A REVIEW OF GEOPHYSICAL APPLICATIONS IN AGRICULTURE AND THEIR POTENTIAL IN VIETNAM

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ABSTRACT: Geophysical methods are effective tools for soil characterization and monitoring because they allow prediction of soil properties from measured geophysical parameters. Despite their notable advantages including rapid data acquisition, large data coverage, high data density and inexpensive survey implementation, the geophysical methods have been getting little attention in Vietnam so far. This article gives an overview of popular geophysical methods being applied in agriculture of several countries in the World to characterize and monitor soil properties. The main applications of each method are summarized and related publications are given for reference. A preliminary experiment of the most popular method, Ground Penetrating Radar, was carried out by the authors to reveal that although geophysical methods are very potential applications in agriculture, a great challenge of applying them in Vietnam is the lack of reliable techniques to accurately infer soil properties from measured geophysical parameters, which can be very noisy and have no explicit relationship with them.

Keywords: *Geophysics, geophysical methods, precision agriculture, soil properties, soil monitoring, soil characterization.*

1. INTRODUCTION

Geophysical methods, traditional tools for studying deep earth properties, in recent years have been actively applied in agriculture to utilize their significant strengths, such as quick measurement, easy deployment, high data density and low operational cost. With the help of geophysical methods, maps of soil properties in vast areas can be created and updated regularly to assist land management, plantation optimization and farm planning. Several techniques for geophysical data analysis have been established and widely applied to determine soil properties (Besson et al., (2013); Blanchy et al., (2020); De Benedetto et al., (2012); Donohue et al., (2013); Jadoon et al., (2015); Grote et al., (2010); Huang et al., (2016); Keller et al., (2017); Moghadas et al., (2019); Wong et al., (2009).

In Vietnam, however, soil properties are still solely measured by sample analyses in laboratories which are time consuming, expensive, and hence leading to sparse data points. Apparently, little attention has been given to geophysical applications in agriculture in spite of their effectiveness. Trung et al., (2008) and Thu et al., (2012) are probably the only two articles found on Vietnamese public domain that tried to use electrical method to predict the high salinity of underground water in a northern Vietnam coastal plain area.

With that background, this article gives an overview of the most common geophysical methods being applied in agriculture over the World and describes a preliminary experiment implemented at Agricultural Academy testing ground aiming to evaluate the potential application of these methods in Vietnamese agriculture.

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2. GEOPHYSICAL METHODS AND THEIR APPLICATIONS IN AGRICULTURE

2.1. Geophysical methods

The applications of geophysical methods in agriculture have been previously described and reviewed by several authors (Romero- Ruiz et al., (2018), (2021); Pradipta et al., (2022)). Table 1, modified from Pradipta et al., (2022), summarizes the most popular methods, their measured physical parameters and the soil properties that can be inferred from them. Related original publications are also given for reference.

Geophysical Methods	Physical parameter	Applications	References
Ground-Penetrating Radar **(GPR)**	Propagation velocity (v) of EM waves	Soil moisture measurement	Zhou et al., (2019); Lu et al., (2017)
		Monitoring SM variabilities	Barca et al., (2019); Zhou et al., (2019); Klotzsche et al., (2018); Jonard et al., (2013); Cavallo et al., (2016)
		Spatial variations of clay content	De Benedetto et al., (2012);
		Identifying the compacted layer	Muñiz et al., (2016); Akinsunmade et al., (2019)
		Delineation of soil and bed rock	Nováková et al., (2013);
		Identifying humous and non-humous layers	Winkelbauer et al., (2011);
Electromagnetic Induction **(EMI)**	Bulk electrical conductivity (σ)	Soil moisture variations	Blanchy et al., (2020); Moghadas et al., (2019);
		Monitoring SM variabilities	Barca et al., (2019); Moghadas et al., (2019);
		Identification of clay, silt, and sand/gravel	Heil et al., (2012); De Benedetto et al., (2012);
		Soil organic matter mapping	Rentschler et al., (2020);
		Soil salinity distribution	Jadoon et al., (2015);
		Detection of soil compaction	Schmäck et al., (2021);
Electrical Resistivity **(ER)**	Resistivity (Ω)	Soil moisture variations	DeJong et al., (2020);
		Identifying root water uptake	Vanella et al., (2018);
		Soil-bed rock delineation	Cheng et al., (2019);
		Identification of compacted zones	Besson et al., (2013);
		Characterization of regolith	Gourdol et al., (2018);

