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METHOD OF DETERMINATION OF SOIL HYDRAULIC CONDUCTIVITY USING AN AUTOMATIC MEASURING SYSTEM SP-86

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A b s t r a c t. This paper describes the method of determination of soil hydraulic conductivity using a new measuring system SP-86. The system cooperates with the IBM PC-86 XT/AT computer in an analog-digital disposition. The results obtained from testing of particular elements of the system and the programme have pointed out that the method for determination of conductivity K(h) can be widely applied in designing and exploitation of drainage systems.

INTRODUCTION

For designing and proper expoiltation of melioration structures and systems, a description and then simulation of the states and processes of water circulation in soil-plant-atmosphere system is indispensable. The above consists the essential link in determining criteria for exploitation efficiency and reliability of these structures. Because of a very complex character of these processes, therefore for their description numerical modelling is being more and more often used.

Water flow in soil profile may occur either at full or at partial saturation of the medium with water. This flow is described by nonlinear differential equations, called in the literature as Richards or Fokker-Planck. The evaluation of soil moisture changes in aeration zone, considering non-steady state of flow in saturation zone requires a very complicated mathematical apparatus.

To obtain a numerical solution of Richards' differential equation we must assume certain initial and boundary conditions as well as we should know the parameters of soil medium determined experimentally. These parameters are as follows: soil moisture (θ) in function of soil suction pressure (h), (i.e. $\theta(h)$), hydraulic conductivity in function of moisture ($K(\theta)$) or suction pressure ($K(h)$), and soil diffusivity ($D(\theta)$ or ($D(h)$).

The soil, being a porous medium, is characterized by great variabiltiy in space and time. That is why the measured data of soil parameters are often very scattered, even despite using the same method of measurement. On the other hand, there is tendency to carry out the measurements 'in situ', to eliminate methods separating soil sample from its environment. More detailed discussion on this subject one can find in other papers [15].

One of the most essential factors deciding upon the reliability of measurement is the time; shortening the time can be obtained by applying automatization of measuring procedures with the help of computer steering in a set of sensors installed in the soil permanently or incidentally. In the measuring system, the computer steers the appliances, collects measuring data, processes them and gives a desired documentation. All these functions together with methodology to measure given soil parameter determine, to wide extent, the kind of indispensable equipment.

In last decade we observe a rapid development of automatic measuring technics.

The system was elaborated under the project CPBP 05.03. for an automatic acquisition and processing of data on physical parameters of soil medium. The system uses a standard interface system IEC-625, compulsory in Poland since 1985 and compatible with the standard PN-83/T-06536. Such a system for a computer of IBM type PC-86XT/AT was constructed at the Institute of Electronics of Warsaw Technical University and is available at the moment.

The system SP-86 allows us to measure the soil water potential (suction pressure), to transform the obtained pressure impulse into electric impulse by pressure sensor, to record and store the obtained value in the computer memory and then to calculate the desired numerical value of a given soil physical parametr according to chosen procedure. To use the measuring system the programme is necessary which allows us to utilize all the elements of the computer and measuring system with the use of a higher order language.

The paper presents also the programme for calculation of the coefficient of soil hydraulic conductivity, analysis of pressure sensors to measure soil water potential, the system for transmission of physical value of the potential from soil medium towards electronic prerssure sensor, and an example of application of measuring system SP-86 for determination of soil hydraulic conductivity $K(h)$.

METHODS AND RESULTS

Programme of the system SP-86 for measuring soil hydraulic conductivity $K(h)$

The programme of the system has been elaborated in BASIC. Block diagram of the programme for use in satudies on soil hydraulic conductivity is presented in Fig. 1. The basic programme, called GLEBA.BAS, allows to carry out the measurement as well as to collect and process the data. The programme PUH.BAS allows us to convert the voltage values U of the sensor's signal measured by the system into corresponding values of suction pressure h, utilizing sensor's characteristics determined earlier. The results obtained are stored in an auxillary file for further processing.

Programme PHAT.BAS improves another very laborious work while elaborating the measured data, that is it recount the values of suction pressure h, obtained with the help of PUH program, into corresponding values of moisture θ. Data for this programme consists of two sets containing corrected values of pressure and soil water desorption characteristics (pF). Listings of the programme with their description are given elsewhere [8].

