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MEASUREMENT OF WATER CHARACTERISTICS IN SOILS USING TDR TECHNIQUE: WATER CHARACTERISTICS OF LOESS SOIL UNDER DIFFERENT TREATMENT

R.T. Walczak, C. Sławiński, M. Malicki, H. Sobczuk

Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-236 Lublin, Poland

A b s t r a c t. The paper presents practical implementation of the TDR (Time Domain Reflectometry) technique and the instantaneous profile method for the determination of differences of hydrophysical parameters of soil caused by changes in a soil structure, brought about by different manners of agricultural utilization of the soil.

K e y w o r d s: TDR, soil water characteristics, soil structure

INTRODUCTION

Within the framework of a joint Austrian-Czecho-Slovak-Hungarian-Polish program of studies on the soil structure, the TDR (Time Domain Reflectometry) technique was applied for the determination of the water potential-water content curve and the coefficient of water conductivity within the usaturated zone of selected soils. As a result of the analysis of many methods for the determination of such characteristics, this technique proved to be the best, due to its simplicity, speed of measurements, and the ease of interpretation of results obtained. For purposes of the study, the authors adopted the experimental apparatus and software used at the Institute of Agrophysics, Polish Academy of Sciences [2,3,5,6].

MATERIALS

For the comparative study, we selected loess soils which were utilized differently for last 40 years, from two profiles localized at Czesławice, 20 km west of Lublin. One of the profiles is located in a field utilized by a private farmer; the other - in a field utilized by the State Experimental Farm.

An important purpose of this study is to observe the effect of changes in the soil structure, caused by different tillage, on its water characteristics. The main criterion for the selection of the material for the study, was different tillage applied on the field cultivated by the private farmer and on the field belonging to the State Experimental Farm. In the latter case, the field was tilled using heavy agricultural machinery, which led to a greater degree of the soil compaction in the top horizon, while the private farmer used lighter machinery and equipment on his field. This resulted in a considerable differentiation in the structure of top horizons of soil in the two fields, which can be seen comparing the bulk density and total porosity of the Ap genetic horizons (1.23 g cm^{-3}, 53.0 % v/v, and 1.39 g cm^{-3}, 46.7 % v/v, for the private and state farm soils, respectively).

METHOD AND EQUIPMENT

Samples of the soil material were taken from the Ap, E and Bt genetic horizons of both profiles. We used metal cylinders 35 cm in diameter and 12 cm high. The soil material was transferred to the laboratory, where samples, in two replications, were put into cylinders 5 cm in diameter and 10 cm high, used as standard in the TDR method. These cylinders are provided with apertures for the installation of TDR probes and minitensiometers. Figure 1 shows a cross- section of such a cylinder, with the TDR probe and the microtensiometer installed, as it is described in [6]. The soil column thus prepared, with moisture and pressure measurement sensors installed, was saturated through capillary uptake. The top of the column was covered and the column was left for 24 h for the moisture and potential distribution to equilibrate. After that the top cover was removed, which led to the drying of the soil sample in the column through evaporation. During that process values of soil moisture and potential at heights of 1, 3, 5, 7, and 9 cm from the bottom of the column (Fig. 2) were automatically recorded by the computer system.

EXPERIMENTAL DATA

Soil water potential and soil moisture were monitored at five levels of the soil column z_i, i=1,...,5, at various times t_j, j=0 ,..., M, in the process of evaporation (M is the number of soil moisture and soil water potential measurements taken for a selected level i). Experimental data obtained in this manner have the following form:

$$\theta = \theta\,(z_i, t_j) \text{ and } \psi = \psi\,(z_i, t_j)$$

Figures 3 and 4 present examples of the experimental data obtained in the process of drying of the soil material from the Ap horizon.

Figure 3 shows the data for the soil from the state farm while Fig. 4 shows the data for the soil from the private farm.

