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SOIL MOISTURE AND BULK ELECTRICAL CONDUCTIVITY VARIABILITY MEASURED BY TDR

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A b s t r a c t. The result of numerous TDR measurements of heterogeneous soil water content are shown. Some statistical parameters of measured water content and bulk electrical conductivity fields are calculated. TDR water content measurement proves to be a quick and reliable measurement method for the assessment of stochastical properties of heterogeneous soils.

K e y w o r d s: TDR water content measurement, soil heterogeneity, random field parameters

INTRODUCTION

The TDR water content measurement is quick and less destructive than other methods, to collect a large amount of measurement data in a short time, and leaves the object of measurements undisturbed [4,7,8,10].

It is especially important when investigating variable soil properties where numerous measurements have to be performed. Nowadays the spatial and temporal variability of soils receive more and more attention due to their influence on the water flow process [1,2, 12]. Heterogeneity of solute flow is considered an important factor influencing the ground water contamination process.

The moisture condition in the Huang Huai Hai river (Yellow River) plain has been investigated recently [11,12] using a neutron moisture meter. Investigations of the spatial water content distribution were done with a 10x10 network by Zhi-Xiong in [11]. The correlation structure of the water content field was investigated. Using such a large grid authors in [11] found a correlation length in the order of 10-20 m, which is rather large in comparison to the grid distance. This means that a more dense grid would give a more accurate correlation. Since the TDR is a more accurate and quicker device we performed a similar but more detail investigation.

Each measurement is biased with a measurement error. The measurement error consists of components of a different nature. Each of them influences the result of measurement [3] in a different way.

The error generated by the instrument can be of dual nature [6];

- Temporal drift of instrument readings due to external conditions changing. This depends on various factors like: external temperature influencing both the instrument and the soil properties, time of apparatus work, battery charge etc., this error is unpredictable due to unknown factors influencing the device. The maximal value of an error can be assessed and part of the error can be removed by recalibration of the device.

- Random measurement error due to the noise of measuring devices. This part of an error has a defined statistical structure and can be minimized by increasing the number of replications of the same measurement.

In our case both errors are in the range of 1% and do not affect our conclusions concerning soil moisture and bulk electrical conductivity variability.

The TDR apparatus employs a constant calibration curve which is calculated for the range of typical soils [4,8], and provides a certain accuracy level for the measurements done with a specific soil. In order to reach a better accuracy one should recalibrate the data for the measured soil using the oven dry method.

The last source of results distribution is the soil heterogeneity itself. We can consider this as an error which influences our measurement of the mean value or as a statistical sample to consider randomness properties of measured value. For different soils it can be of different importance. In all cases an increase in the number of measuring points leads to a better approximation of the mean value of the water content [9]. Numerous measurements allow us to see a correlation structure for the measured parameter.

In the case of TDR apparatus we observe a random error of the volumetric water content measurement together with temporal drift in the order of 1%. This means that observed variability having an amplitude in the order of ±5.0% has its origin in soil heterogeneity rather than in the apparatus error.

EXPERIMENT DESCRIPTION

We chose a 21x21 m experimental plot located in Fengqiu Agro-Ecological Experimental Station in Henan province at North China Plain. As the field was well described we used additional data collected previously for other purposes. This concerned specifically water retention curves, soil profile description and, in part, bulk density data.

The soil in this region was developed from the alluvion of the Yellow River. Thus, the soil profile shows up a definite layered structure. The top 30- to 40-cm-thick layer was formed of a sandy loam soil with a bulk density of 1.48 g/cm^3. The next 40- to 50-cm - thick layer was formed of a silt clay loam soil with the bulk density of the order of 1.41 g/cm^3, while the bottom layer, 80 to 100 cm deep from the surface, was formed of the sand loam soil with the bulk density 1.47 g/cm^3.

The chosen plot of farmland was rain-fed for one and a half years, no irrigation was applied during this time. We assumed that the soil moisture distribution field was similar to that formed in natural conditions. The ground water table was about 1.5 m deep from the soil surface. At least one month had passed since the latest precipitation of 68.9 mm. The experiment was set immediately after the harvest of the soybean from the plot.

The soil profile was considered highly homogeneous in horizontal layers, concerning texture and the bulk density. Layers were well developed, that influences the water content distribution.

Experimental setup

The TDR measurements were done on a square plot 21x21 m (Fig. 1).