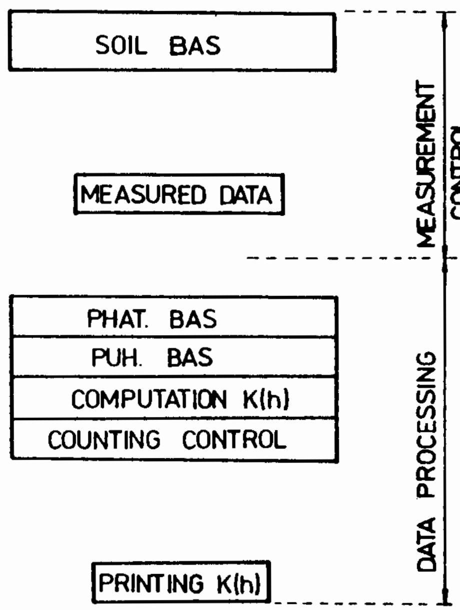

Fig. 1. Block diagram of the programme of system for measuring unsaturated soil hydraulic conductivity.

Transducers applied to measure soil suction pressure (*h*)

The replacement of manometric measurements by transducers in measuring technics for soil suction pressure determination started a considerable progress. In the measuring system SP-86, for the determination of the function *K*(*h*) there were applied piezoresistor transducers of the series 126PC15D1, manufactured by Honeywell, and PS-100 by Mera.

For evaluation of the transducers' quality in view of their application for the determination of *K*(*h*), their voltage characteristics has been used (*U* (*h*)). The studies were carried out in the suction range from about -700 hPa to about +700 hPa. The obtained pairs of voltage (*U*) and suction points (*h*) were elaborated statistically using programme STATGRAF.

For each sensor a regression function an its parameters were determined. Statistical analysis of deviations between measuring points and the line determined by the regression equation decided wheather sensor characteristic was composed of one, two, or three stright lines. Coefficient of correlation and standard deviation were criteria for evaluation of the corectness of the applied division into groups of points, for which the regression was done. The division of the characteristic into two or three lines allowed us to improve the measurement exactness from 5 to 10 times. Exemplary results of sensor measurement characteristics are given in Figs 2 and 3.

The results point out that most useful appeared to be sensors manufactured by the firm Honeywell, both from the designing as well as economic point of view.

System for transmission of soil suction pressure (*h*)

Ceramic elements, used so far to measure soil suction pressure did not cooperate satisfactorily with other elements of measuring system. Therefore, we have elaborated own technology to produce ceramic elements incorporated into the system SP-86.

Ceramic material consists of silt-kaoline mixture with certain admixtures, burnt at a temperature of 1150 °C. The properties of this material were compared with the laboratory porous cups made in Japan and with the field cups produced by the Institute of Agrophysics. The study concerned the determination of resistance and water conductivity. An analysis of differences between pressure in the medium where the ceramic element was placed, and the measuring system was performed. The medium was hydraulic system filled up with water, where pressure was applied stepwise. Water flow between the medium and the measuring system was practically eliminated by using the transducer. The results obtained are presented in Figs 4, 5, and 6. They clearly point that pressure compensation occurs very quickly in all the tested porous cups. For example, the stabilization time for pressure in readout system was as follows: for ceramics manufactured in Warsaw - 0.1-0.3 min; for Japanese ceramics - 0.1-0.3 min; and for ceramics from Lublin - 0.5-1.0 min.

Determination of the soil hydraulic conductivity coefficient using measuring system SP-86

The method of determining the soil hydraulic conductivity coefficient *K*(*h*) with the use of automatic measuring system SP-86 is based on drying method, classified by Klute [6] into directlaboratory methods of nonstationary flow conditions (Fig. 7).

