Journal of Mining and Earth Sciences

Website: http://jmes.humg.edu.vn

Applications of geophysical methods in agriculture and their potential in Vietnam

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ARTICLE INFO

Article history:
Received 25th Nov. 2023
Revised 10th Mar. 2024
Accepted 27th Mar. 2024

Keywords:
Geophysical methods,
Precision agriculture,
Soil properties,
Soil monitoring.

ABSTRACT

Geophysical methods are very popular in Vietnam and have been applied for several decades in deep-earth investigations such as geological mapping, mineral resource searching, and especially oil and gas exploration. In the world, they have proven to be great tools in agriculture as well for soil characterization and monitoring thanks to their notable advantages including rapid data acquisition, large data coverage, high data density, non-destructive and inexpensive survey implementation. However, in Vietnam, the applications of geophysical methods in agriculture have received little attention probably due to the lack of suitable equipment and data processing techniques. This article gives an overview of popular geophysical methods being applied in agriculture in several countries to characterize and monitor soil properties such as moisture, salinity, density, texture, structure, porosity, etc. The main uses of each method are summarized, and relevant publications are given for reading recommendations with the aim of suggesting similar applications in Vietnam. Accordingly, Ground Penetrating Radar (GPR) and Electromagnetic Induction (EMI) are the most versatile with minimum field crew for data acquisition. They should be prioritized to try in Vietnamese agriculture. Since EMI equipment is not currently available in Vietnam, only a GPR test survey was implemented in the Agricultural Academy experimental field by the authors of Hanoi University of Mining and Geology. The preliminary result shows that the biggest challenge is to find reliable techniques to accurately infer soil properties from measured geophysical parameters, which have no explicit relationship with soil properties. Noise suppression is another problem that needs to be addressed to ensure sufficient data quality.

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DOI: 10.46326/JMES.2024.65(2).10

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 despite their effectiveness. Nguyen et al. (2008) and Trinh et al. (2012) are probably the only two articles found in the Vietnamese public domain that tried to use electrical methods to predict the high salinity of underground water in the Northern Vietnam coastal plain area.

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

2. Geophysical methods applied in agriculture

2.1. GPR method

Ground Penetrating Radar (GPR) emits electromagnetic waves via an antenna transmitter and receives them from an antenna-receiver. The velocity of the wave can be calculated by a formula:

$$V = \frac{1}{1+\frac{\varepsilon\mu}{2}\sqrt{1+\left(\frac{\sigma^2}{\varepsilon\omega}\right)}} \quad (1)$$

Where μ - magnetic permeability; σ - electrical conductivity; ε - dielectric constant; and ω - angular frequency.

When high-frequency electromagnetic waves (tens of MHz to several GHz) are transmitted into the ground, parts of the energy will be reflected at each boundary of two layers which have different dielectric permeability. The receiving antennas record the reflected signals with their amplitudes and traveling times. Analyzing attributes of reflected signals can reveal the nature of the soil layers which passes through and the travelling times provide information about the depth of the layers.

An illustration of a ground-penetrating radar survey on the field and the resulting cross-section is shown in Figure 1 to demonstrate that the GPR measurement is rather simple by moving the

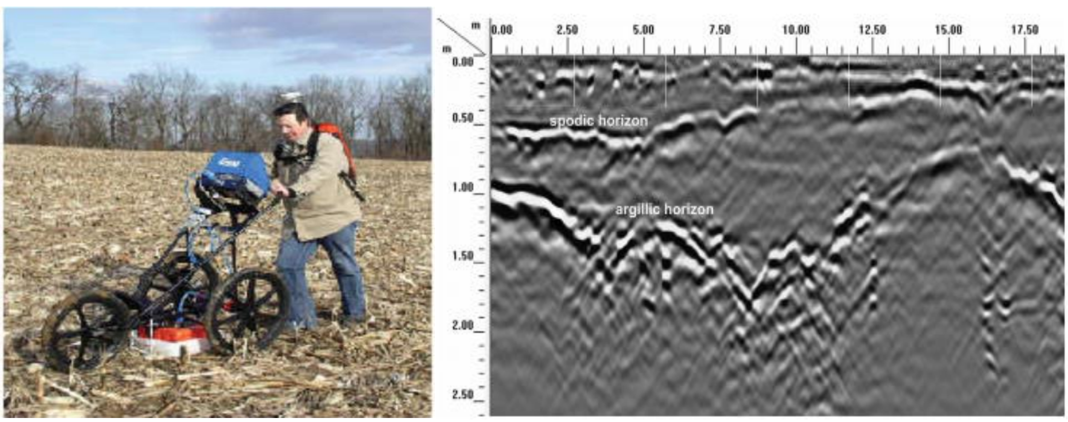

Figure 1. GPR survey in the field can be carried out by one man with a handy equipment. After the data processing, radargram section can reflect the sand and clay layers (Ditzler et al., 2017).

equipment through the field. The resulting data, when properly processed, can be used to determine the petrographic composition and thickness of the soil layers (Ditzler et al., 2017). The cross-section shows that the upper boundaries of the sporadic and argillic strata stop abruptly and separate contrasting soil materials, producing high-amplitude reflected waves.

