CONSIDERATIONS ON CONTACTLESS ELECTROMAGNETIC TECHNIQUES FOR MEASURING SOIL CONDUCTIVITY

Tudor BURLAN-ROTAR[1], Constantin STANESCU[1], Melania TAMAS[1]

[1] "Politehnica" University of Bucharest

Abstract : Conventional determination of resistivity by galvanic method requires a relatively large amount of labor to apply them in practice and is therefore expensive. It is the lateral or vertical variations of resistivity which form the basis of any interpretation. However the hight cost of resistivity surveying generally means that fewer measurements are made than would be desirable, with the result that either (i) the surveyi area is not made large enough to establish a reasonable background against which the anomalous areas are to be delineated or (ii) the anomalous itself is obscure and lacks definition. The application of electromagnetic techniques for measuring soil resistivity or conductivity is known for a long time. Conductivity is preferable in inductive techniques as instrumentation readings are generally directly proportional to the conductivity and inversely proportional to the resistivity. The operating principle of this method is: a transmitter Tx coil supplied with alternating current at a frequency audio is placed on the ground. A receiver Rx coil is located a short distance s away from Tx coil. The magnetic field varies in time and Tx coil induces very small currents in the ground. These currents generate a secondary magnetic field Hs is sensed by the Rx receiver coil together with primary magnetic field Hp. The ratio of the secondary field Hs to the primary magnetic field Hp (Hs/Hp) is linearly proportional to terrain conductivity. Measuring this ratio, it is possible to construct a contactless, direct-reading linear terrain conductivity meter. This more recent technique for measuring conductivity by electromagnetic induction using VLF (very low frequency), is a non-invasive, non-destructive sampling method. The measurements can be done quickly and inexpensively. Electromagnetic induction technology was originally developed for the mining industry, and has been used in mineral, oil, and gas exploration, groundwater studies, and archaeology. In these applications, differences in conductivity of subsurface layers of rock or soil may indicate stratified layers or voids that could be of interest.
Keywords: electromagnetic, inductive, conductivity, contactless

1. INTRODUCTION

Ground resistivity measurement technique for geological mapping has been used for over half a century. Many deficiencies, however, prevented this technique to be widely accepted in engineering purposes.

One of the shortcomings is that conventional resistivity determination by galvanic method requires a relatively large amount of manpower for its application in practice and is thus expensive.

Another shortcoming is that the lateral and vertical resistivity variations have no interpretation. Also another problem inherent in conventional techniques for determining the resistivity is that although the actual depth exploration is determined by the distance between electrodes, resistive inhomogeneities are small compared to that depth, but which are located near the electrodes, can cause significant error in measurement.

These fluctuations in the measurement results are true geological noise. As a result of inhomogeneities, such noise limited resolution could be reached, even if the instruments themselves are able to provide a much higher accuracy.

2. ELECTROMAGNETIC METHOD FOR MEASURING SOIL RESISTIVITY

The application of electromagnetic techniques for measuring soil resistivity or conductivity is known for a long time. (Conductivity is preferred in inductive techniques as instrumentation readings are generally directly proportional to the conductivity and resistivity inversely proportional.)

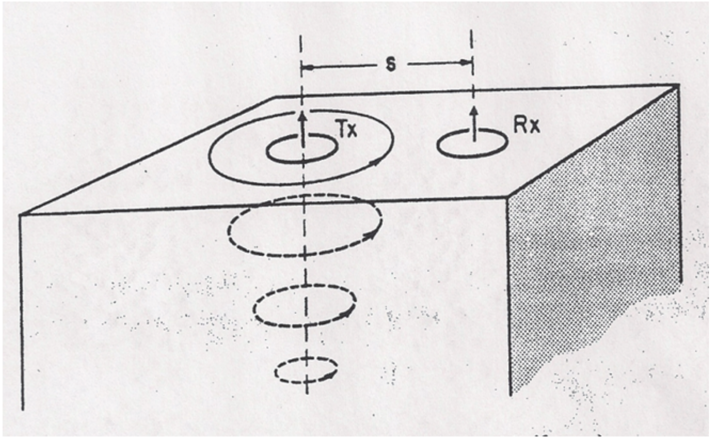

Fig. 2.1. Principle of electromagnetic soil conductivity measurement.

The operating principle of this method is:

A Tx transmitter coil supplied with alternating current at a frequency audio is placed on the ground.