In this method, slowly changing flow in soil sample of undisturbed structure in a short time interval is considered as steady flow. The value of function *K*(*h*) can be obtained from

$$K(h)_{x_i}^{j+\frac{1}{2}} = \frac{\sum_{0}^{x_i} \left(Q_{t_{j+1}} - Q_{t_j} \right)}{F \ \Delta t} \frac{1}{\frac{\overline{\Delta h}}{\Delta x} - 1} \qquad (1)$$

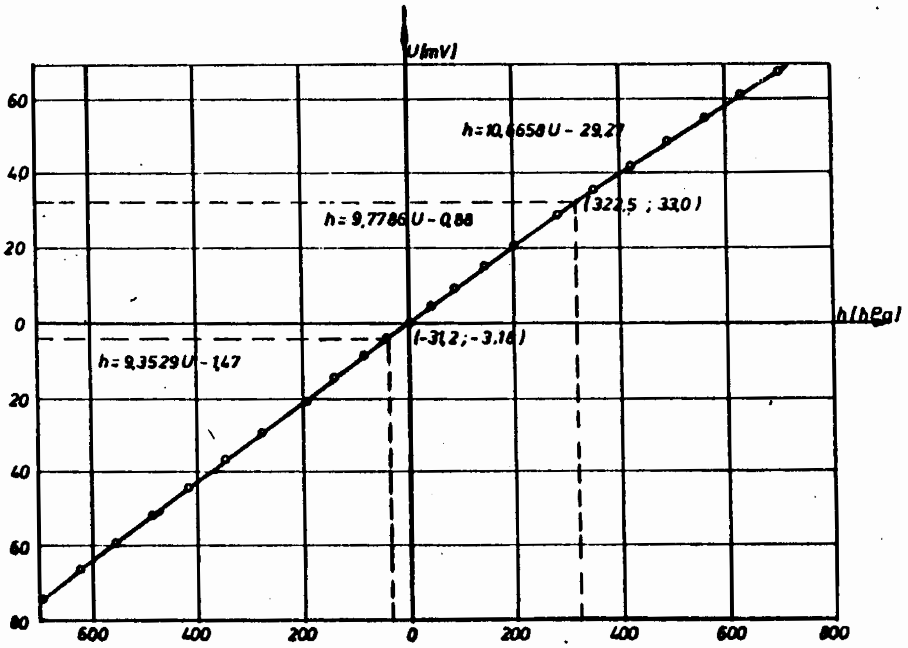

Fig. 2. Characteristics of 126PC15D1 sensor manufactured by HONEYWELL supplied with direct current of voltage 10 V +0.003V (defined with three stright lines).

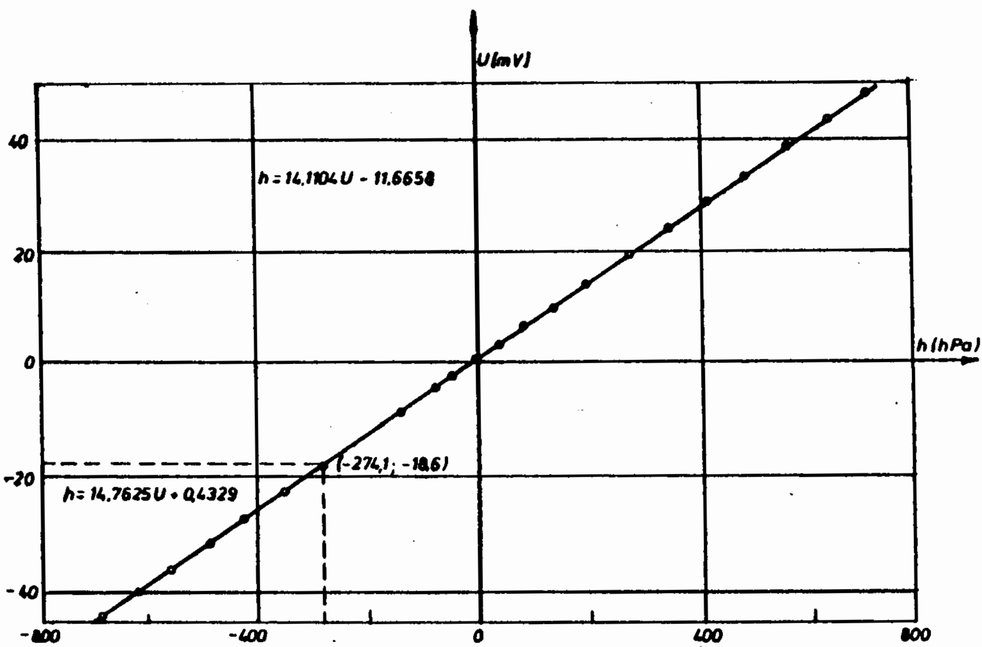

Fig. 3. Characteristics of PS-100 sensor manufactured by MERA, supplied with direct current of voltage 2 mA (defined with two stright lines).