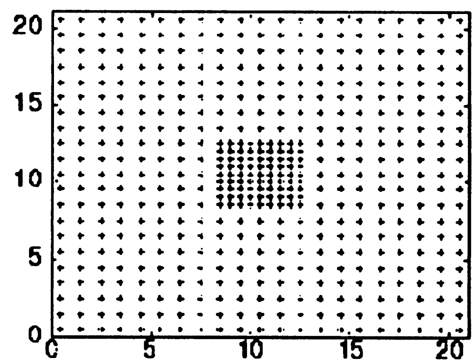

Fig. 1. Measurement point location.

The whole plot was divided into squares 1x1 m with the measuring point chosen at the center of each square. All together we marked 441 measurement points in the coarse network.

The coordinates of each point on the field were calculated from the formula: $x=i$ - 0.5 m, $y=j$ - 0.5 m, where i is the consecutive column number (X - direction) and j is the number of the row in Y direction.

The choice of the field dimension was motivated by the fact that the previous investigation showed the autocorrelation length of the water content in the order of 10-20 m. TDR measurements are able to distinguish the water content difference in the order of 1% and the time of measurement is relatively short, therefore we expected to find a more exact structure for the water content distribution.

We measured the random water distribution in equally spaced points of 1 m. Furthermore we made an additional measurement in the central square of the plot with a higher spatial resolution, i.e., we used a 4x4 m plot and performed measurements in a network 0.5x0.5 m.

The fine network measurement was complementary to the coarse network and gave information about short distance moisture variability.

In order to avoid the influence of time dependence of the water content in the soil profile in results of the spatial variability measurements, we restricted the total dimension of the plot to perform the measurement at each depth within one working day.

We used a field moisture meter TDR (described in more in detail in [4]) which gave one reading of the water content and electrical conductivity per approximately 40 s. This fact restricted the number of measurements per working day to the value about 400-500.

The TDR probe consisted of two rods of 2 mm diameter and 100 mm long fixed at the end of plastic rod of 25 mm diameter (Fig. 2). The TDR as well as EC signal was transmitted to and out of the probe by the coaxial cable with the plug.

We assumed that the readout was representative for the position at the middle of the rods, which meant that inserting rods from the surface to the soil to a 100 mm depth was equivalent to a measurement at a 50 mm depth. In fact the readout represented a mean value over rods length, weighted by the sensitivity function specific for the TDR probe geometry.

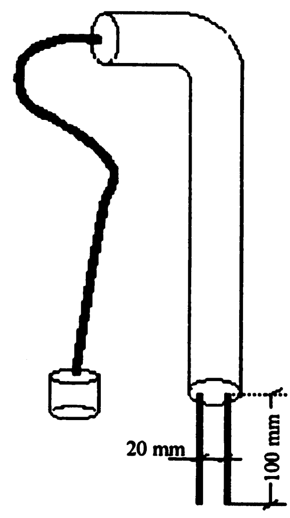

Fig. 2. The TDR probe used for water content and electrical conductivity measurements.

We measured water content at four depths: 5, 15, 25 and 35 cm. Measurements at the first three depths were done with a resolution 1x1m, measurements at the depth 35 cm were done with a resolution of 2x2 m.

A similar procedure was employed for measurement in a small scale (the central square): the first three layers were scanned with a resolution of 0.5x0.5 m and the deepest layer with a resolution of 1x1m.

Each measurement was done immediately after preparing an access hole to the given depth. The tool for making access holes consisted of a metal cylinder of a diameter of 30 mm in order to make the entry of TDR probe. The soil which had been taken out of the access holes was used for bulk density and oven dry water content determination.

We permanently installed the set of TDR probes in the soil profile close to the measured plot in order to monitor the water content change during the run of the experiment. The water content change during the measurement days was within 2%, it was much less than the variability within each layer. We considered, for our purpose, the water content in the profile constant during the time of measurement.

We also took samples of the soil from each depth in order to measure the water content by an oven dry method. The number of samples taken was 30 per each layer.

RESULTS

The water content measurement results at different depths are presented in Fig. 3.

The large amount of data allow us to present the frequency distribution of measurement values for different depths. Figures 4 and 5 present the frequency distribution of water content TDR measurements and electrical conductivity, measured simultaneously, for different depths.

Water content measurement frequency (number of measurements for specific water content) curves for each depth show the spread of the gathered data set (Fig. 4). The structure of the soil profile influenced the results. When going deeper the mean water content gets higher, especially for the last curve which belongs to the different genetic layer. The third layer (25 cm) shows a large scatter due to the transient character of the soil at this depth. There is the interface between different soil layers. Measured electrical conductivity shows much higher relative dispersion especially at the depths 25 and 35 cm (Fig. 5) than water content.