A Rx receiver coil is located at a distance (small) from Tx coil. Time-varying magnetic field and Tx transmitter coil induces very low currents in the ground. These currents generate a secondary magnetic field Hs. The Rx receiver coil induce a current in the field with contributions mainly due Hp Tx and secondary field Hs.

The current induced in the coil receiver Rx is directly proportional to the conductivity of the soil:

$$\frac{H_s}{H_p} \cong \frac{i\omega\mu_0\sigma S^2}{4} \tag{2.1}$$

where :

H_s = secondary magnetic field at Rx coil;

H_p = primary magnetic field at Rx coil;

ω = 2 π f (pulsation);

f = frequency;

μ_0 = permeability of vacuum;

σ = soil conductivity;

s = distance between coils;

$i = \sqrt{-1}$

Since the ratio of the secondary magnetic field and the primary magnetic field is directly proportional to the soil conductivity, can write apparent conductivity indicated by the instrument as defined by the equation:

$$\sigma_a = \frac{4}{\omega\mu_0 S^2}\left(\frac{H_s}{H_p}\right) \tag{2.2}$$

The unit for conductivity is Siemens per meter or, more conveniently, milli Siemens per meter (mS / m).

2.1 Advantages of electromagnetic method

The advantages of electromagnetic:

- *Excellent conductivity resolution*. Opening side swept volume of earth inductive technique is about the same as the depth. The result is that small changes in conductivity, for example, of the order of 5% or 10% are accurately measured.

A problem in the conventional method of measuring the resistivity was that this inhomogeneity located near the electrodes causes large errors.

Examining the current flow in a homogeneous space for inductive technique described here that, near the emitter current density is very high and we can expect that the presence of an inhomogeneous conductors are here to have a big effect. However, if the current density is high, the radius of the current loop is low and their distance from the receiver coil is large, so that the loops are tightly coupled with the receiver. Thus errors due to local conductivity variations are negligible.

- *Current injection*. Specific problems encountered with conventional current injection materials such as gravel, bedrock, snow and ice, etc. are not found in current injection instruments using induction.
- *Quick and easy measurements*. The classical method for each measurement, four electrodes are inserted into soil and measurement is relatively close to the space between the electrodes. Making repeated maneuvers presents numerous opportunities for breakage. These problems are avoided and an inductive magnetic measurement technique can be performed five to ten times faster using this technique.

2.2 Disadvantages of electromagnetic method

As with all geophysical instruments the use of inductive technique has several disadvantages as follows:

- *Limited dynamic range* (1-1000 mS / m). For low values of conductivity land, obtaining of sufficient soil to produce a detectable magnetic field coil reception is difficult. On the other hand, if high values of soil conductivity, the EM measurements are no longer linearly proportional to the conductivity of the soil.
- *Establish and maintain the zero of the instrument*. Ideally, when zero adjustment tool, it should be suspended in space. In this case, a region of the ground looking very resistant to accurately measure its conductivity using conventional techniques, and to adjust to zero the instrument.

It requires zero setting of the instrument to be accurately maintained at zero for long periods and temperature variations encountered during geophysical measurements in different areas of the Earth. Zero can be calibrated with an error of up to ± 0.2 mS per meter. Such an error would be negligible in the normal range of soil conductivity. However, if the measurements are carried out on a very strong field, the error may become significant.

3. BLOCK DIAGRAM OF THE DEVICE BASED ON THE METHOD OF ELECTROMAGNETIC (EM).

The device is composed of two parts. The emission consists of a transmitting coil that receives signal Tx emission module (a square wave generator of fixed frequency of 10-20 kHz). The reception desk is made of Rx coil and receiver (amplifier with one or more floors, followed by a detector). Receiver modulator output is connected to a measuring instrument (mA) through a potentiometric circuit. Level zero is set in the potentiometer.

Figure 3.1 is a block diagram of the device and the types of polarization used: vertical dipole (VD) and horizontal dipole (HD).