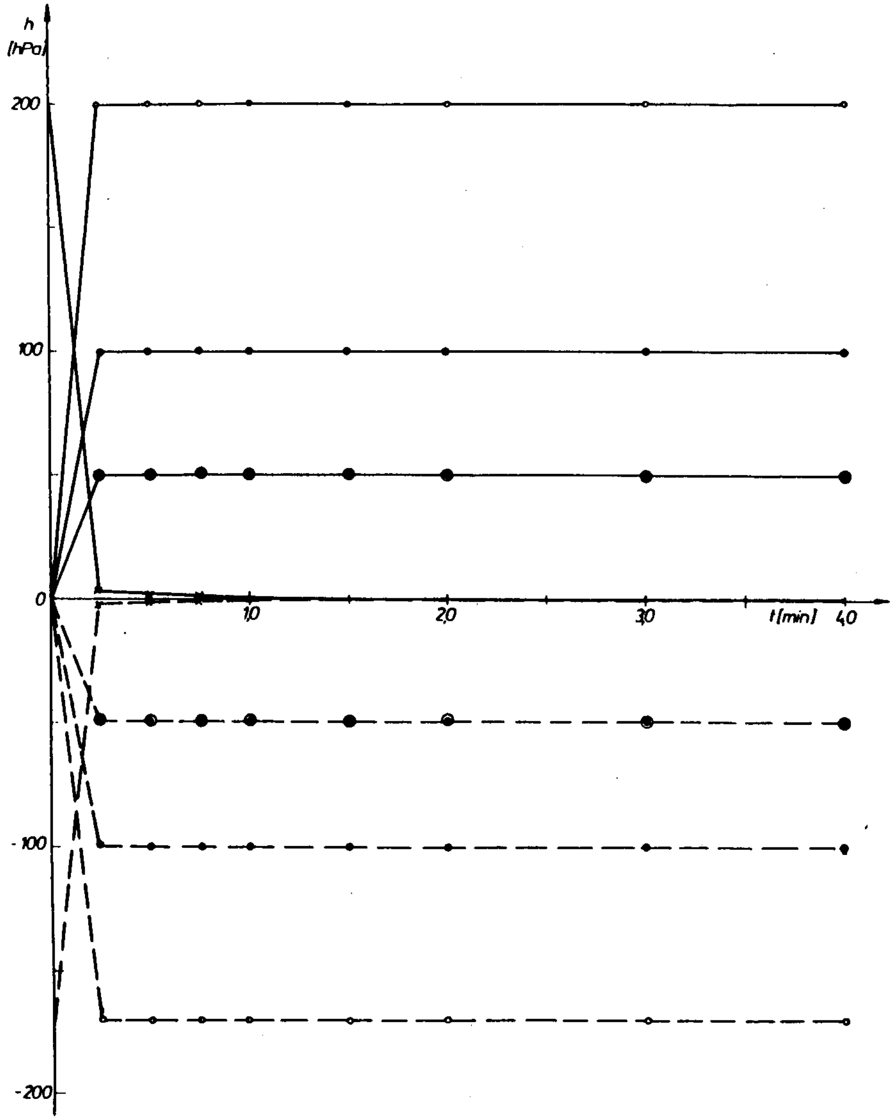

Fig. 4. Hydraulic characteristics of ceramic elements produced in Warsaw Agric. Univ.; laboratory version.

where $K\,(h)^{j+\frac{1}{2}}_{x_i}$ is the soil hydraulic conductivity (cm s^{-1}); $\sum\limits_{0}^{x_i}\left(Q_{t_{j+1}} - Q_{t_j}\right)$ is a volume of moisture loss in the column from the level x=0 to the calculated level x_j(cm3), F -cross-section area (cm^2), $\Delta t = t_{j+1}$-t_j- measurement time (s),

$$\Delta \bar{h}=\frac{1}{2}\left[\left(h^{j+1}_{i+\frac{1}{2}} + h^{j}_{i+\frac{1}{2}}\right) - \left(h^{j+1}_{i-\frac{1}{2}} + h^{j}_{i-\frac{1}{2}}\right)\right]\text{-}$$

- the difference of mean suction pressure in the layer $i+\frac{1}{2}, i-\frac{1}{2}$ (cm), $\Delta x = x_{i+\frac{1}{2}} - x_{i-\frac{1}{2}}$ - difference of distances (cm).

