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Editorial: Digital soil mapping using electromagnetic sensors

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Editorial on the Research Topic
Digital soil mapping using electromagnetic sensors

Recent technological advances have led to the development of new instruments that measure different parts of the electromagnetic spectrum. In addition, significant cost reduction, and increased robustness are seen for the existing ones making them more affordable and easier to use (1, 2). Proximal soil sensors are increasingly being adopted to augment labor- and cost-intensive field and laboratory procedures by allowing rapid estimation and high-resolution mapping of soil properties via proxy measurements. Information collected with these soil sensors supports soil resource management, which is crucial to meet the growing population demand sustainably. In short, proximal soil sensing offers the potential for non-invasive soil exploration, whereby near-continuous spatiotemporal information can be collected. Particularly in line with global efforts to preserve and optimize soil health, the relevance of this approach will only increase with time.

As electromagnetic soil sensing is often fragmented across various scientific disciplines and applications this Research Topic aims to bring together cutting-edge and breakthrough research and identify key perspectives in the field. Four papers are combined that topically revolve around:

1. advances in hardware development for ground-based and airborne electromagnetic soil sensing;
2. modelling procedures aimed at resolving the distribution and variation of soil properties in the shallow subsurface;
3. advancing interpretative frameworks for relating electromagnetic properties to natural and anthropogenic subsurface targets;
4. multi-scale and multi-sensor data analysis;
5. quantitative integration of invasive and non-invasive soil information.

While all contributions under this Research Topic employed electrical conductivity (EC) measurements by either electromagnetic induction (EMI) or galvanic techniques in field-based studies, they address a wide variety of objectives. These are listed in chronological order depending on the publication date. We refer to the apparent electrical conductivity data, which is outputted by these instruments as EC_a, and depth-specific electrical conductivity estimates after an inversion routine as EC_t.

In the first article, Deragon et al. improved the regional peat thickness map at the field scale in a digital soil mapping approach by using the EC_a data collected by a galvanic sensor, digital elevation model and the regional map itself as covariates. They tested ordinary kriging, multiple linear regression, regression kriging and machine learning models (Cubist, Random forests and Support vector machines). The best predictions of peat thickness were observed by ordinary kriging of the sampled data, followed by multiple linear regression kriging and support vector regression, both using the regional map as an additional covariate. The prediction error (RMSE) of the best models at the field scale is twice as low compared to the regional map. This demonstrates the significant value added by proximal soil sensing and how the existing coarse-resolution maps can be leveraged to generate fine-resolution maps at the field scale. This article relates to topical points 2, 3 and 4.

In the second article, De Carlo et al. showed an efficient way to combine the accuracy of the point-scale soil moisture measurements done by invasive sampling and the spatial coverage of EMI-based EC data to create soil moisture maps in a vineyard. Sampling locations were selected based on EC zoning. A freeware code licensed from USGS, *MoisturEC* (3) was used to integrate the data, which allowed more accurate estimation of the moisture distribution along with the error quantification compared to moisture predictions by using EC_a or EC_t. This article mainly relates to topical points 4 and 5.

In the third article, O'Leary et al. used a neural network based clustering approach (self-organizing maps) to optimize the choice of initial model for inverting ECa data from an EMI sensor. Moreover, they presented an objective methodology called multi-cluster average standard deviation (MCASD) to select the appropriate number of clusters. The EC_t data modelled based on this approach correlated well with the soil properties compared to inverted EC_t from a uniform initial model. They also emphasized how the clustering approach can aid sensor-guided soil sampling, highlighting the benefits of performing sensor surveys first to inform and optimize the sampling strategy. The article mainly relates to topical points 2 and 3.

In the fourth article, Blanchy et al. compared and contrasted the efficacies between two different types of EMI instruments, one working on multi-frequency and the other on single frequency but with multiple receiver coils at different distances from the transmitter coil. The authors presented both synthetic modelling and a field-based study, demonstrating that both instrument types resolve the conductivity structure equally well and exhibit similar noise levels. Hence, the multi-frequency instrument can be better suited for difficult-to-measure terrains from a practical standpoint. However, they have a few important limitations that need to be acknowledged: i) shallower sensitivity patterns in highly conductive grounds (i.e., 150 mS/m) thereby limiting the depth of exploration and ii) substantial overlap in sensitivities in low conductive environments, making it challenging to resolve the vertical EC variability (i.e., EC_t). The article relates to topical points 1 and 2.

We anticipate the following exciting avenues for soil sensing, with a focus on soil health measurement and monitoring, in the near future: i) the adoption of novel on-the-go sensing technologies, such as gamma-ray spectroscopy, ii) adapting traditional lab-based infrared spectroscopy more suitable for in-field use, iii) further development of real-time data processing algorithms and AI techniques to enhance predictive capabilities and data interpretation of sensors, iv) the integration of different sensors into a multi-sensor platform, along with improved mobility on unmanned aerial vehicles, and v) further efforts to bridge the gap between proximal and remote sensing of soils.

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TK: Writing – original draft. PD: Writing – review & editing. MF: Writing – review & editing. MK: Writing – review & editing. JT: Writing – review & editing. AC: Writing – review & editing. MG: Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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