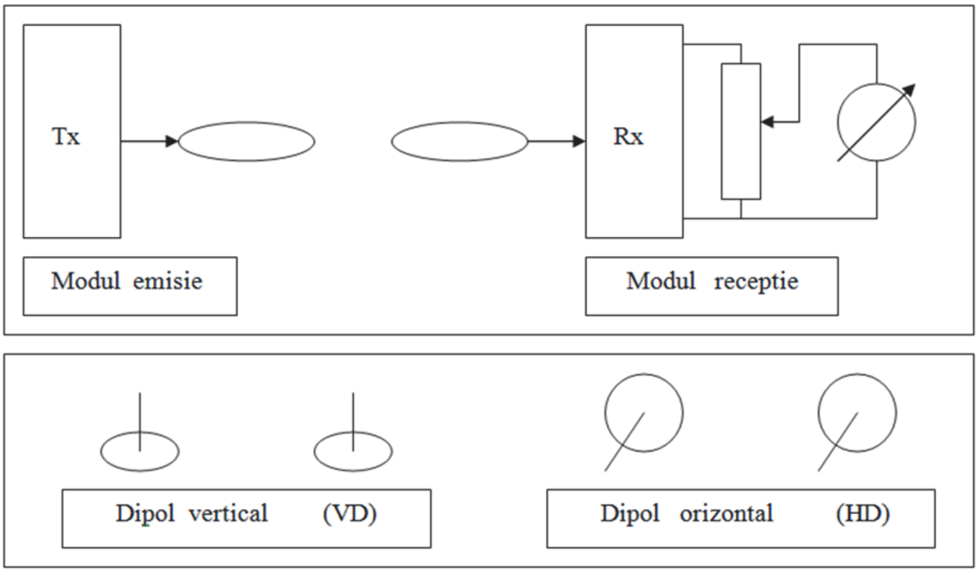

Fig. 3.1. Block diagram of the device and polarization types used:
Vertical dipole (VD) and horizontal dipole (HD)

The polarization is selected by positioning plan in which there are two coils, Tx coil and Rx coil. It uses horizontal polarization dipole when the coil axis is parallel to the soil surface and vertical dipole when the coil axis is perpendicular to the soil surface.

4. CHARACTERISTICS OF THE DEVICE ACCORDING TO THE TYPE OF POLARIZATION

The dependence of the penetration depth of the distance between the coils and the type of polarization: horizontal dipole (HD), vertical dipole (VD) is presented in Table 4.1

Table 4.1. **The penetration depth depending on the type of polarization and the distance between the coils**

Distance between the coils (meters)	The penetration depth (meters)	
	Horizontal dipole	Vertical dipole
1	0,75	1,5
2	1,5	3
4	3	6

Consider the following initial conditions:

For a homogeneous or stratified horizontal ground current flow is entirely horizontal. In addition, the current flow at any point in the ground is independent of current flow at any point and the magnetic coupling between the current loops are negligible. Accordingly the depth of penetration is limited only by the distance between the coils.

The response of the device as a function of depth (in a homogeneous halfspace):

Whether on a homogeneous halfspace surface which are located the Tx and Rx coils at distance s. Consider a thin layer dz at a depth z.

The depth plotted as fractions of s - distance between coils, is represented on O_x :

$$z = \frac{depth}{s} \tag{4.1}$$

It can be built, so for the vertical polarization, the function $\phi_V(z)$ shown in Figure 4, which describes the relative contribution of the secondary magnetic field due to a thin layer at a depth z. It is observed that the layer located at a depth of about 0.4s gives maximum contribution of secondary magnetic field, but that layer to a depth of 1.5s, yet contribute significantly.

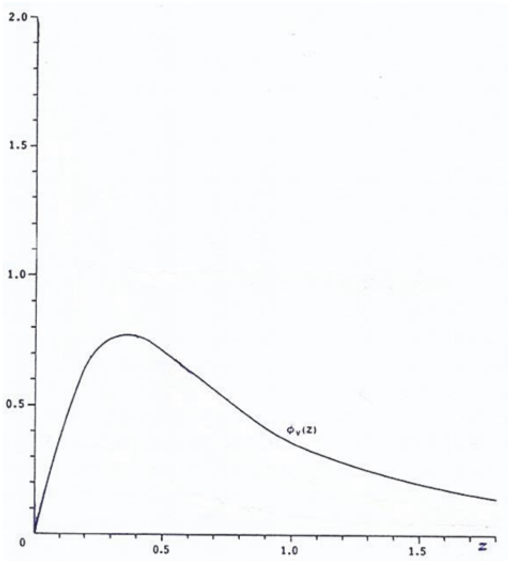

Fig. 4.1. Operation of the device in vertical polarization mode (VD).