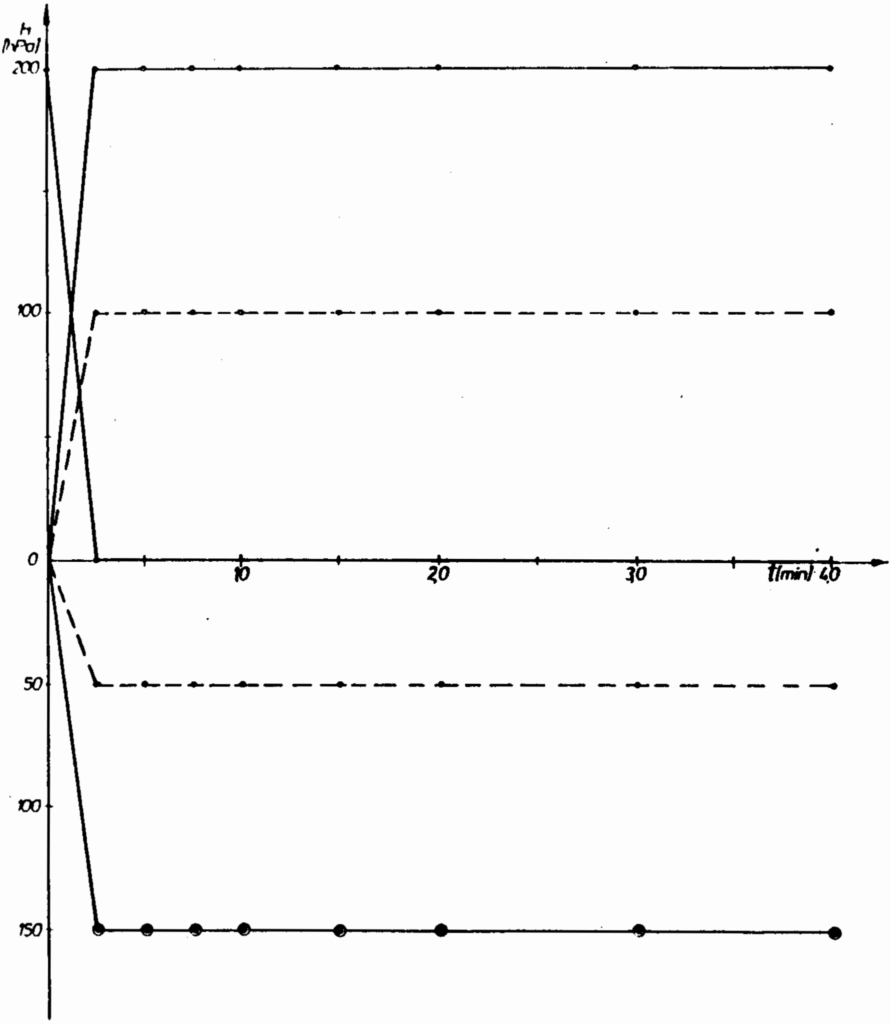

Fig. 5. Hydraulic characteristics of Japanese ceramic elements; laboratory version.

This method allows us to determine the dependency $K(h)$ in the range of h from 0 to about -700 hPa. For the study, the undisturbed soil sample is taken of 40-70 mm height and about 80 mm in diameter. The bottom base of the cylinder is tightly closed with a metaplexi cover. Ceramic elements are mounted in holes on cylinder wall. Ceramic elements are jointed with transducers which, in turn, are connected with easily separable wires to the system SP-86. The column prepared in such a way is then filled with water through the inley in the metaplexi plate. The changes in weight of the column should be done with accuracy of about 0.01 g by using the balance, type MEDICAT, Ltd., 1600C.

To recalculate the measured values of h into soil moisture we must know the soil water desorption curve (Fig. 8), measured in the laboratory on silt, silt-kaolin blocks and in high-pressure chambers. An exemplary study on the determination of $K(h)$ function was done for light loam of specific density 2.63 g cm^3, density - 1.62 g cm^3, filtration coefficient 20.9 cm/day, and organic matter content 0.6 %.