		Soil structural change after compaction	Keller et al., (2017); Besson et al., (2013);
Spectral Gamma	Gamma ray energy (MeV)	Clay content and soil quality	Ameglio, (2018);
		Soil moisture variations	Sunori et al., (2021);
		Soil salinity distribution	Viscarra Rossel et al., (2007);
		Total soil organic carbon and cation exchange capacity	Kassim et al., (2021);
Seismic	seismic velocities (v_p and v_s)	Detection of compacted soil	Romero-Ruiz et al., (2021); Donohue et al., (2013);

2.2. Geophysical applications in agriculture

Ground-Penetrating Radar method

Ground-Penetrating Radar method (GPR) is a method of non-destructive electromagnetic wave reflection, high frequency electromagnetic wave, commonly used for high-resolution near-ground studies. Antennas transmit high-frequency electromagnetic waves from a few tens of MHz to several GHz into the soil, part of the energy reflect back to the antenna at the boundary of the two layers which have different dielectric permeability. The change of electromagnetic wave energy tells the nature of the medium it passes through. GPR method has been widely applied in agriculture to predict soil layers, soil compaction and soil moisture (Muñiz et al., (2016); Akinsunmade et al., (2019); Nováková et al., (2013).

Electromagnetic induction method

Electromagnetic induction (EMI) method measures selected components of an electromagnetic (EM) field forming in the soil by induction caused by an artificial EM field. The characteristics of the induced EM field is linked with the subsurface electrical resistivity. The measured apparent conductivity (ECa) after being corrected gives the soil conductivity vertically at varied depths. The soil conductivity data in turn can be further processed to indicate different soil properties such as the amount and type of clay content, the moisture variations, the bulk density, or the salinity distribution (Huang et al., (2016).

Resistivity method

This method measures soil's resistivity which also dependent on other properties such as porosity, moisture content, structure and architecture of the soil (Samouëlian et al., (2005). For example, the DC resistivity of the soil depends on the mineral salt concentration of the water in the pore or the total dissolved mineralization, so the method can be used to evaluate soil salinity or to define the salty – pale boundary of the aquifer (Romero- Ruiz et al., (2018).

Gamma method

Gamma ray emission originates from spontaneous radioactive decay and it does not depend on any other objective or subjective case. The activity of radioactive isotopes depends on soil geochemistry so the gamma activity can be used to predict organic content, clay content, as well as other geochemical soil elements (Viscarra et al., (2007).

Seismic method

The seismic method measures the seismic wave and their propagation velocities through the subsurface from the source to receivers. Since seismic wave partly reflects at each soil boundary, the seismic method can be used to map subsurface soil boundaries. It can also be used to predict the soil porosity and density which control the propagation velocities. The main disadvantage of seismic method is that it is expensive and requires bulky equipment to be implemented. Although not as popular in soil monitoring as other geophysical methods, in certain circumstance, the seismic geophysical method still can be applied to provide valuable information on soil properties (Pradipta et al., (2022).

3. EXPERIMENTAL APPLICATION OF GEOPHYSICAL METHODS FOR SOIL PROPERTY PREDICTION IN VIETNAM

Acknowledging the importance of geophysical applications in soil characterization, the Ministry of Science and Technology has funded an experimental project to predict soil properties from geophysical parameters using technology of industry 4.0. As a part of the project, a GPR survey line was carried out in the Agricultural Academy experimental field (Figure 1a) and the acquired data have been processed by filtering the noise but apparently the resulted cross section is still noisy (Figure 1b). In this section, the horizontal axis is the distance in meters, the vertical axis is time on one side and depth on the other side. Three soil boundaries can be interpreted as colored lines in the section. The first boundary is sub-horizontal and has a depth of about 30 cm, the shallowest part of the boundary is about 25 cm while the deepest part is about 35 cm. The soil layer between the first and the second boundaries has an average thickness of 20 cm with the thinnest interval of 15 cm and the thickest interval of 25 cm. The third layer has the thickness ranged from 15cm to 40cm. Below the third boundary, some coherent features can still be observed but they are difficult to interpret due to excessive noise level.

Other soil properties besides the boundaries cannot be calculated at this stage of the project because they require modeling of GPR data together with actual lab measured data points for calibration (Winkelbauer et al., (2011), Zhou et al., (2019), Barca et al. (2019), that are not currently available.