The dynamics of the soil water potential in time for the five soil column levels is presented

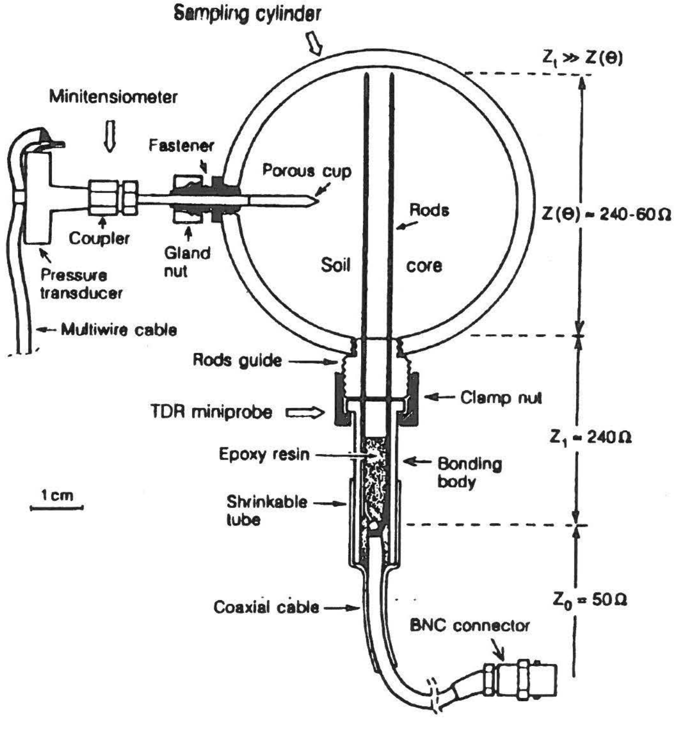

Fig. 1. Cross-section of the 'measuring cell' with the TDR soil moisture miniprobe installed. Also the minitensiometer is shown in details. Discontinuities of the miniprobe impedance are marked with dashed line.

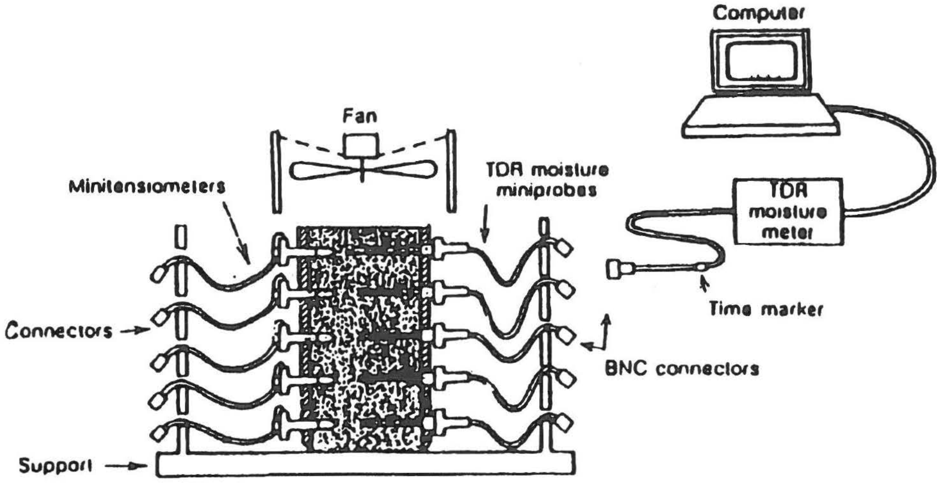

Fig. 2. Structural setup of the experimental stand. A soil core under investigation is kept in a metal sampling cylinder. An array of five minitensiometers and another array of five TDR soil moisture miniprobes are installed, marking of five independently monitored layers of the soil. Spiral arrangement of the probes is not visualized.