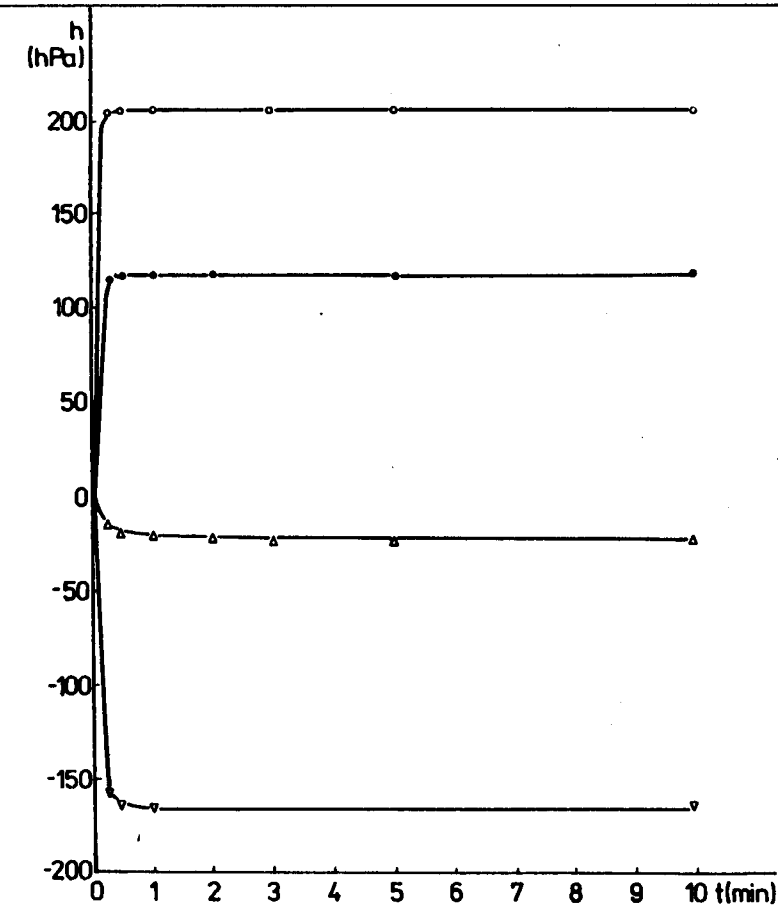

Fig. 6. Hydraulic characteristics of ceramic elements produced at the Institute of Agrophysics.

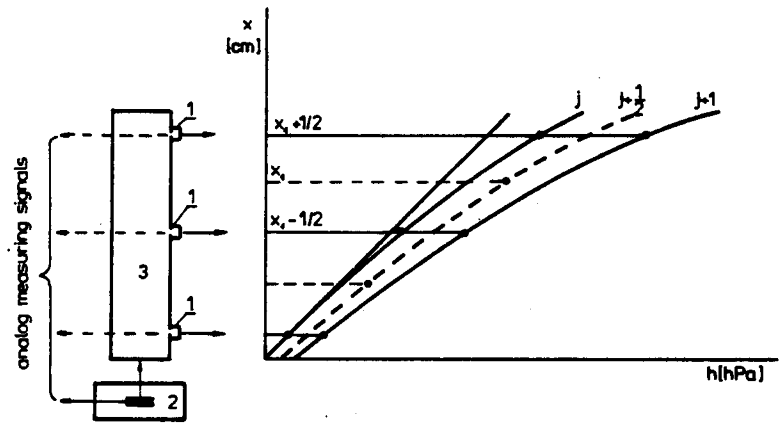

Fig. 7. Scheme of the soil hydraulic conductivity measurement K(h) with the method of drying: 1 - transducers; electronic balance; 3 - soil column.