Acquired raw GPR data are usually processed to reduce contaminated noise and can be inverted into various useful soil properties. For example, the sand ratio map in Figure 2 and water content variation in Figure 3 were derived from GPR data (Grote et al., 2010).

The method is particularly useful for rapid estimation of water content in shallow soil layers over large areas (Lesmes et al., 1999; Grote et al., 2010; Huisman et al., 2003; Galagedara et al., 2005).

2.2. Electromagnetic induction method (EMI)

The electromagnetic induction (EMI) method measures vertical or horizontal components of an EM field forming in the soil by induction in response to a prescribed EM field. The electrical resistivity of the soil affects the measured voltages or EM induction. The field measurement by the EMI method can also be carried out by one man with handy equipment (Figure 4). Since the machine does not require direct contact with the soil, data collection is fast and inexpensive

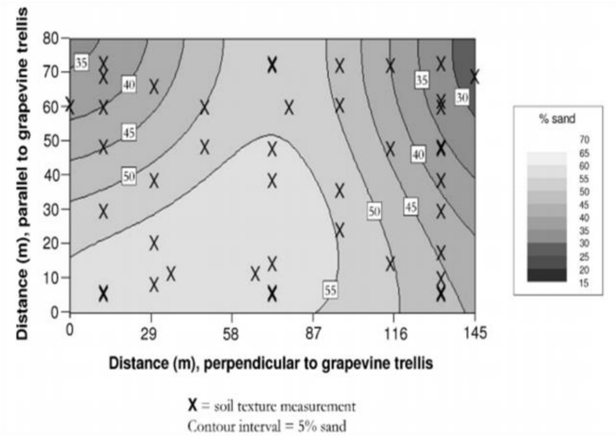

Figure 2. Sand composition on 20cm thick soil cover (Grote et al., 2010).

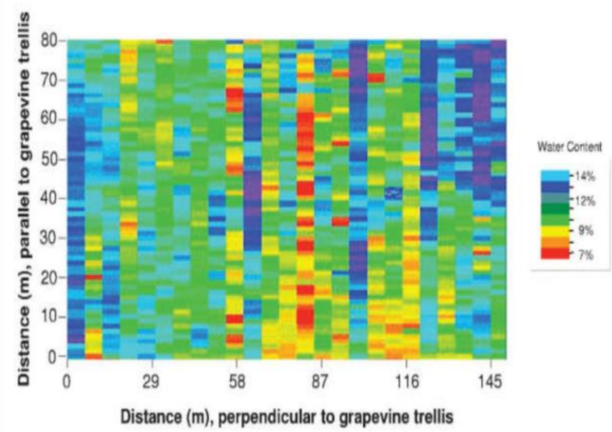

Figure 3. Measurement of water content in the area using a 900 MHz GPR wave (Grote et al., 2010).

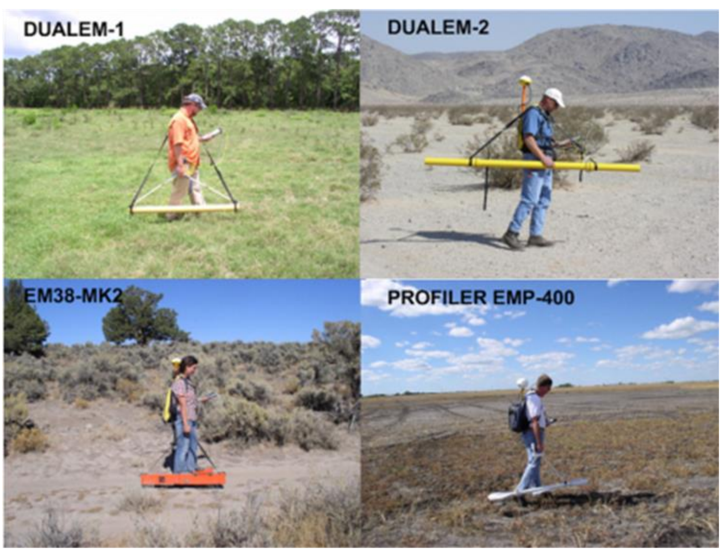

Figure 4. EMI equipments are easy to move and compact (Doolittle and Brevik, 2014).

allowing one to measure a large area with dense data points.