It is worth noting here that geophysical parameters and soil properties are interdependent but inexplicitly. Therefore, careful data processing techniques and sophisticate modeling algorithms are crucial to receive accurate information of soil characteristics. This is probably the main reason why the geophysical methods have not been applied for soil characterization and monitoring in Vietnam.

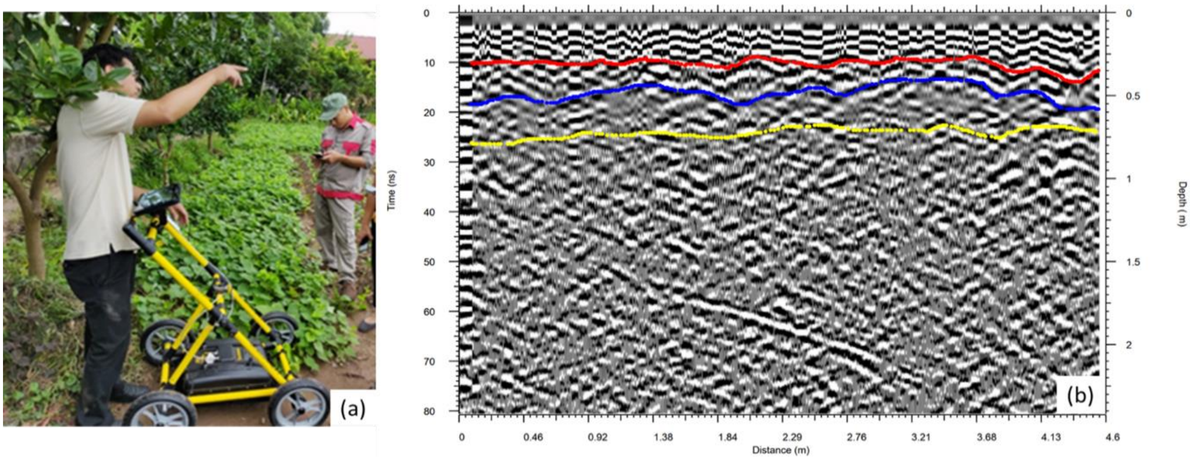

Figure 1. A trial application of GPR to predict subsurface soil layers implemented in the experimental field of the Agricultural Academy using Geoscaner equipment (a) and the resulted cross section with interpretation (b).

4. SUMMARY AND CONCLUSION

The review has demonstrated that geophysical methods are useful tools for soil characterization and monitoring. They have proven effective in soil property studies thanks to the several advantages, including rapid data acquisition, high data density, large data coverage with inexpensive implementation.

The main challenge is that soil properties cannot be directly indicated by measured geophysical parameters, instead they are inferred from them by sophisticate data analysis and data modeling techniques, that are not readily available in Vietnam. This is probably the main reason why geophysical methods have not been applied for agricultural purposes in the country so far.

A preliminary experiment of GPR method reveals that the data can be useful but need a lot of processing effort to reduce the great amount of contaminated noise. A combination of varied suitable geophysical methods and the use of industry 4.0 technologies can be a solution to provide more reliable information about soil properties (Sunori et al., (2021).

