i.e., a single inter-coil distance and multiple frequencies). The latter instrument is easier to handle, and thus it is potentially more suitable for the rugged topography of mountain slopes. However, it is important to compare the value of information (e.g., sensitivity patterns and data quality) obtained from both instruments.

To begin with, the performance of both devices is assessed using synthetic modeling. Following from this the analysis is focused on two mountainous catchments: one located in the Alpine region above 2000 m a.s.l., the other in a Mediterranean catchment in Southern Italy. Both sites have differing geological and hydrological conditions and provide a useful comparison to determine the suitability of multi-frequency and multi-coil devices and highlight necessary considerations of EMI acquisition.

The Potential of Geophysics for Field Phenotyping

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A key pathway to maximize yields in a sustainable way is to select and grow crops that are optimally adapted to their environment. Plant performance is controlled by characteristics or ‘traits’ which are partially genetically determined. Nevertheless, cultivars with the same genome express different appearances in different environments and under different management practices. Phenotyping has therefore become the foundation of breeding practice. While above-ground traits are already extensively studied, phenotyping the below-ground traits is less straightforward, due to the opaque nature of soil. Non-invasive geophysical techniques to study the root system and soil profile have substantially advanced in recent years. Their biggest potential lies in their indirect monitoring of water depletion or other changes in the root zone. Timelapse electrical resistivity tomography (ERT) is particularly promising as part of a comprehensive field phenotyping installation. Nevertheless, it remains unclear whether the technique can deliver the resolution, sensitivity and accuracy to capture the subtle, but decisive differences between cultivars.

In this study, we simulated a range of possible continuous ERT measurement setups and tested them for their potential to distinguish between small differences in below-ground dynamic plant traits of grass. Using a Bayesian Evidential Learning framework (BEL1D), we assess the sensitivity of different electrode layouts in recovering plant induced soil drying patterns. This approach also incorporates the uncertainty in the pedophysical relationships and soil properties often encountered in the field. The technique is currently being implemented in a unique field phenotyping installation as a part of the European phenotyping network EMPHASIS.