The EMI equipment measures apparent conductivity (ECa), which reflects the conductive property of the soil vertically at specified depths. The conductivity of the soil depends on the dissolved ion content, the amount and type of clay in the soil, the water composition, and the temperature and phase of soil water. The ECa value increases with increasing salt concentration, water or clay content, and temperature, the method can also be used to determine the changes in some agar compositions (Allred et al., 2010).

As described by Corwin (2008), the adaptation of the EMI method in agriculture is mainly driven by the reliable, fast, and easy results for measuring soil salinity at the blade scale in fields and landscapes. In soil surveying the identification and mapping of salt-affected soils has traditionally been done by visual observations supported by laboratory analyses. Visual observations, although permitting general salinity mapping, provide only qualitative information and depend on the presence of vegetation cover, surface salts, and soil structural characteristics. Laboratory methods are time-consuming and expensive to complete but provide only a limited number of measurement points that may or may not be representative of the field or soil landscape. A great advantage of EMI is its ability to generate a large number of quantitative measurements that can be spatially linked, thus being able to describe and distinguish changes in salinity-salt Na) and mineralization (sodicity-sodium Na, CA, Mg, and carbonate salts) of soil at field and landscape scales (Figure 5).

With arid and semi-arid situations occurring in many parts of the world, the relationship between irrigation and soil parameters has been studied in some advanced countries, one of which can be mentioned is that of Huang et al. (2016) in Canada. In their research, Huang and colleagues have shown the relationship between ECa measured results of EMI and soil composition parameters. In Figure 6a, a 2D image of the distribution of lightning components by depth is presented. In the central area, at a depth of less than 1 m, the clay ratio is lowest (sand mixed with meat), then gradually increases. The cover part has the highest percentage of clay. In the eastern soil structure, there is a homogenous mixture of

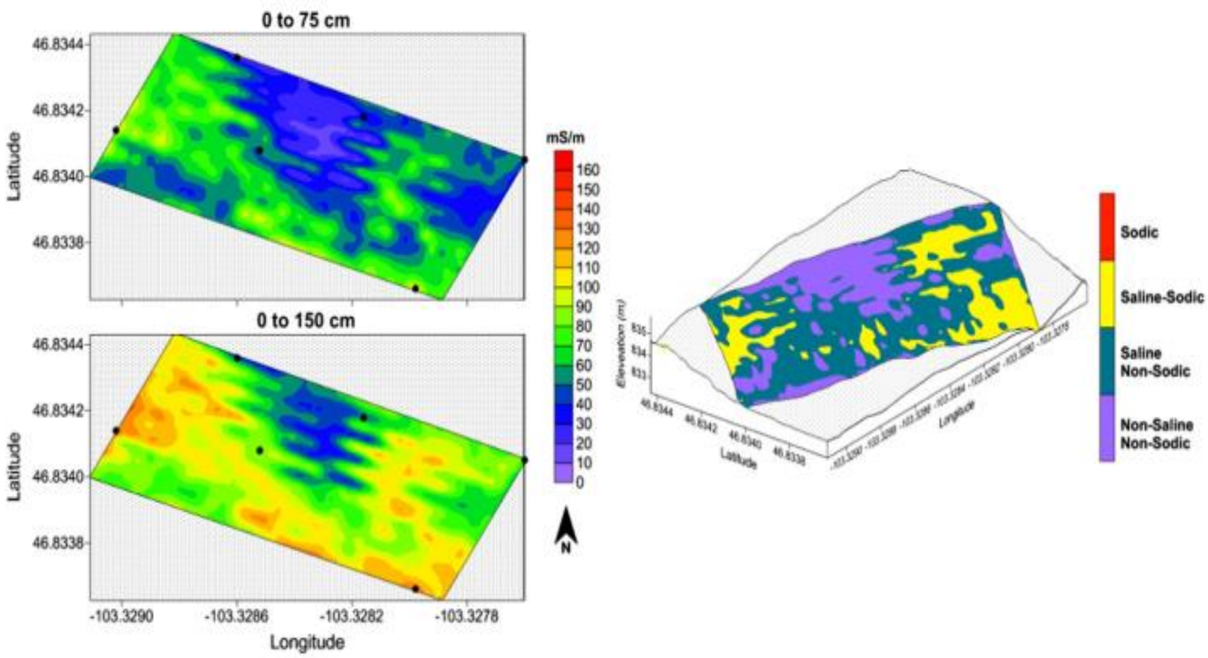

Figure 5. ECa measurements for 2 different depths (on the left), classification according to the salt content of southwestern North Dakota on the right (Corwin, 2008).