The summary results about data statistics presented in Table 1. The data in the Table 1 show a continuous increase of the water content with depth in the first three layers with an abrupt change in the fourth layer. This change is caused by the soil profile structure. Below 30 cm there is a significant change in the soil texture, namely there is a clayey layer with an abrupt top boundary.

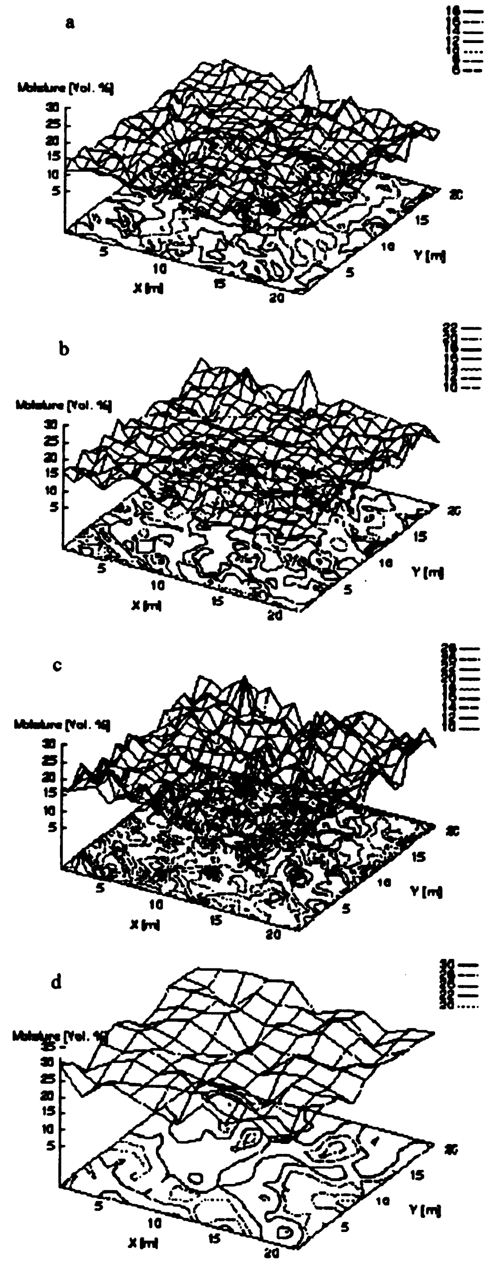

Fig. 3. The water content spatial distribution measured at depths: 5cm (a), 15 cm (b), 25cm (c) and 35 cm (d).

The autocorrelation functions are defined as [5]:

$$\rho_{uu}(\tau) = \frac{\frac{1}{M}\Sigma_{i=1}^{M} u(r_i)u(r_i+\tau) - \frac{1}{M^2}\Sigma_{i=1}^{M} u(r_i)\Sigma_{i=1}^{M} u(r_i+\tau)}{\left\{\frac{1}{M}\Sigma_{i=1}^{M} u(r_i)^2 - \frac{1}{M^2}\left[\Sigma_{i=1}^{M} u(r_i)\right]^2\right\}^{\frac{1}{2}}\left\{\frac{1}{M}\Sigma_{i=1}^{M} u(r_i+\tau)^2 - \frac{1}{M^2}\left[\Sigma_{i=1}^{M} u(r_i+\tau)\right]^2\right\}^{\frac{1}{2}}}$$

where M - is the measuring point density for a given distance τ from the considered point at the position r_i.

The autocorrelation curves for the water content at different depths are presented in Fig. 6. In contradiction to previous measurements [11,12] the autocorrelation functions grow very quickly with the distance and reach unity at distance of about 5 m. This means that the unknown value of water content can be considered random when one moves a distance of about 5 m from the measurement point. Thus the prediction or interpolation of data deviation at points at a distance of about 5 m from the measurement points is not possible due to the lack of correlation between moisture contents at these distances.

Figure 7 shows the measurement difference between the TDR method and the oven dry method.

At the surface the scatter of TDR measured water content versus oven dry measured

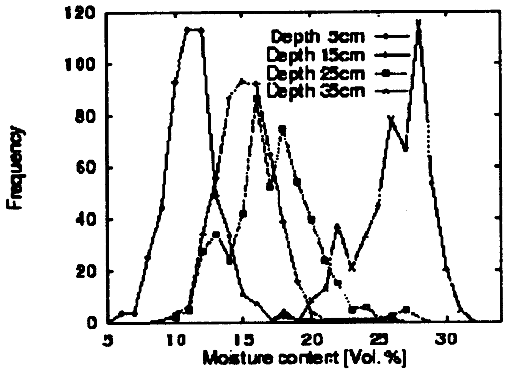

Fig. 4. Frequency distribution of water content TDR measurements for different depths.

