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DETERMINING BULK ELECTRICAL CONDUCTIVITY OF SOIL FROM ATTENUATION OF ELECTROMAGNETIC PULSE*

M.A. Malicki, J. Kokot, W.M. Skierucha

Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin 27, P.O.Box 201, Poland

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A b s t r a c t. Bulk electrical conductivity of soil, ecB_{TDR}, determined using attenuation-based TDR measurements disagreed with reference data, ecB_{ref}, determined using the four-electrode reference method. To explain this discrepancy it was assumed that there exist more reasons other than the soil *ecB* that cause the pulse attenuation. Fitting a polynomial to the $ecB_{ref}(ecB_{TDR})$ relationship made the TDR attenuation-based method applicable for the determination of the soil bulk electrical conductivity.

K e y w o r d s: soil electrical conductivity, soil salinity, time domain reflectometry

INTRODUCTION

To determine soil salinity, as expressed in terms of electrical conductivity of soil water, *ecW*, the bulk electrical conductivity, *ecB*, and the relative dielectric constant, ε, of the soil have to be known [6]. The two parameters can be obtained using time domain reflectometry (TDR), which provides nondestructive simultaneous measurements of ε and *ecB* from the same sensor, over the same sampling volume [1-3,5,8].

THEORY

TDR - time domain reflectometry - was primarily applied to determine soil moisture [4,7] as correlated to the soil relative dielectric constant, ε:

$$\sqrt{\varepsilon} = \frac{c}{2L} t \qquad (1)$$

where: c (m s^{-1}) - velocity of propagation of electromagnetic waves in vacuum equal 3 10^8, L (m) - distance the pulse covers in the soil, equal to the length of the rods of the TDR sensor, t (s) - time necessary for the pulse to cover the distance L.

From Eq. (1) it can be seen that in order to calculate the dielectric constant of the soil, knowledge of time the pulse covers a certain, fixed distance in the soil, is necessary.

The TDR method of the determination of the soil bulk electrical conductivity is based on the assumption that the applied electromagnetic pulse looses its energy due to the electrical conductivity of the soil. Thus, from the measurement of attenuation of the pulse being propagated in the considered soil, *ecB* can be found according to:

$$ecB = \frac{1}{120\pi L} \ln\left(\frac{U_{in}}{U_{out}}\right)\sqrt{\varepsilon} \qquad (2)$$

where U_{in}(V) is magnitude of the electromagnetic pulse entering the soil, U_{out}(V) - magnitude of the electromagnetic pulse leaving the soil, ε - relative dielectric constant of the soil.

From Eq. (2) it can be seen that in order to calculate *ecB* of the soil, magnitudes of the electromagnetic pulse at the beginning and

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end of the distance L it covers in the soil are necessary.

MATERIALS AND METHODS

A set of 9 samples of soil material having gradually differentiated sand and clay content was investigated. Air dry samples were moistened with solutions of KCl in 5 steps to cover the range of moisture from air dryness up to saturation.

Measurements of the soil bulk electrical conductivity, ecB_{TDR}, were performed with application of the Time-Domain Reflectometry. Also parallel reference readings of the soil bulk electrical conductivity, ecB_{ref}, were taken with the four-electrode probe. LOM/mts TDR soil moisture, temperature, salinity meter and ELCON/4el soil bulk electrical conductivity meter from Easy Test were used respectively. The procedure was repeated for solutions having different salinities (concentrations of KCl).

RESULTS AND DISCUSSION

Results obtained with the discussed attenuation-based TDR measurements of the soil electrical conductivity, ecB_{TDR}, of the investigated soil samples, as derived from TDR pulse attenuation accordingly to Eq. (2), disagreed with the reference data, ecB_{ref}, determined using the four-electrode reference method. Figure 1 illustrates their comparison.

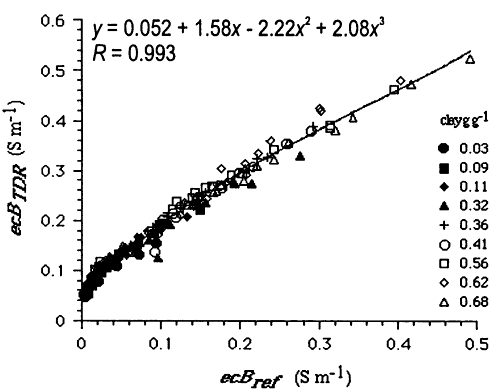

Fig. 1. Bulk elelctrical conductivity, ecB_{TDR}, of the investigated soil samples obtained using TDR pulse attenuation method accordingly to Eq. (2), versus reference data, ecB_{ref}, detemined using four-electrode reference method.

To explain the discrepancy it was assumed that more than the single, above mentioned reason of the pulse attenuation should be taken into account.

Electromagnetic waves undergo attenuation when propagating for the following reasons:

- energy is partly radiated into the surrounding (the soil);
- energy is partly dissipated (converted to heat) during dielectric polarization of the material it propagates in (solid particles + soil water);
- energy is dissipated due to electrical conductivity of the material (soil water) it propagates in.

Attenuation of the pulse is related to imaginary part, ε'', of the soil dielectric constant. When ecB reaches magnitude close to zero, like in case of dry or wet but not salty soil, then ε'' reaches a finite, nonzero magnitude. This implies discordance of the ecB_{TDR}-ecB_{ref} relationship due to a remarkable intercept caused by the dielectric losses in the soil.

The ecB_{TDR} versus ecB_{ref} line seems to justify the above explanation. Its shape revealed nonlinearity. Fitting a polynomial to the $ecB_{ref}(ecB_{TDR})$ relationship (see Fig. 2) made the TDR attenuation-based method applicable for the determination of the soil bulk electrical conductivity.

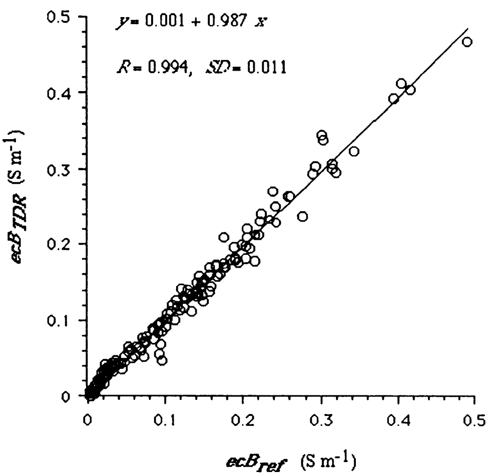

Fig. 2. Comparison of the bulk electrical conductivity of the investigated soils, ecB_{TDR}, with the reference data, ecB_{ref}, after correction accordingly to the polynomial of Fig. 1.

CONCLUSIONS

Direct calculation of bulk electrical conductivity of the soil from attenuation of the electromagnetic pulse leeds to significant error.

The TDR attenuation-based method for the determination of the soil bulk electrical conductivity can be applied after fitting a polynomial to the $ecB_{ref}(ecB_{TDR})$ relationship.

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