sand and meat. This figure also shows at some locations at landmarks 2,3 and 4 that high gravel (>9%) should be noted in the subsurface. Figure 6b shows that at position 5, ECe measured from soil samples is less than 2 dS/m, indicating a non-saline area in the topsoil and deeper soils. However, at the average depth at the 5th position (from 0.5 to 1 m) to the 3rd and 4th points, the slightly saline soil is quite uniform (2<ECe<4 dS/m). At positions 1 and 2, a gradual increase in ECe indicates soils from no salinity to mild and severe salinity (>8 dS/m) below the surface

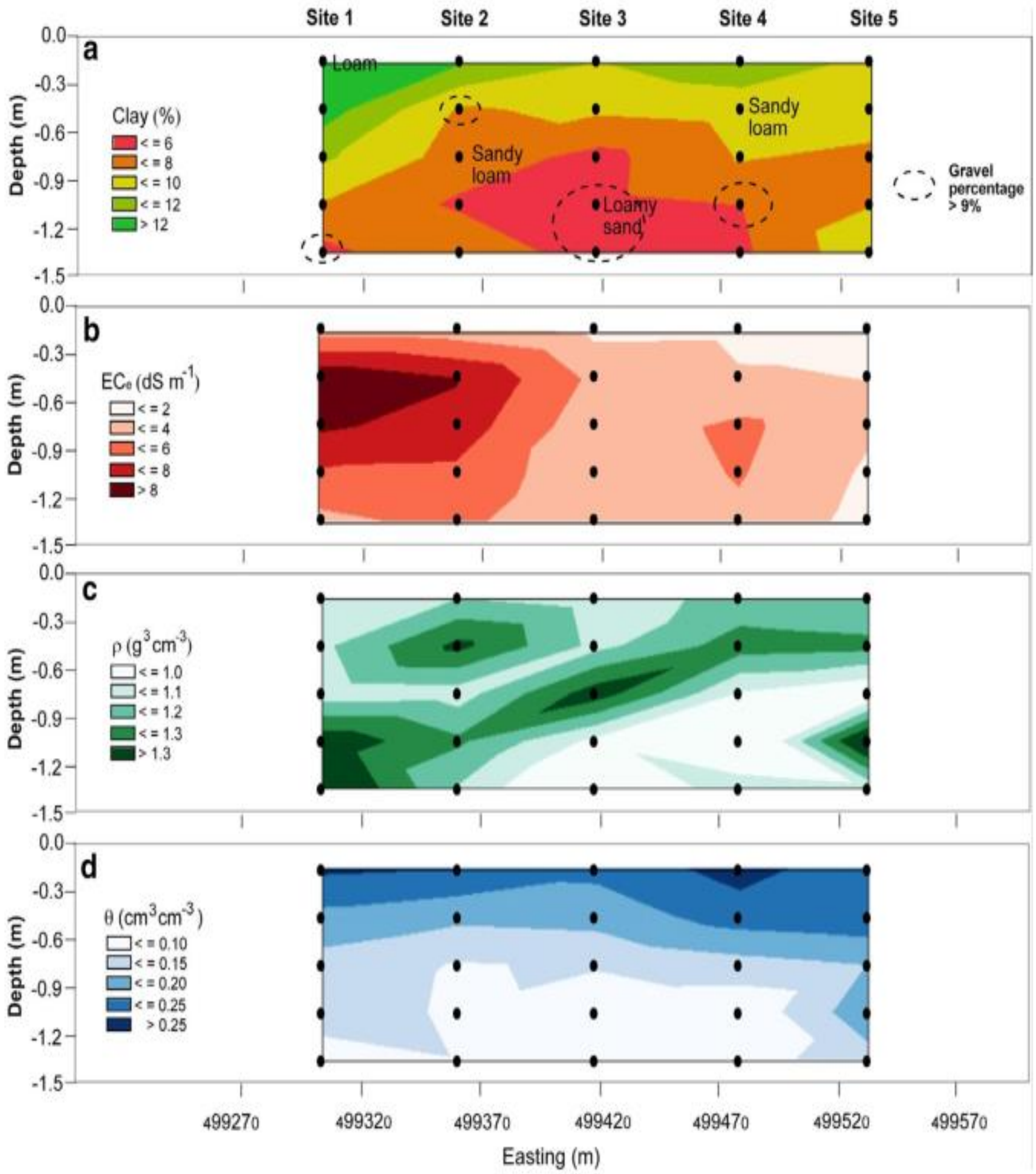

Figure 6. Representation of soil properties in the area at San Jacinto (Canada) at sampling locations 1,2,3,4,5 and analyzed in the laboratory for comparison. The cross-sections show the properties of the soil, respectively, including a - lightning (%), b - conductivity of the saturated extract (ECe, dS/m), c - bulk density (ρ, g/ cm³) and d - volumetric water content (θ, cm³/cm³). Note the soil sample marked with black dots. Samples with more than 9% gravel are marked with dashed circles (Huang et al., 2016).

before gradually decreasing again to the level of no salinity (according to deep positions). Figure 6c shows that the bulk density ρ (g/cm^3) varies from small (0.9 g/cm^3) to medium (1.4 g/cm^3). Figure 6d shows that the volume of water content (cm^3/cm^3), in the topsoil is the largest (> 0.27) for the mechanical composition of the topsoil varies from sandy loam to all flesh. The value indicates the water saturation of the topsoil which varies from greater than 0.25 and gradually approaches 0, corresponding to the change in soil composition in Figure 6.

Apparently, the EMI method can provide information on different soil parameters including moisture, temperature, salinity and clay content.

2.3. Resistivity method

Resistivity is closely related to some important soil properties such as porosity, moisture content, structure, and architecture of the soil. Therefore, the resistivity method has been widely used in research and applications in soil science.