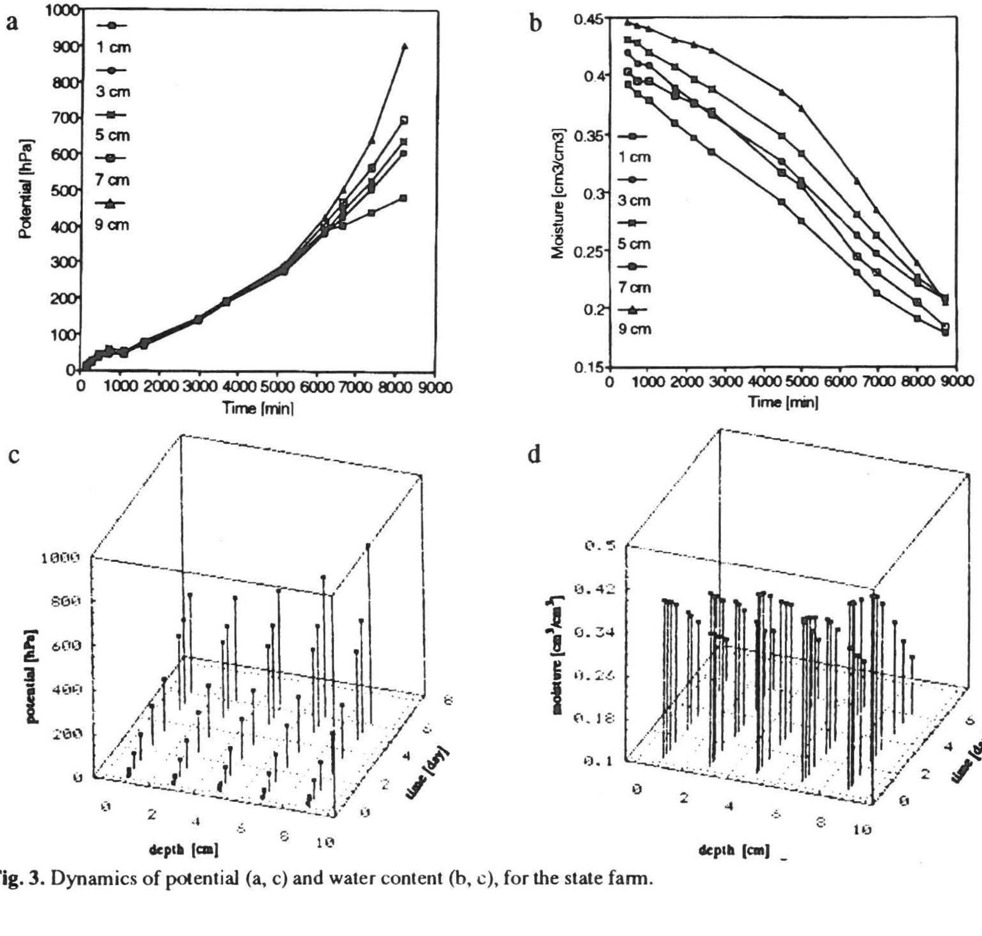

Fig. 3. Dynamics of potential (a, c) and water content (b, c), for the state farm.