It is interesting to note that in the neighborhood of the surface layer has a very small contribution to the secondary magnetic field and, therefore, this configuration is insensitive to changes in conductivity near the surface.

Figure 5 illustrates the function $\phi_H(z)$ for the case when the transmitter and receiver operate in the operating mode to horizontal coplanar dipoles.

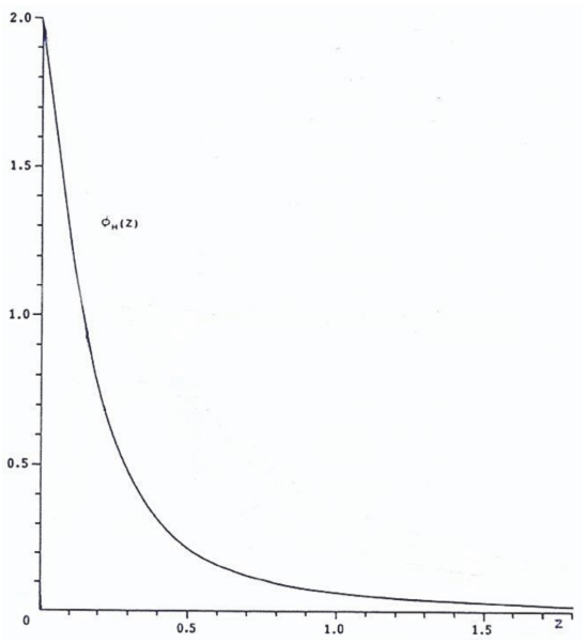

Fig. 4.2. Operation of the device in horizontal polarization mode (HD).

For comparison of the different ways to respond to layers at different depths in Figure 6 are shown in the same coordinate system, both functions: vertical polarization (VD) and horizontal polarization (HD).

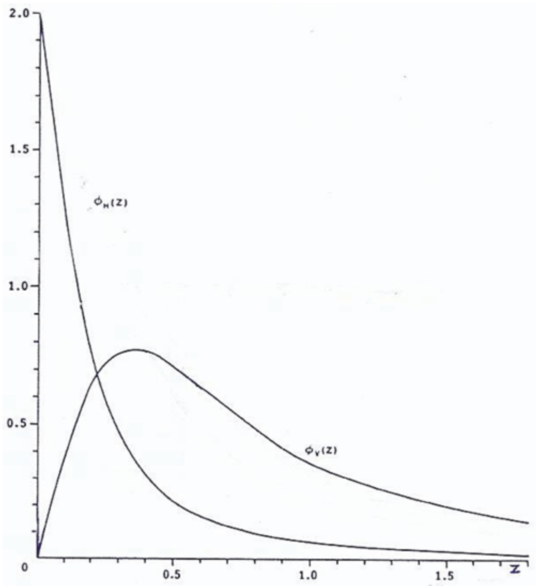

Fig. 4.3. Representation of both functions: $\phi_V(z)$ and $\phi_H(z)$ (to highlight how different the response of different layers).

It is noted that at depths slightly smaller than the distance between the coils, the signal measured by the device is about twice higher for vertical polarization to horizontal polarization case.

The horizontal dipole orientation, the instrument is more sensitive to soil layers in the vicinity. The vertical dipole orientation device is more sensitive to the deeper layers.

Thus, by performing measurements in both modes, it is possible to measure the increase or decrease in conductivity with depth.

5. MEASUREMENT TECHNIQUE.

The operating principle of the device is shown in Figure 5.1.

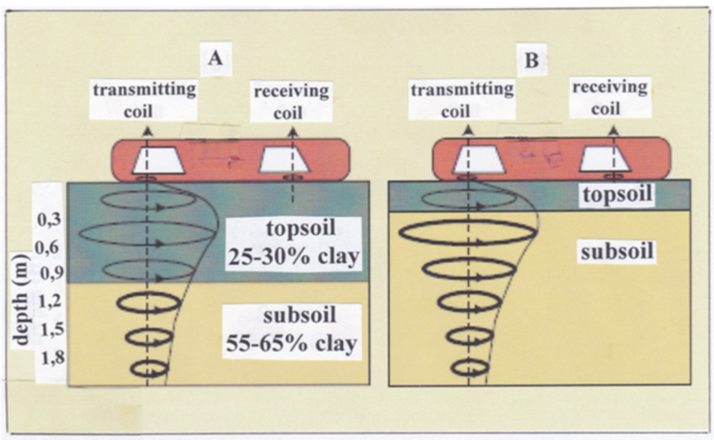

Fig. 5.1. The principle of operation of the device. If B is greater conductivity measured apparent that clay exhibits higher electrical conductivity.