The electrical resistivity depends on the composition of Cl- in the water so the DC electrical method will show the salinity content of soil. Moreover, the resistivity method determines the total dissolved mineralization and thus defines the boundary salty–pale of the aquifer (Figure 7).

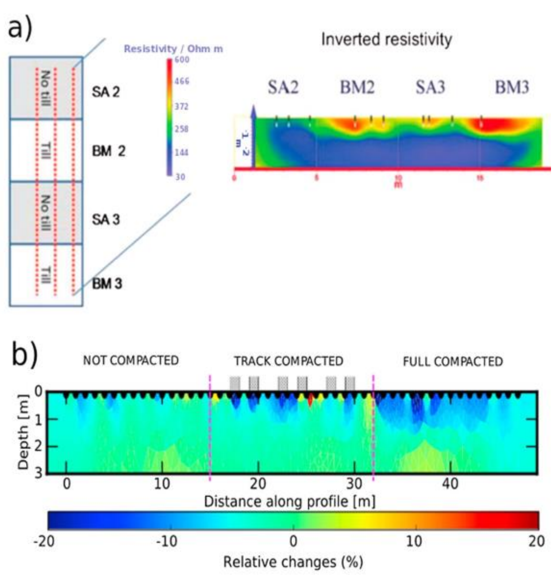

Figure 7. The change in soil salinity obtained from the resistivity measurement method. (Romero-Ruiz et al., 2018).

2.4. Gamma method

Radioactive gamma rays have good penetrating ability and can pass through about 30 cm in the soil environment (Van Egmond et al., 2018). The gamma ray emission originates from spontaneous radioactive decay and it does not depend on any other objective or subjective case. Therefore, the application of physical laws and phenomena of radioactive decay in general and the application of gamma rays, in particular, are widely applied in many fields of science and life. The detection and acquisition of gamma rays is done in the outer space field using a spectrometer or gamma intensity. Gamma-ray-emitting isotopes may have sources of natural or artificial origin. Radioisotopes, especially naturally occurring radioactive isotopes, exist and are present everywhere on earth with different concentrations and activities. It represents and is characteristic of geochemical, physical as well as characteristic properties of many geographical features substances and objects that exist in nature. These existences and properties are no exception to different types of soil. The study of the relationship between the activity of radioactive isotopes and superimposed soil geochemistry will provide the relationship between gamma activity and soil data (Viscarra

Figure 8. Equipment can be mounted on a vehicle for fast and convenient measurement.

Rossel et al., 2017). In soil survey, gamma spectra equipment was attached to a vehicle moving in the field (Figure 8).

Figure 9 shows the mapping of particle size ratio from 0 to 50 mm measured by ground gamma spectroscopy and drone gamma method. Another source of gamma spectra that can also be used to provide soil data is aeronautical gamma spectrometry which shows the distribution of elements, such as Potassium, Uranium, or Thorium, in relation to clay content and soil quality according to Ameglio (2018).