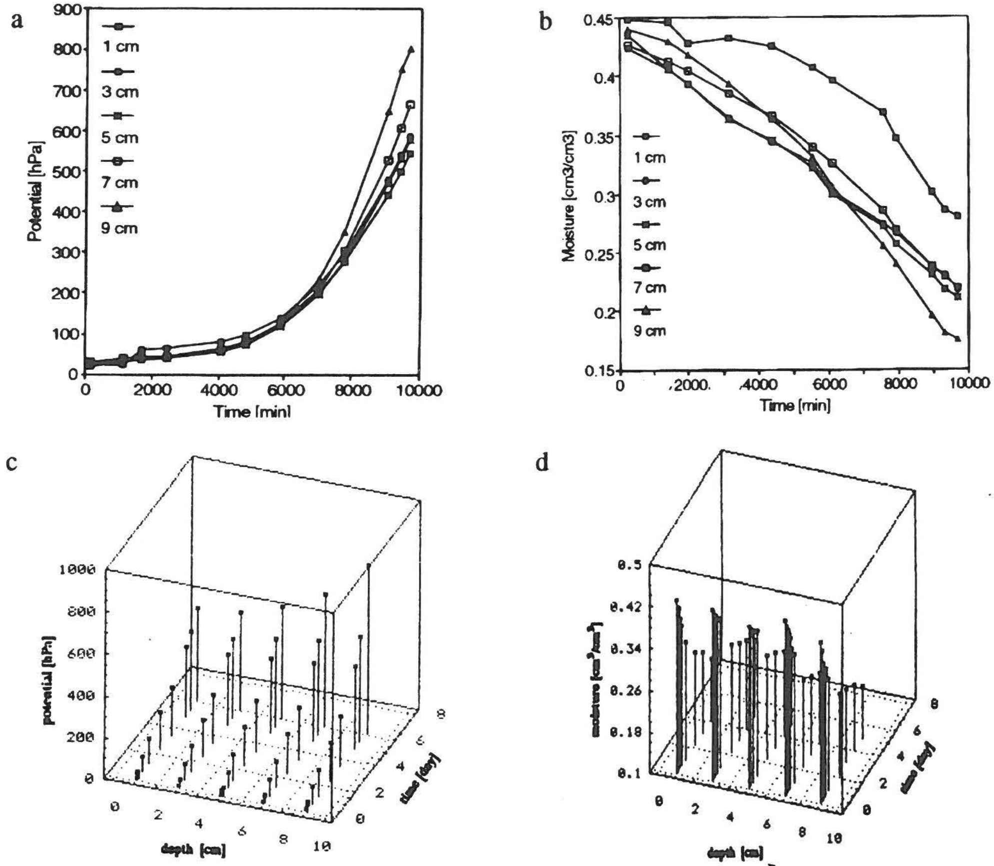

Fig. 4. Dynamics of water potential (a, c) and water content (b, d) for private farm.

in Figs 3a and 4a, while corresponding three-dimensional diagrams in a system of depth-time-potential co-ordinates are presented in Figs 3c and 4c. Likewise, Figs 3b, 4b and 3d, 4d present the dynamics of moisture in the soil column in time and space.

DATA PROCESSING

The experimental data for the soil water potential and moisture as the function of position and time carry a measurement error. Since the readout and the computer recording of the values of moisture and soil water potential for the level studied occur one after the other, they are also separated in time. In order to smooth out and interpolate the experimental data, we employed Bezier functions [1] proposed by [5,6], in the form:

$$\varphi_i^N(\tilde{x}) = \frac{N!}{(N-i)!\,i!}\,\tilde{x}^i\,(1-\tilde{x})^{N-i} \qquad (1)$$

where: $\Phi \leq \tilde{x} < 1$, ! is a factorial function, $i = \Phi, N$ for which the condition is fulfilled:

$$\sum_{i=\varphi}^{N} \varphi_i^N(\tilde{x}) = 1 \qquad (2)$$

This permits the creation of two fields: potential and moisture field dependent on time and position, according to the formulae:

$$\hat{\theta}(\tilde{z}, \tilde{t}) = \sum_{i=\varphi}^{N} \sum_{j=\varphi}^{M} \theta(z_i, t_j)\, \varphi_i^N(\tilde{z})\, \varphi_j^M(\tilde{t}) \qquad (3a)$$

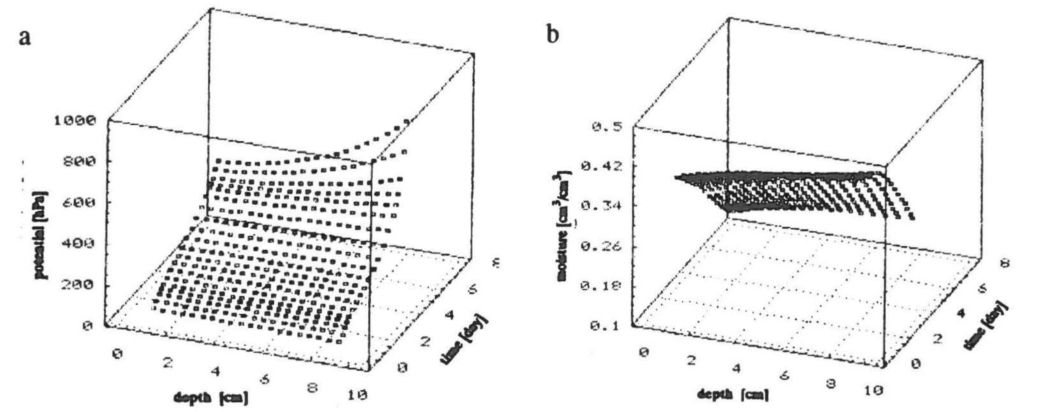

Fig. 5. Time-depth dependence of water potential and soil moisture smoothed from measured points (private farm).