Tx transmitting coil induces ground current loops, with a depth-dependent intensity. The relative intensity of the induced current is illustrated by the relative diameter loop current. Maximum intensity is at 30cm and still significant at depth of 1.5m.

These currents generate a secondary magnetic field Hs which is sensed, together with the primary magnetic field, Hp, by the receiver coil.

The ratio of the secondary magnetic field Hs and Hp primary magnetic field (Hs \ Hp) is directly proportional to the conductivity of the soil.

In agriculture, the device is used to measure the salinity and soil moisture. Other agricultural applications currently include mapping, depth estimation topsoil, sand deposition depth after flood damage estimation due to herbicides, etc.

For each of the applications mentioned above, a relationship must be established between the value determined by device and soil characteristic of interest. Once the relationship is established, measurements can be made quickly.

To establish a relationship between the value determined by using the soil and the characteristic of interest for selected points on the ground, are taken simultaneously: soil samples (using a probe) and the apparent conductivity of the soil (through measurement device EM) . The data from these points is made EM calibration device. Thus, the final map is drawn deep fertile soil.

Experimental correlations were found in moderate to good conductivity between the apparent conductivity and the results of the classical method, the soil samples, the most accepted and precise method for determining soil salinity.

A mobile data collection unit is mounted on a wooden trailer away from metal objects and away from the vehicle engine interference, which could affect determinations. The mobile unit consists of EM device coupled to an analog to digital convertor, a computer and a receiver of differential global positioning system (DGPS).

The unit operates as follows: the analog signal coming from dispozutivul EM is converted into a digital signal and recorded by computer. Together with this information the computer also records your location (where the measurement was performed) received from the DGPS receiver.

The mobile equipment used for data acquisition in the field is shown in Figure 5.2.

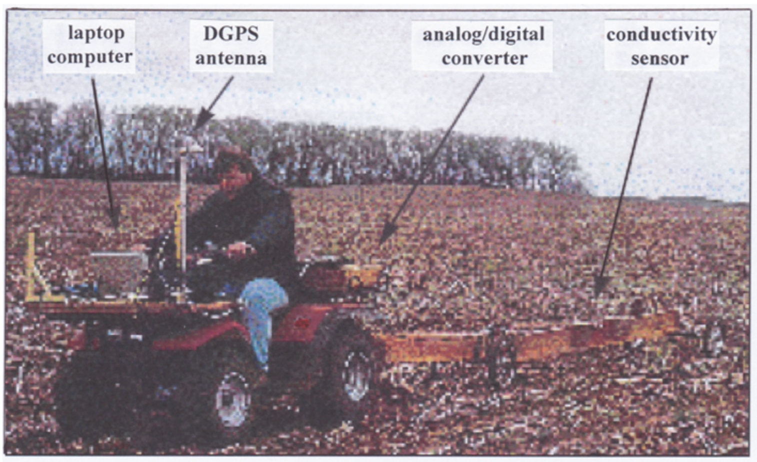

Fig. 5.2. Mobile equipment used for data acquisition in the field.

Using this device, data of entire fields can be collected quickly, and then, with appropriate software, you can make maps of soil conductivity. For 1hectar field data can be collected about one hour.

After drawing the map of the land, for confirmation, it can be compared with aerial photograph (of the same pitch) made in the vegetation season.

In the early 1980s, electromagnetic induction method (EM) has been accepted as a useful method for getting maps of soil salinity. The method provides assessment tools to monitor the salinity.

Information about the depth of topsoil are a valuable tool in choosing appropriate crop management needs.

6. EXPERIMENTAL RESULTS

EM device indicate areas where higher electrical conductivity (soil more fertile) are marked on the map with dark green - green crops. Soil areas with lower conductivity, are marked with color light brown - areas where coverage is less dense crop yellowing occurs due to moisture stress.

Using aerial photography to see plant cover is easy to see differences in productivity potential and how well models of potential productivity are correlated with measurements of soil conductivitatatii using EM device.