Analysis of activity characteristics, and relationships between radioisotopes that emit radiation gamma in soil with soil characteristics, moisture, salinity, humus content, organic content, soil type, type of soil minerals, clay content and trace elements as well as other geochemical soil elements will provide the data and background information for testing, classifying and setting policies for rational and effective use, reclamation and conservation of land resources plant.

2.5. Seismic method

Although seismic methods are not as commonly used as EMI or GPR methods in precise agriculture due to their higher cost, this method, in addition to providing parameters such as the thickness of soil, soil porosity, sand and clay composition, can provide parameters that other methods could not determine such as the change of soil structure under the tillage process.

Figure 10 is an example demonstrating the variation of longitudinal wave velocity (P-wave velocity) that can be used to predict the change of soil properties due to compaction because if the soil is compressed, its P-wave velocity will increase. The application of seismic methods is the most direct way to determine the degree of compression subsidence of the land. Unlike invasive methods or analytical sampling that only obtain discrete information, the seismic wave

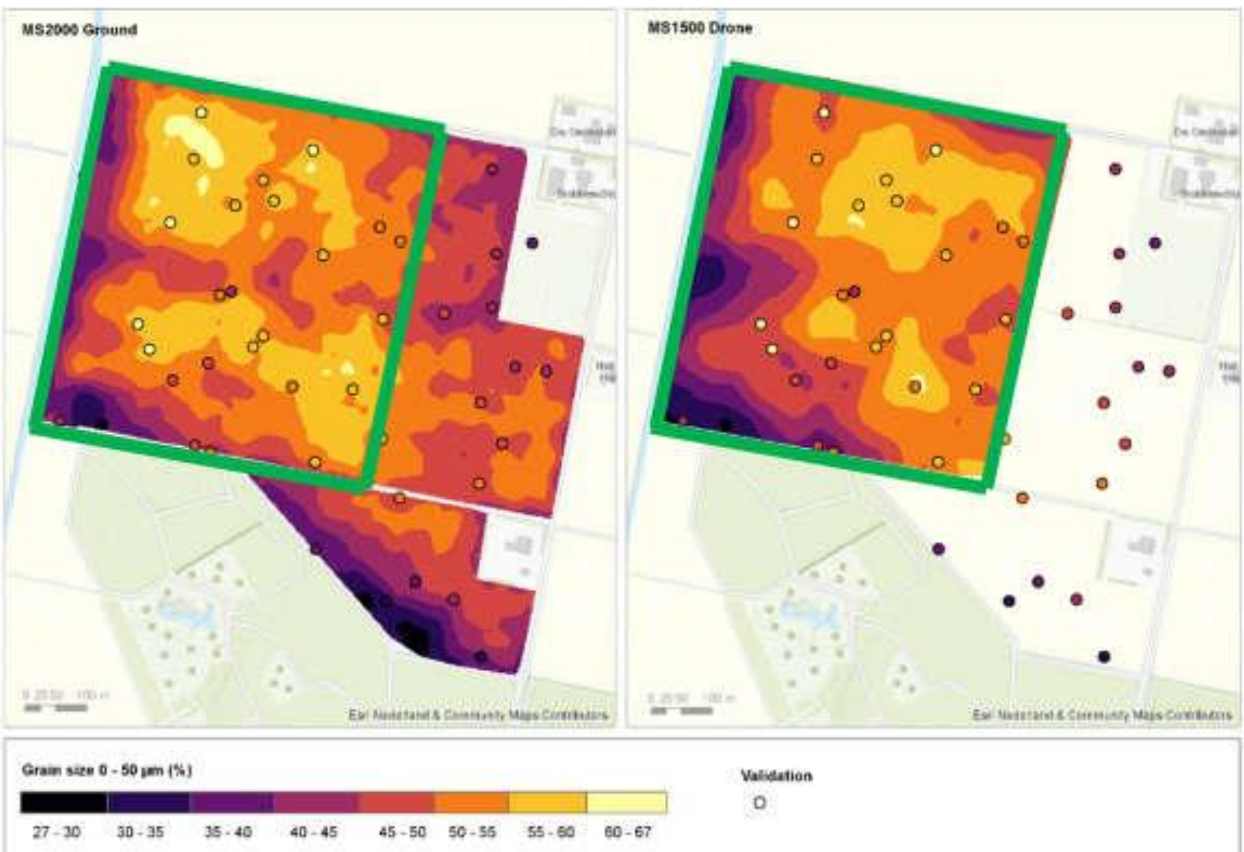

Figure 9. Research results by ground gamma method and gamma measurement by drone show that the particle size ratio from 0 to 50 mm is distributed at a depth of 0÷30cm (Ameglio, 2018).