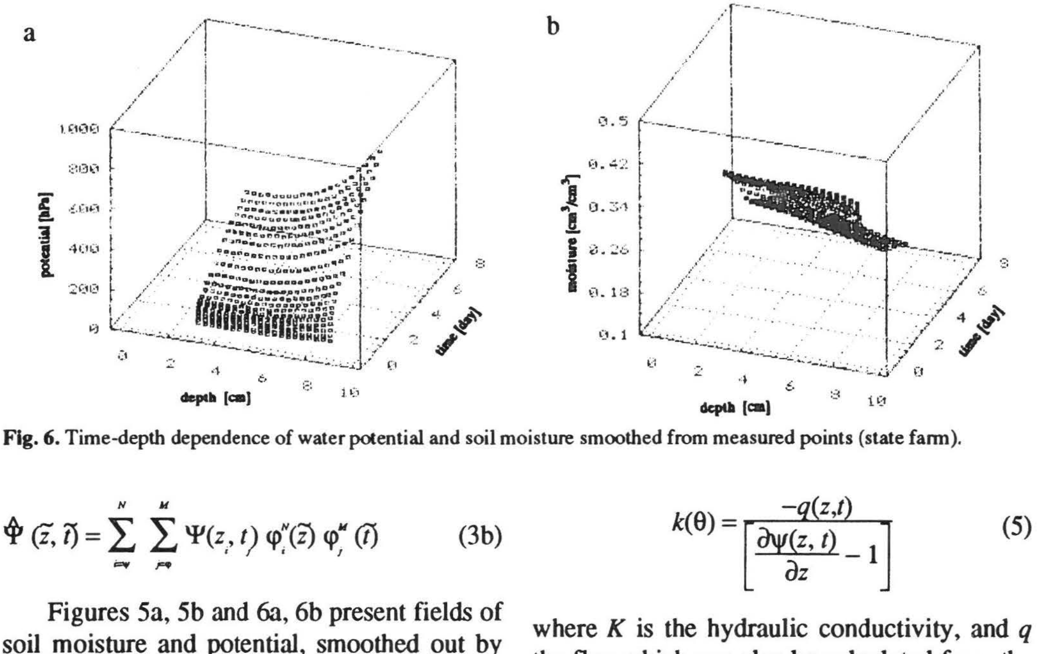

Fig. 6. Time-depth dependence of water potential and soil moisture smoothed from measured points (state farm).

$$\hat{\Psi}(\tilde{z},\tilde{t})=\sum_{i=0}^{N}\sum_{j=0}^{M}\Psi(z_i,t_j)\,\varphi_i^N(\tilde{z})\,\varphi_j^M(\tilde{t}) \qquad (3b)$$

Figures 5a, 5b and 6a, 6b present fields of soil moisture and potential, smoothed out by means of the method described above, for the experimental data obtained for the Ap horizon, from the state and the private farms respectively. Assuming that the process of water transport takes place under isothermal conditions and is one-dimensional, an one-dimensional Darcy equation was used for the calculation of the coefficient of hydraulic conductivity, in the form:

$$q(z,t)=-k(\theta)\left[\frac{\partial\psi(z,t)}{\partial z}-1\right] \qquad (4)$$

from which, after transformation, we obtain:

$$k(\theta)=\frac{-q(z,t)}{\left[\dfrac{\partial\psi(z,t)}{\partial z}-1\right]} \qquad (5)$$

where K is the hydraulic conductivity, and q the flux which can also be calculated from the equation:

$$q(z,t)=-\int_0^z\frac{\partial\theta(z,t)}{\partial t}\,dz\,. \qquad (6)$$

RESULTS

Comparing the water characteristics of genetic horizons within each of the profiles one can find that differences between the retention curves are not large (Figs 7, 8). The water content is the lowest for the Ap horizon at the state farm, which is probably caused by