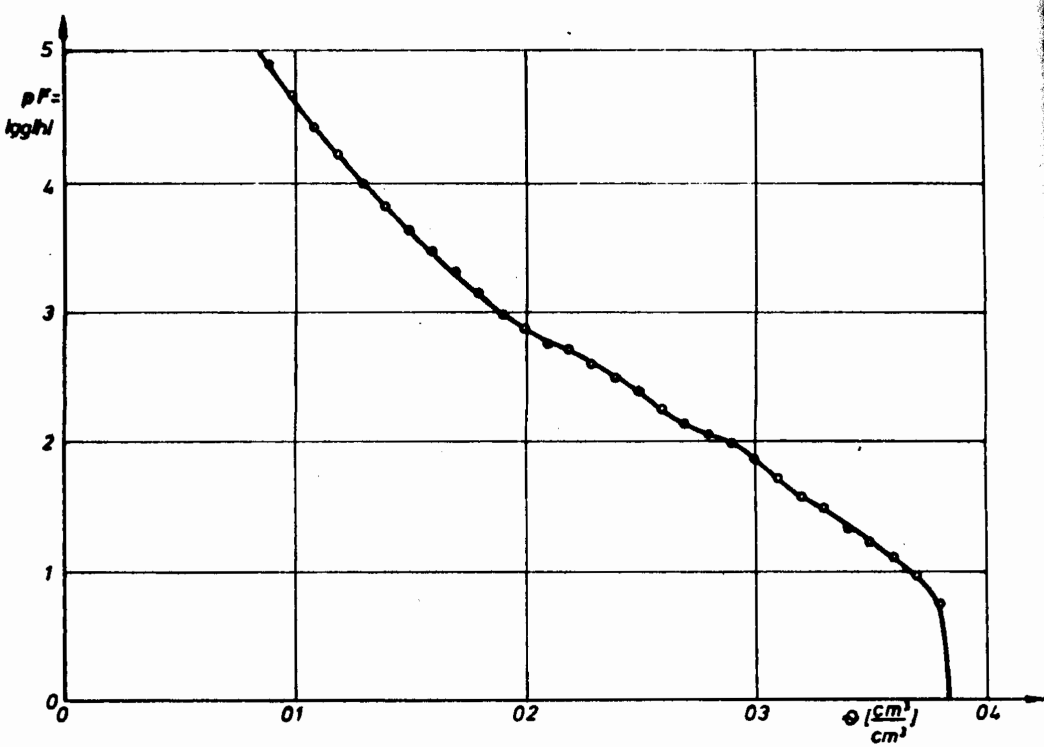

Fig. 8. Soil water desorption curve for tested light loam.

The measurements to determine the dependency $K(h)$ are limited to cyclic and automatic registration, by the system, of changes in sample weight and value of soil water potential. After completing the measuring cycle the data are processed and the value of $K(h)$ coefficients are obtained. The course of the function $K(h)$ in full range of h can be obtained by integration of the laboratory method with an analytical method proposed by van Genuchten [10,11], which is presented in Fig. 9.

CONCLUSIONS

The described method for determination of soil hydraulic conductivity using an automatic measuring system enables testing this parameter with various empirical and semi-empirical methods.

It also makes possible to collect reasonably wide set of direct measurements which, in turn, allows us to analyse indirect methods used so far.

1. The method elaborated allows us to determine the course of soil hydraulic conductivity curve within the suction pressure range from 0 to -700 hPa, that is in the range most frequently occurring in melioration practice.

2. The most suitable ceramic elements to measure soil suction pressure h appeared to be microsensors (series 126PC15D1), manufactured by Honeywell.

3. The results obtained have pointed out that pressure compensation occurs very quickly in all the tested ceramic cups and that they may be used for determination of soil hydraulic conductivity coefficient $K(h)$ with the non-steady state method.

4. Because of a great soil variablity in field conditions, the method proposed in this paper allows us to carry out many measurements which are necessary for melioration purposes.