The EM behave linearly proportional to the conductivity of the soil when the distance between the coils is less than the depth of penetration. However, in soils with a higher apparent conductivity of 80 mS / m, EM measurements are not linearly proportional to the conductivity of the soil.

Linear response of the device is directly proportional to the conductivity and soil when the distance between the coils is less than the depth of penetration. However, in soils having a higher bulk conductivity of 80 mS / m, the EM measurements are no longer linearly proportional to the conductivity of the soil.

7. CONCLUSIONS

The device for measuring the conductivity of materials by electromagnetic method (without contact) has a wide range of applications.

Its usefulness in areas such as geology (search for metal ores, oil, salt, etc.), archeology, agriculture (for measuring humidity, salinity) was confirmed in time.

BIBLIOGRAFIE

[1] Effects of Liquid-Phase Electrical Conductivity, Water Content, and Surface Conductivity on Bulk Soil Electrical Conductivity, Rhoades, J. D., P. A. Raats, and R. J. Prather. (1976), Soil Sci. Soc. Am. J. 40:651-655.

[2] Measurement of Apparent Electrical Conductivity of Soils by an Electromagnetic Induction Probe to Aid Salinity Surveys, de Jong, E., A. K. Ballantyne, D. R. Cameron, and D. L. Read. (1979), Soil Sci. Soc. Am. J. 43:810-812.

[3] An Electromagnetic Induction Technique for Reconnaissance Surveys of Soil Salinity Hazards, Williams, B. G., and G. C. Baker, (1982), Australian Journal of Soil Res. 20: 107-118.

[4] The Use of Electromagnetic Induction for Locating Subsurface Saline Material. In 'Relation of Groundwater Quantity and Quality, Williams, B.G., Fiddler, F-T., 1983, (Proceedings of the Hamburg Symposium, August 1983). IAHS Publishing No 146 189-196.

[5] A Rapid Method for Estimating Weighted Soil Salinity from Apparent Soil Electrical Conductivity Measured with an Aboveground Electromagnetic Induction Meter, Wollenhaupt, N. C., J. L. Richardson, J. E. Foss, and E. C. Doll. (1986), , Can J. Soil Sci. 66:315-321.

[6] The Use of Electromagnetic Induction to Detect the Spatial Variability of the Salt and Clay Contents of Soil, Williams BG & Hoey D 1987, Australian Journal of Soil Research 25, 21-28.

[7] Estimating Spatial Variations of Soil Water Content Using Noncontacting Electromagnetic Inductive Methods, Kachanoski RG Gregorich EG & Van Wesenbeeck IJ 1988., Canadian Journal of Soil Science 68, 715-722.

[8] Soil Electrical Conductivity and Soil Salinity: New Formulations and Calibrations, Rhoades, J.D., N.A. Manteghi, P.J. Shouse, and W.J. Alves. 1989., Soil Sci. Soc. Am. J. 53:433-439.

[9] New Calibrations for Determining Soil Electrical Conductivity Depth Relations from Electromagnetic Measurements, Rhoades, J. D., S. M. Lesch, P. J. Shouse, and W. J. Alves. (1989), Soil Sci. Soc. Am. J. 53:74-79.

[10] Determining Soil Electrical Conductivity-Depth Relations Using an Inductive Electromagnetic Soil Conductivity Meter, Rhoades, J.D. and D.L. Corwin. 1991., Soil Sci. Soc. Am. J. 45:255-260.

[11] The Use of Electromagnetic Measurements of Apparent Soil Electrical Conductivity to Predict the Boulder Clay Depth, Brus DJ Knotters M van Dooremolen P van Kernebeek P & van Seeters RJM 1992. Geoderma 55, 79-84.

[12] Salinity Estimates in Irrigated Soils Using Electromagnetic Induction, Diaz, L., and J. Herrero. (1992), , Soil Sci. 154(2): 151-157.