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REFERENCES

1. Akinsunmade, A.; Tomecka-Suchoń, S.; Pysz, P., 2019, Correlation between agrotechnical properties of selected soil types and corresponding GPR response. *Acta Geophys.*, *67*, 1913–1919.
2. Ameglio, L., 2018, June. Review of developments in airborne geophysics and geomatics to map variability of soil properties. *In International Conference on Precision Agriculture, Canada. XIV.*
3. Barca, E., De Benedetto, D. and Stellacci, A.M., 2019. Contribution of EMI and GPR proximal sensing data in soil water content assessment by using linear mixed effects models and geostatistical approaches. *Geoderma*, *343*, pp.280-293.
4. Besson, A.; Séger, M.; Giot, G.; Cousin, I., 2013, Identifying the characteristic scales of soil structural recovery after compaction from three in-field methods of monitoring. *Geoderma*, *204–205*, 130–139.
5. Blanchy, G.; Watts, C.W.; Richards, J.; Bussell, J.; Huntenburg, K.; Sparkes, D.L.; Stalham, M.; Hawkesford, M.J.; Whalley, W.R.; Binley, A., 2020, Time-lapse geophysical assessment of agricultural practices on soil moisture dynamics. *Vadose Zone J. 19,* e20080.
6. Cavallo, G., De Benedetto, D., Castrignanò, A., Quarto, R., Vonella, A.V. and Buttafuoco, G., 2016. Use of geophysical data for assessing 3D soil variation in a durum wheat field and their association with crop yield. *Biosystems Engineering*, *152*, pp.28-40.
7. Cheng, Q.; Tao, M.; Chen, X.; Binley, A., 2019, Evaluation of electrical resistivity tomography (ERT) for mapping the soil–rock interface in karstic environments. *Environ. Earth Sci.*, *78*, 1–14
8. De Benedetto, D.; Castrignano, A.; Sollitto, D.; Modugno, F.; Buttafuoco, G.; Papa, G.L., 2012, Integrating geophysical and geostatistical techniques to map the spatial variation of clay. *Geoderma*, *171–172*, 53–63
9. De Jong, S.M.; Heijenk, R.A.; Nijland, W.; Van Der Meijde, M., 2020, Monitoring Soil Moisture Dynamics Using Electrical Resistivity Tomography under Homogeneous Field Conditions. *Sensors*, *20*, 5313.
10. Donohue, S., Forristal., D., & Donohue, L. A. (2013). Detection of soil compaction using seismic surface waves. Soil and Tillage Research, 128, 54–60.
11. Jadoon, K.Z.; Moghadas, D.; Jadoon, A.; Missimer, T.M.; Al-Mashharawi, S.K.; McCabe, M.F., 2015, Estimation of soil salinity in a drip irrigation system by using joint inversion of multicoil electromagnetic induction measurements. *Water Resour. Res.*, *51*, 3490–3504
12. Jonard, F., Mahmoudzadeh, M., Roisin, C., Weihermüller, L., André, F., Minet, J., Vereecken, H. and Lambot, S., 2013. Characterization of tillage effects on the spatial variation of soil properties using ground-penetrating radar and electromagnetic induction. *Geoderma*, *207*, pp.310-322.
13. Grote, K., Anger, C., Kelly, B., Hubbard, S. and Rubin, Y., 2010. Characterization of soil water content variability and soil texture using GPR groundwave techniques. *Journal of Environmental & Engineering Geophysics*, *15*(3), pp.93-110.
14. Gourdol, L.; Clément, R.; Juilleret, J.; Pfister, L.; Hissler, C., 2018, Large-scale ERT surveys for investigating shallow regolith properties and architecture. *Hydrol. Earth Syst. Sci. Discuss.*, 1–39.
15. Heil, K.; Schmidhalter, U., 2012, Characterization of soil texture variability using the apparent soil electrical conductivity at a highly variable site. *Comput. Geosci.*, *39*, 98–110.
16. Huang J., Scudiero H., Bagtang M., Corwin D.L., Triantaflis J., 2016, Monitoring scale specific and temporal variation in electromagnetic conductivity images, s. Irrig. Sci., 34, 187–200.