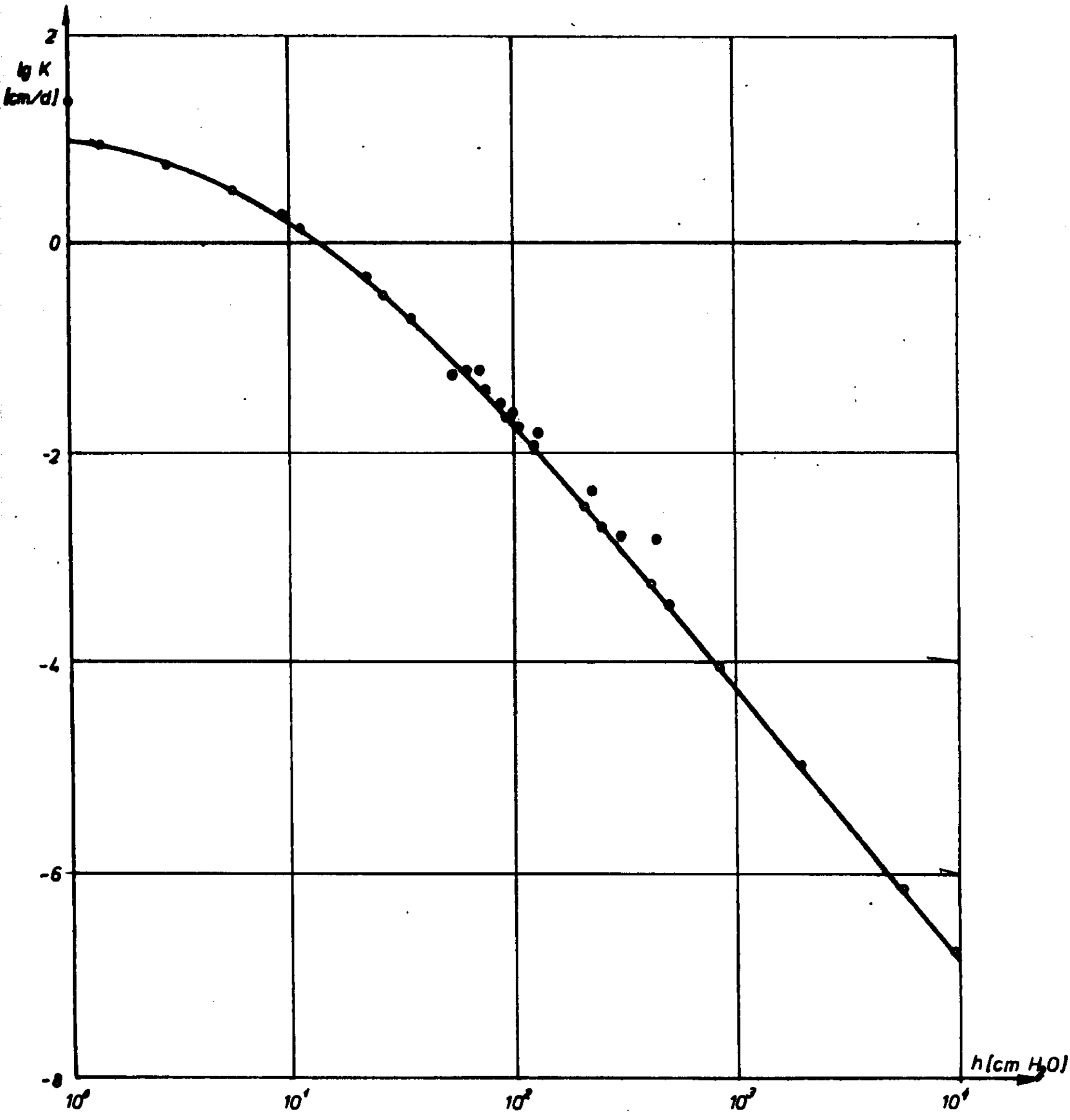

Fig. 9. Results of hydraulic conductivity coefficient measurement K(h) in light loam: 1 - obtained with measuring system SP-86; 2 - calculated from corrected equation of van Genuchten.

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METODYKA OKREŚLANIA PRZEWODNOŚCI HYDRAULICZNEJ GLEB PRZY UŻYCIU AUTOMATYCZNEGO SYSTEMU POMIAROWEGO SP-86

W artykule przedstawiono metodykę określania przewodności hydraulicznej gleby przy użyciu opracowanego systemu pomiarowego SP-86. System ten współpracuje w układzie analogowo-cyfrowym IEC-625 z komputerem IBM PC-86XT/AT. Uzyskane wyniki testów poszczególnych elementów systemu oraz oprogramowanie wskazują, że metodyka określania przewodności K(h) może znaleźć szerokie zastosowanie w zakresie projektowania jak i eksploatacji systemów melioracyjnych.