[13] Soil Salinity Mapping with Electromagnetic Induction and Satellite-Based Navigation Methods, Cannon ME McKenzie RC & Lachapelle GP 1994. Canadian Journal of Soil Science 74, 335-343.
[14] Estimating Depths to Clay Pans Using Electromagnetic Induction Methods, Doolitlle JA Sudduth KA Kitchen NR & Indorante SJ 1994. Journal of Soil and Water Conservation 49, 572-575.
[15] Estimating Herbicide Partition Coefficients from Electromagnetic Induction Measurements. Jaynes DB Novak JM Moorman TB & Cambardella CA. 1995. Journal of Environmental Quality 24, 36-41.
[16] Yield Mapping by Electromagnetic Induction, Jaynes, D.B., T.S. Colvin, and J. Ambuel. 1995. p. 383-394. In P.C. Robert, R.H. Rust, and W.E. Larson (ed.), Proc. 2nd Intl. Conf. on Site-Specific Management for agricultural Systems. ASA, CSSA, and SSSA, Madison, WI.
[17] Noninvasive Soil Water Content Measurement Using Electromagnetic Induction, Sheets K.R. and J.M.H. Hendrickx. 1995. Water Resources Res. 31(10): 2401-2409.
[18] Electromagnetic Induction Sensing as an Indicator of Productivity on Claypan Soils, Sudduth KA Kitchen NR Hughes DF & Drummond ST 1995, Proceedings of the Second International Conference on Site Specific Management for Agricultural Systems. (Eds. Probert, P.G., Rust, R.I.H. & Larson, W.E.). pp 671-681.
[19] Evaluation of Calibration Methods for Interpreting Soil Salinity from Electromagnetic Induction Measurements, Johnston, M. A., M. J. Savage, J. H. Moolman, and H. M. du Plessis. (1997), Soil Sci. Soc. Am. J., 61:1627-1633.
[20] Monitoring for Temporal Changes in Soil Salinity Using Electromagnetic Induction Techniques, Lesch, S. M., J. Herrero, and J. D. Rhoades. (1998), Soil Sci. Soc. Am. J. 62:232-242.

CONSIDERATII ASUPRA MASURARII CONDUCTIVITATII SOLULUI PRIN METODA ELECTROMAGNETICA FARA CONTACT

Tudor BURLAN-ROTAR[1], Constantin STANESCU[1], Melania TAMAS[1]

[1] Univesitatea "Politehnica" din Bucuresti

Rezumat: Determinarea conventionala a rezistivitatii prin metoda galvanica necesita o cantitate relative mare de forta de munca si este deci costisitoare. La baza oricarei interpretari stau variatiile laterale sau in plan vertical ale rezistivitatii. Costurile ridicate pentru realizarea hartilor cu rezistivitatea solului impun sa se realizeze mai putine determinari decat ar fi de dorit, cu rezultatul ca, fie (i) suprafata explorata nu este suficient de mare pentru a stabili un fundal rezonabil in raport cu care zonele cu anomalii sunt fie delimitate sau (ii) zonele cu anomalii nu sunt bine conturate. Aplicarea tehnicii electromagnetice pentru masurarea rezistivitatii solului este cunoscuta de mult timp. Conductivitatea este de preferat în tehnica inductiva deoarece indicatiile instrumentului sunt direct proportionale cu conductivitatea şi invers proportionale cu rezistivitatea . Principiul de functionare al acestei metode este: o bobina de emisie Tx alimentata cu curent alternativ , la o frecventa audio este plasata pe sol . O bobina de receptie Rx, este situata la o distanta mica s de bobina de emisie Tx . Campul magnetic variaza în timp şi bobina de emisie Tx induce curenti circulari de foarte mica intensitate în pamant. Aceşti curenţi genereaza un camp magnetic secundar Hs care este detectat de catre bobina de receptie Rx împreuna cu câmpul magnetic Hp . Raportul dintre campul magnetic secundar Hs si campul magnetic primar Hp (Hs \ Hp) este direct proportional cu conductivitatea solului . Astfel este posibil sa se construiasca un dispozitiv care sa masoare conductivitatea solului prin tehnica electromagnetica fara contact. Aceasta tehnica recenta pentru masurarea conductivitatii prin inductie electromagnetica folosind VLF (foarte joasa frecventa) este o metoda non-invaziva, non-distructiva. Masuratorile se pot face rapid si ieftin. Tehnologia de inductie electromagnetica a fost initial dezvoltata pentru industria miniera si a fost folosita pentru detectare de minerale, petrol si gaze naturale, studii de ape subterane si arheologie. In aceste aplicatii, diferentele de conductivitate ale straturilor subterane de roca sau sol pot indica stratificari sau goluri care ar putea prezenta interes.

Cuvinte cheie: electromagnetic, inductiv, conductivitate, fara contact.