17. Kassim, A.M., Nawar, S. and Mouazen, A.M., 2021. Potential of on-the-go gamma-ray spectrometry for estimation and management of soil potassium site specifically. *Sustainability*, *13*(2), p.661.
18. Keller, T.; Colombi, T.; Ruiz, S.; Manalili, M.P.; Rek, J.; Stadelmann, V.; Wunderli, H.; Breitenstein, D.; Reiser, R.; Oberholzer, H.; 2017, Long-Term Soil Structure Observatory for Monitoring Post-Compaction Evolution of Soil Structure. *Vadose Zone J.*, *16*, 1–16.
19. Klotzsche, A., Jonard, F., Looms, M.C., van der Kruk, J. and Huisman, J.A., 2018. Measuring soil water content with ground penetrating radar: A decade of progress. *Vadose Zone Journal*, *17*(1), pp.1-9.
20. Lu, Y.; Song, W.; Lu, J.; Wang, X.; Tan, Y., 2017, An Examination of Soil Moisture Estimation Using Ground Penetrating Radar in Desert Steppe. *Water*, *9*, 521
21. Moghadas, D.; Jadoon, K.Z.; McCabe, M., 2019, Spatiotemporal monitoring of soil moisture from EMI data using DCT-based Bayesian inference and neural network. *J. Appl. Geophys.*, *169*, 226–238.
22. Muñiz, E.; Shaw, R.K.; Gimenez, D.; Williams, C.A.; Kenny, L., 2016, Use of Ground-Penetrating Radar to Determine Depth to Compacted Layer in Soils Under Pasture. In *Digital Soil Morphometrics*; Springer: Cham, Switzerland; pp. 411–421.
23. Nováková, E.; Karous, M.; Zajíček, A.; Karousová, M., 2013, Evaluation of ground penetrating radar and vertical electrical sounding methods to determine soil horizons and bedrock at the locality Dehtáře. *Soil Water Res.*, *8*, 105–112.
24. Rentschler, T.; Werban, U.; Ahner, M.; Behrens, T.; Gries, P.; Scholten, T.; Teuber, S.; Schmidt, K., 2020, 3D mapping of soil organic carbon content and soil moisture with multiple geophysical sensors and machine learning. *Vadose Zone J.*, *19*, e20062
25. Pradipta, A., Soupios, P., Kourgialas, N., Doula, M., Dokou, Z., Makkawi, M., Alfarhan, M., Tawabini, B., Kirmizakis, P. and Yassin, M., 2022. Remote Sensing, Geophysics, and Modeling to Support Precision Agriculture—Part 1: Soil Applications. *Water, 14(7),* p.1158.
26. Romero- Ruiz A., Linde N., Keller T., Or D., 2018, A review of Geophysical Method for structure characterization, doi 10.1029/2018RG000611, Review of Geophysics, pp 673-697.
27. Romero-Ruiz, A.; Linde, N.; Baron, L.; Solazzi, S.G.; Keller, T.; Or, D. Seismic signatures reveal persistence of soil compaction. *Vadose Zone J. 2021*, *20*, e20140.
28. Samouëlian, A., Cousin, I., Tabbagh, A., A, B. and Richard, G. 2005. Electrical resistivity survey in soil science: A review. *Soil and Tillage Research 83,* 173-193.
29. Schmäck, J.; Weihermüller, L.; Klotzsche, A.; Hebel, C.; Pätzold, S.; Welp, G.; Vereecken, H., 2021, Large-scale detection and quantification of harmful soil compaction in a post-mining landscape using multi-configuration electromagnetic induction. *Soil Use Manag.*, *38*, 212–228.
30. Sunori, S.K., Kumar, S., Anandapriya, B., Nesamani, S.L., Maurya, S. and Singh, M.K., 2021, December. Machine Learning Based Prediction of Soil pH. *In 5th International Conference on Electronics, Communication and Aerospace Technology (ICECA) (pp. 884-889). IEEE.*
31. Thu, T.H. and Trung, N.N., 2012. Xác định ranh giới xâm nhập mặn tầng chứa nước Pleistocen khu vực ven biển Đồng bằng sông Hồng theo kết quả phân tích hóa và đo sâu điện. *Tạp chí Khoa học và Công nghệ biển*, *12*(4A), pp.163-170.
32. Trung, N.N., Thu, T.H., Nghia N.V., 2008, Ứng dụng phương pháp điện và mô hình thủy văn và điện trở suất trong đo vẽ bản đồ và dự báo xâm nhập mặn tại Thái Bình, *Tạp chí Địa chất, số 31-32,* pp 241-248.
33. Vanella, D.; Cassiani, G.; Busato, L.; Boaga, J.; Barbagallo, S.; Binley, A.; Consoli, S., 2018, Use of small scale electrical resistivity tomography to identify soil-root interactions during deficit irrigation. *J. Hydrol.*, *556*, 310–324.
34. Viscarra Rossel, R.A., Taylor, H.J. and McBratney, A.B., 2007. Multivariate calibration of hyperspectral γ- ray energy spectra for proximal soil sensing. *European Journal of Soil Science*, *58*(1), pp.343-353.
35. Zhou, L.; Yu, D.; Wang, Z.; Wang, X., 2019, Soil Water Content Estimation Using High-Frequency Ground Penetrating Radar. *Water*, *11*, 1036.

36. Winkelbauer, J.; Völkel, J.; Leopold, M.; Bernt, N., 2011,Methods of surveying the thickness of humous horizons using ground penetrating radar (GPR): An example from the Garmisch-Partenkirchen area of the Northern Alps. *Forstwiss. Centralblatt*, *130*, 799–812.
37. Wong, M.T.F., Oliver Y.M. & Robertson, M.J., 2009. Gamma-Radiometric Assessment of Soil Depth across a Landscape Not Measurable Using Electromagnetic Surveys. *Soil Sci. Soc. Am. J.*, *73*, 1261-1267.