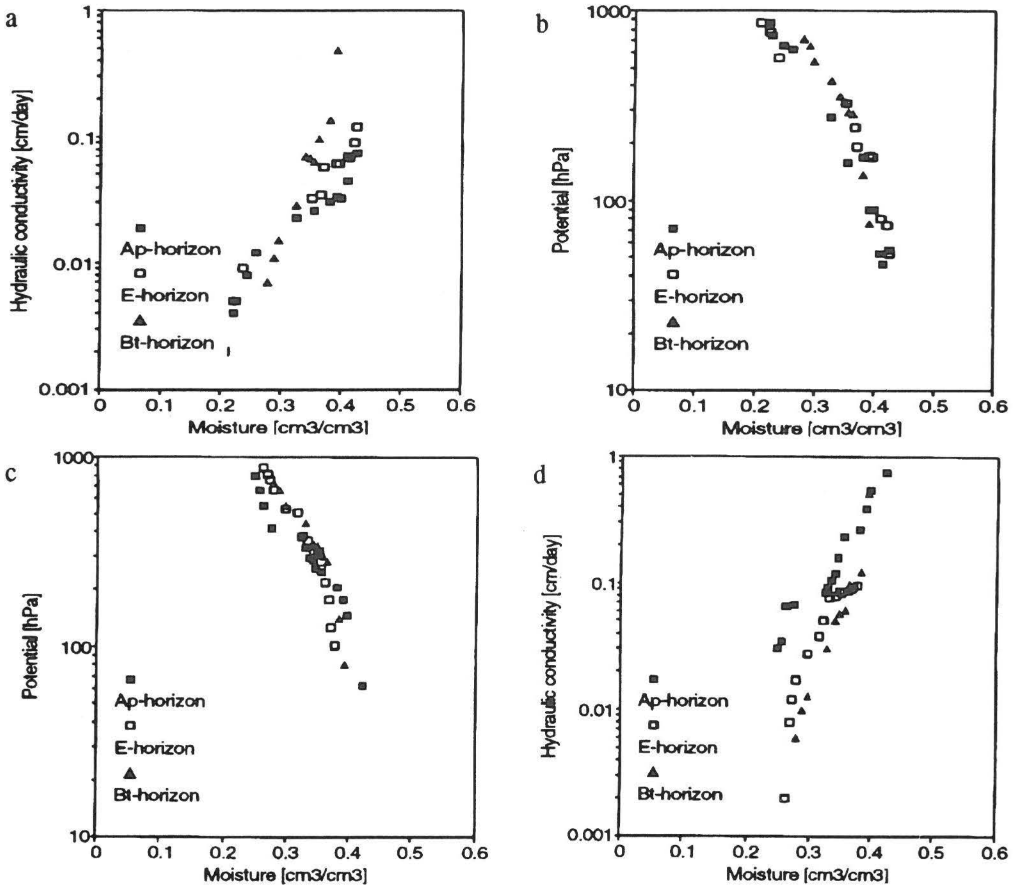

Fig. 7. Hydraulic conductivity and water potential as a function of moisture for state (a, b) and private farms (c, d).

the soil compaction by heavy machinery. Water retention for the Ap horizon soil at the private farm has higher values, except for the value for small pore diameter. The characteristics of the hydraulic conductivity versus water content show a distinct differentiation between the horizons in the two profiles (Figs 7c and 7d). The highest values of the hydraulic conductivity for the state farm (especially at high moisture level) are found in the Bt horizon, whereas the lowest values are observed in the Ap horizon which is subjected to heavy loading. The opposite relation is found for the private farm. The highest values of the hydraulic conductivity are recorded for the Ap horizon through the whole range of moisture, lower values are observed for the E horizon, and the lowest for the Bt horizon. This situation prompts the conclusion that the tillage technology at the private farm, with no heavy equipment, results in better hydrophysical properties of the Ap horizon.

Comparing the same horizons in both profiles (Fig. 8) it was noted that the water characteristics for the Bt horizon do not show differences between the profiles under study. There are differences between the characteristics determined for the Ap and E horizons, and they are especially big for the hydraulic conductivity. The differentiation of these characteristics for the deeper horizon, E, is smaller and it does not justify any unambiguous conclusion about the difference between the soil at the state and the private farm. In the case of the Ap horizon the water retention curve for the soil cultivated in the private farm is slightly above that for