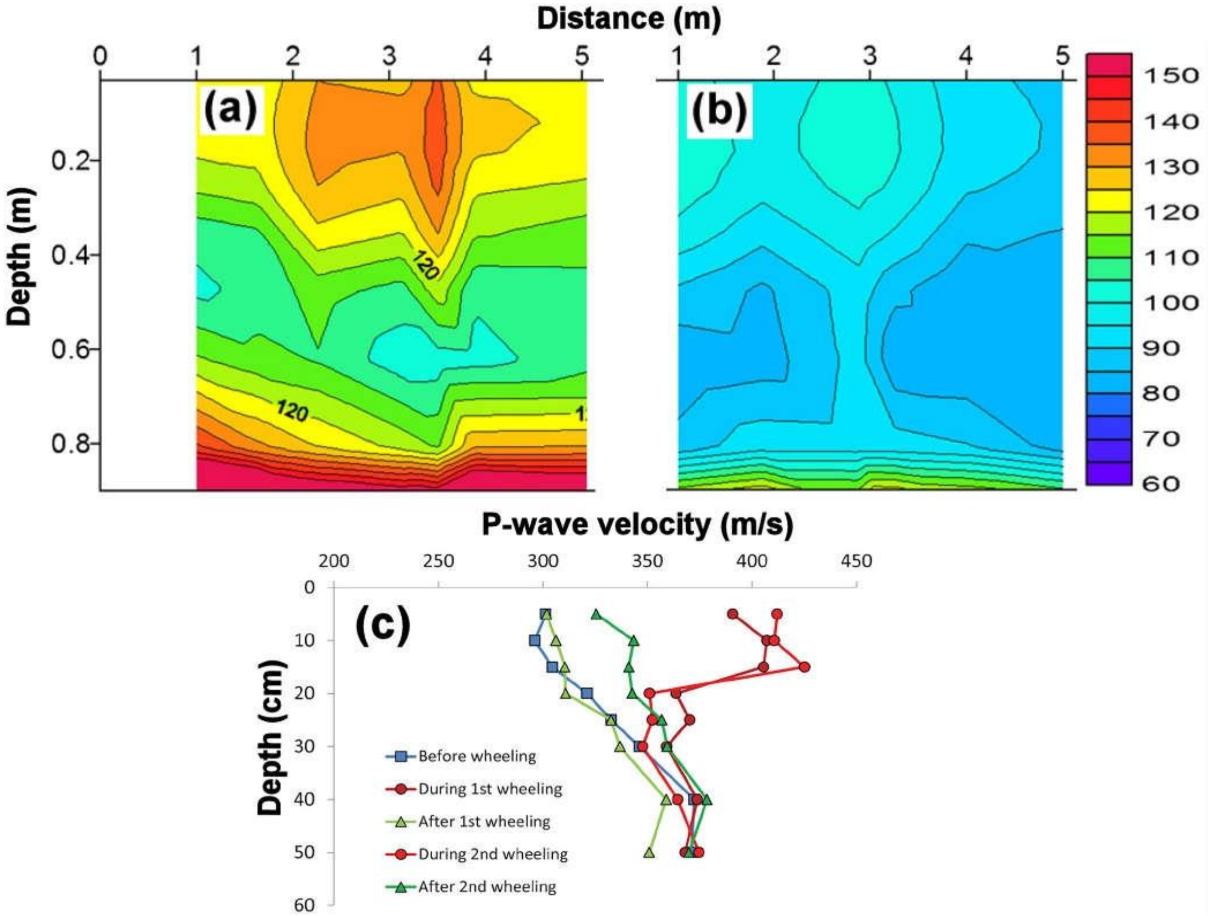

Figure 10. Sensitivity of seismic measurements to soil compaction and loading: Parts of S wave from Multichannel analysis of seismic waves inferred from the compressed region (a) and the undistorted region (b), note the lower S-wave velocities for undistorted soil (according to Donohue et al., 2013); and (c) P wave velocity with depth measured in the rolling experiment marks changes in the load and after the wheel passes (Keller et al., 2013).

analysis method yields all the properties physico-mechanical properties of the soil and rock of the whole region are represented by different scales and the depth of detail soil layer below.

There are basically four types of seismic waves that can be applied to in situ soil analysis (Sheriff and Geldart, 1995): two types of body waves that can propagate in the soil in any direction at unlimited depth; two surface waves propagate through the soil layer close to the earth's surface. The second type has depth shallower, wavelength-dependent penetration, well suited to subsoil studies for agricultural and forestry production activities. The mapping of the wave properties can indicate areas with different porosity, compaction or settlement levels, water saturation levels, uniformity, etc., thereby helping to plan suitable plant varieties as well as other activities necessary for land reclamation.