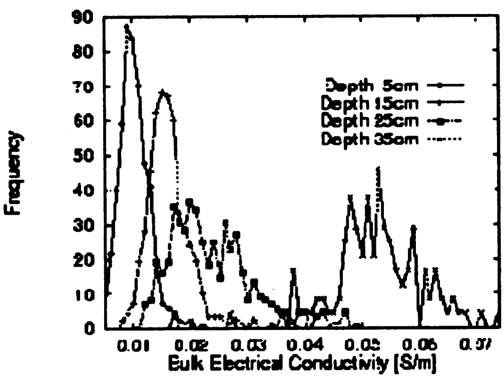

Fig. 5. Frequency distribution of bulk electrical conductivity for different depths.

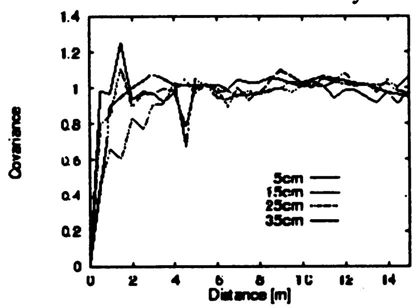

Fig. 6. The autocorrelation function for water content measurements at different depths.

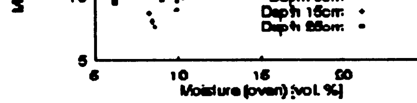

Fig. 7. The comparison of TDR water content with the oven dry measured water content for different depths.

Table 1. Statistical parameters of the water content and bulk soil electrical conductivity at different depths

Number of points	Depth (cm)	Mean water content (%)	Standard dev. (%)	Mean conduct. (S/m)	Standard dev. (S/m)
497	5 (0-10)	11.27	1.91	0.010	0.0026
497	15(10-20)	15.25	2.16	0.016	0.0038
497	25(20-30)	17.08	3.07	0.024	0.0073
149	35(30-40)	26.18	2.53	0.053	0.0087

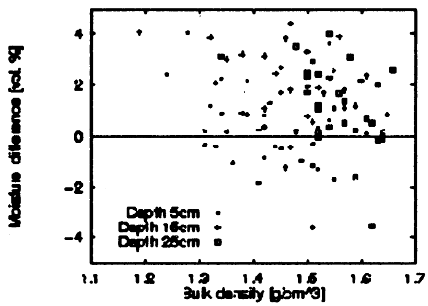

Fig. 8. The difference of water contents: TDR measured and oven dry, versus the bulk density of the soil.

water content is relatively high. We think the main cause is the water content variability due to evaporation from the rough soil surface. The depth of dry layer on the soil surface varies according to local conditions, influencing both methods of measurements in a different way. Both methods (TDR and oven dry) of water content measurement give a kind of mean value of water content over the sample volume. Both mean values are differently calculated. In the case of sample heterogeneity or in the case of water content gradient existence, both mean values are not equivalent. These facts are responsible for a larger scatter of TDR to oven dry - measured water content at the soil surface layer.

Deeper layers (15 and 25 cm) show a good correlation between the two methods of measurement. The scatter becomes relatively low when going deeper, to 15 and 25 cm. The points are spread along a 1:1 line. Measurement points are slightly over the 1:1 line, which means that the calibration characteristics of the TDR device depends on the bulk density and type of the soil.

Figure 8 shows that there is no a significant dependence of the water content difference (TDR-oven dry) on the bulk density of the soil. This means that the variability of the water content is not affected by the bulk density variability but rather by other factors.

CONCLUSIONS

The TDR measurements of the volumetric water content is a convenient tool for numerous field measurements in a short time.

As it gives a simultaneous reading of the bulk electrical conductivity, it may be used for monitoring salt migration in the soil profile.

The permanently mounted TDR probes allow us to monitor the soil water content, soil bulk electrical conductivity, and soil temperature changes at different depths.

The numerous measurements of the water content by TDR allow an easy assessment of the water content variability parameters such as mean value of water content over the area, standard deviation of measurements, autocorrelation function etc.. Resulting values play a crucial role in the modeling of water flow in the heterogeneous media.

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