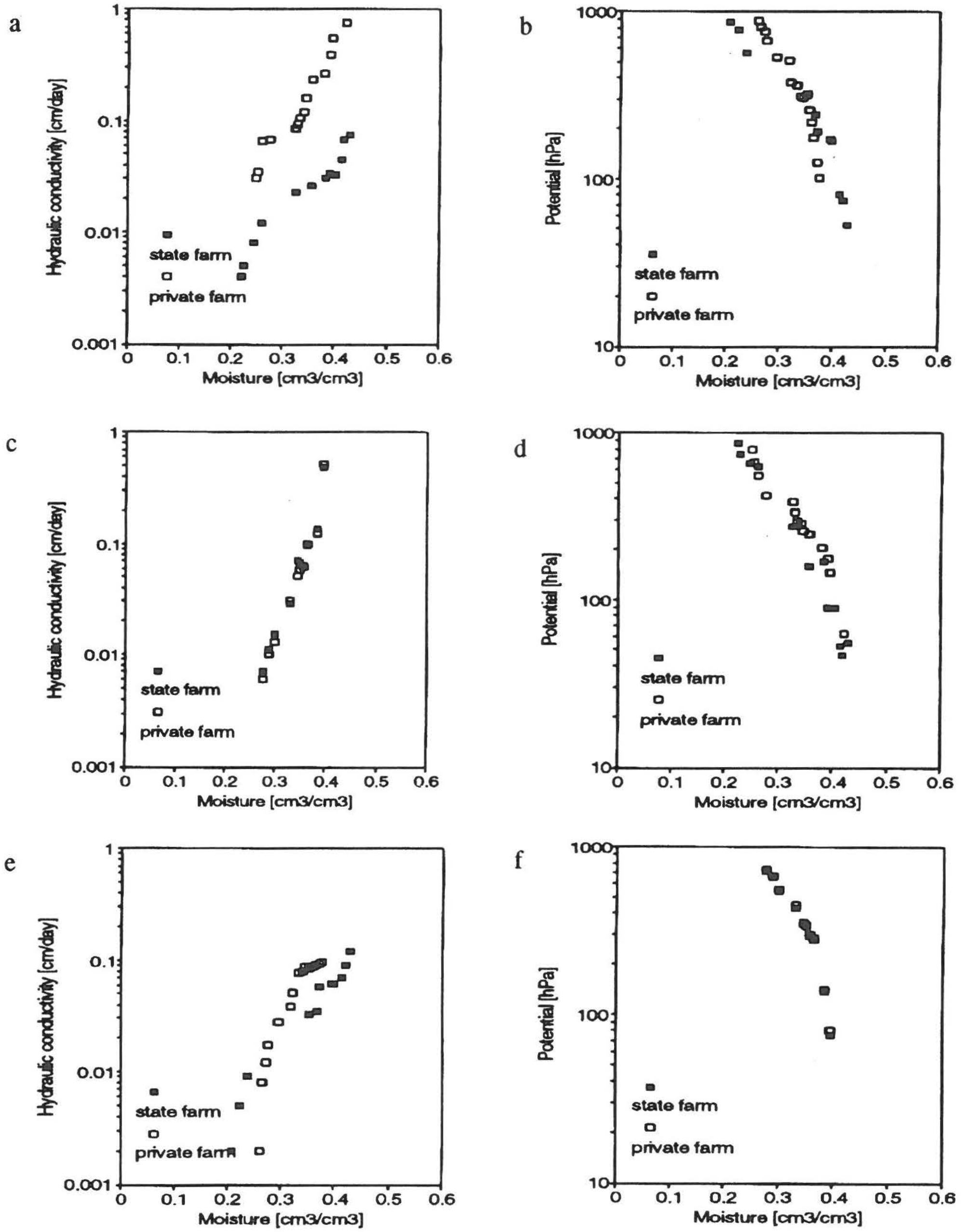

Fig. 8. Comparision of hydraulic conductivity and water potential water content relationship for Ap (a, b) E, (c, d) and Bt (e, f) horizons.

the state farm soil. The values of the hydraulic conductivity for this horizon are considerably higher for the soil cultivated in the private farm.

The results suggest that the configuration of the solid phase, characterized by the pore distribution and continuity, is clearly better on the private farm. The fact that the hydraulic conductivity values for moisture close to saturation are about ten times higher for the private farm as compared to the state farm soil is of special importance. This is a particularly useful property of loess, because the associated increase in the amount of water infiltrating into the profile diminishes the probability of water run-off, and consequently decreases the susceptibility to erosion.

The differences in the physical properties investigated are caused by different tillage and harvesting technologies. In the state farm the machinery used was heavy and the effect of compaction of the upper soil layer was more pronounced.

The study carried out shows that the proposed apparatus and the analysis of results can be used for comparison of the effect of different tillage technologies on water characteristics as parameters describing the soil structure.

CONCLUSIONS

1. The TDR technique, together with the instantaneous profile method, permits the determination of the effect of changes in the soil structure, caused by the manner of the soil utilization, on the hydrophysical properties of the soil.

2. The method of agricultural utilization of soil has a considerable effect on the hydrophysical properties of its upper layer.

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