The applications of geophysical methods in agriculture have been previously described and reviewed by several authors Romero-Ruiz et al. (2018), Romero-Ruiz et al. (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. From this table, it can be seen that EMI and GPR probably are the most suitable methods to apply in Vietnam's agriculture because they are the most versatile and robust. They also require a minimum field crew for data acquisition.

Table 1. Summary of applications of geophysical methods in agriculture.

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	Novakova 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 (Ωm)	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 (vp and vs)	Detection of compacted soil	Romero-Ruiz et al. (2021); Donohue et al. (2013)

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 the 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 11a) and the acquired data were processed by filtering the noise but apparently the resulting cross section is still noisy (Figure 11b) probably due to bad surface condition after rains or incorrect choice of source frequency. In this section, the horizontal axis is the distance in meters, and the vertical axis is time on one side and depth on the other side. Soil boundaries are defined as horizontally coherent reflected signals on the section. Three boundaries can be interpreted as colored lines in Figure 11(b). 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 a thickness ranging from 15 cm to 40 cm. 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 sophisticated modeling algorithms are crucial to receiving accurate information on soil characteristics. This is probably the main reason why the geophysical methods have not been applied for soil characterization and monitoring in Vietnam.

4. Conclusions

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 several advantages, including rapid data acquisition, high data density, large data coverage with inexpensive implementation, and most importantly they are nondestructive methods.

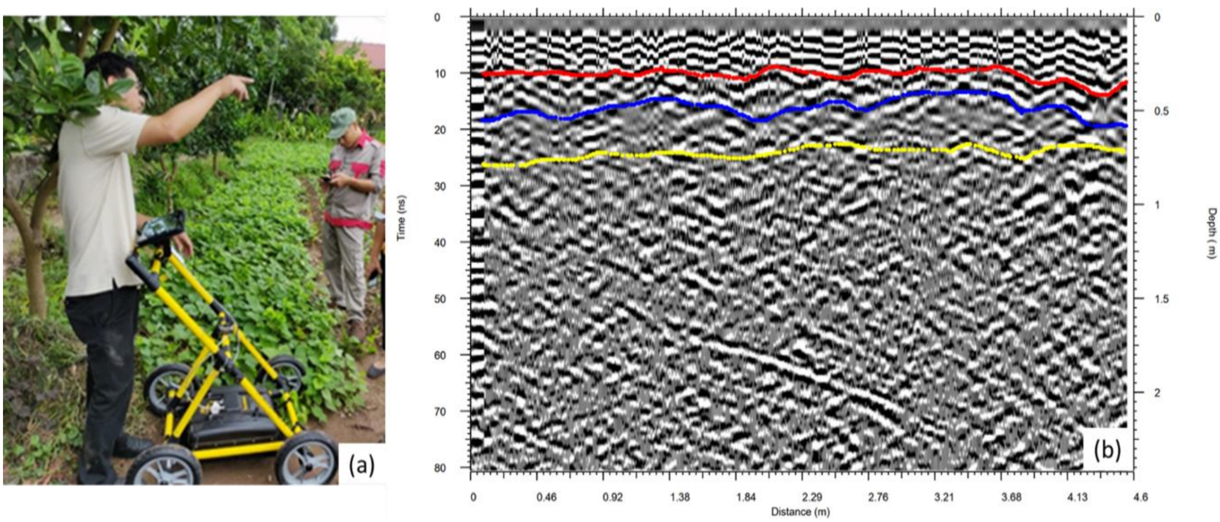

Figure 11. A trial application of GPR to predict subsurface soil layers implemented in the experimental field of the Agricultural Academy using Geoscaner equipment (a) and the resulted cross section with interpretation(b).

The main challenge is that soil properties cannot be directly indicated by measured geophysical parameters, instead, they are inferred from them by sophisticated 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 the GPR method reveals that the data can be useful but needs a lot of processing effort to reduce the 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.

Acknowledgment

Thanks to the National Science and Technology Program entitled "Supporting research, development and technology application of industry 4.0" for funding the research with project code: KC-4.0/19-25 and HUMG science program for funding the research project's research T21-21. Based on these researches, this article is derived.

Contributions of authors

Huong Thien Phan - GPR methods; Duong Hong Vu - paper editing (figures, tables,...); Hung Danh Tran - summary of geophysics; Tung Thanh Nguyen - summary of geophysics.

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