Pak. J. Agri. Sci., Vol. 30, No. 2, 1993

DETERMINATION OF SOIL MOISTURE RETENTION AND UNSATURATED HYDRAULIC CONDUCTIVITY CURVES FROM PRESSURE OUTFLOW EXPERIMENT

Asad Sarwar, Asaf Sarwar* & Talat Mahmood
International Waterlogging and Salinity Research Institute, Lahore
**University of Agriculture, Faisalabad*

Reliable estimate of unsaturated hydraulic conductivity and soil moisture retention curves of a soil are difficult to obtain because of their extensive variability in the field. A laboratory pressure outflow method is suggested to determine the hydraulic parameters of soil. The outflow time relation data obtained through pressure outflow experiment were fitted to the Van Genuchten - Maulem model through 'SFIT' computer model to obtain moisture retention and hydraulic conductivity curves of soil. The method in combination with 'SFIT' gave relatively quick good description of the hydraulic behaviour of soil.

INTRODUCTION

The use of numerical models for simulating fluid flow and mass transport in the unsaturated zone has become very popular during the last few years but unfortunately we are unable to fully characterize the soil water system. Probably the most important reason is the lack of information regarding the parameters responsible for the physical processes in the soil. To enable simulation for the physical processes, the soil hydraulic properties, i.e. soil water retention curve h (Θ) and unsaturated hydraulic conductivity k (Θ), which play a predominant role in the movement of water and salts in the unsaturated zone must be known.

Numerous methods are available for measuring the water retention and hydraulic conductivity curves of soils (Klute and Dirksen, 1986; Hendrickx *et al.*, 1990). These methods are laborious and time consuming. One rather convenient method is the parameter optimization which can be successfully used in the laboratory as well as in the field. The parameter optimization method is attractive because parameter estimation can be obtained from transient flow events.

Van dam (1990) performed an extensive evaluation of the pressure outflow method and proposed multiple pressure outflow methodology to estimate soil moisture retention and unsaturated hydraulic conductivity. The purpose of this study was to evaluate the pressure outflow method (Van dam, 1990) for the determination of soil moisture retention and unsaturated hydraulic conductivity curves of silt loam soil.

The experiment was conducted in the Cooperative Laboratory of Soil Survey of Pakistan (SSP) with 10 unit outflow apparatus, installed in the SSPO premises and operated jointly by SSP and International Waterlogging and Salinity Research Institute/Netherlands Research Assistance Project (WASRI/NARP). The pressure outflow data were used in combination with 'SFIT' computer program which optimized the parameters in Van Genuchten (1980) hydraulic property model.

MATERIALS AND METHODS

Theory: Van Genuchten (1980) described both the k (h) relation and the soil water retention curve with four independent parameters (θr, θs, α, n) which have to be estimated from observed soil water retention data. The volumetric water content θ is expressed as a function of the pressure head h with the empirical equation:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha h)^n]^m} \qquad (1)$$

where

θ_r = residual volumetric content ($cm^3\ cm^{-3}$),
θ_s = volumetric water content at saturation ($cm^3\ cm^{-3}$),
α,1,n = shape parameters of the curve where $m = 1 - 1/n$ (2)

Maulem (1976) and Wosten (1987) gave an expression for K (h) based on theoretical pore size distribution as:

$$K(h) = K_s S_e^{\lambda} \left[\frac{\int_0^s \frac{1}{h(x)} dx}{\int_0^1 \frac{1}{h(x)} dx} \right]^2 \qquad (3)$$

where

λ = an unknown parameter,
x = a help variable, and
S_e = relative saturation.

S_e can be written as:

$$S_e = \frac{(\theta - \theta_r)}{(\theta_s - \theta_r)} \qquad (4)$$

Combining equations 1, 2 and 3 results in the following equation for hydraulic conductivity:

$$K(S_e) = K_s S_e^{\lambda} [1 - (1 - S^{1/m})^m]^2 \qquad (5)$$

where

λ = shape parameter of the curve.

Equation (5) in terms of the pressure head is written as:

$$K(h) = K_s^{\lambda} \frac{[1 + (\alpha h)^n]^m - (\alpha h)^{n-1}]]^2}{[1 + (\alpha h)^n]^{m(\ +2)}} \qquad (6)$$

Pressure outflow method: For this experiment, the samples of 300 cm^3 (7.26 x 7.26) silt loam soil were taken from the adjacent field of the lysimeters installed by IWASRI at Lahore.

The pressure outflow unit consists of three modules such as pressure supply, sample holder and reading device. The pressure supply system consists of an air compressor attached through a number of manometers to a master pressure pipe. The pressure can be regulated through adjustable valve. Small pressures can be maintained by water manometers and large pressures by mercury manometers. The sample holder consists of two tempe plates (pressure cells). The lower tempe plate has two outlets, one is for air exclusion and the second for discharge to the burette. A small 0-ring was placed in a saving on the lower part of the holder over which ceramic plate is placed. Above ceramic plate, another rubber ring (bigger in size) was placed in the sides of the lower part to avoid air/pressure leakages.

Upper tempe has one outlet to put pressure on the soil samples. Between the pressure and soil sample, a synthetic filter was placed so that samples can be saved from sudden pressures. The discharge outlet is connected through a silicon tube to the burette to collect the outflow from the soil samples. The core was carefully inserted into the lower part of the sample holder and then the upper part was fixed on the sample. The system was carefully tightened with screws. A complete setup of the pressure outflow method is shown in Fig. 1.

Measurements: The water and ceramic plates used in the experiment were deaerated in a desiccator with the help of a suction pump. Assembled samples were checked for leakage by applying a high pressure for short time span. After assembling, the soil was saturated from below through ceramic plates under natural conditions without applying any suction pressure. After

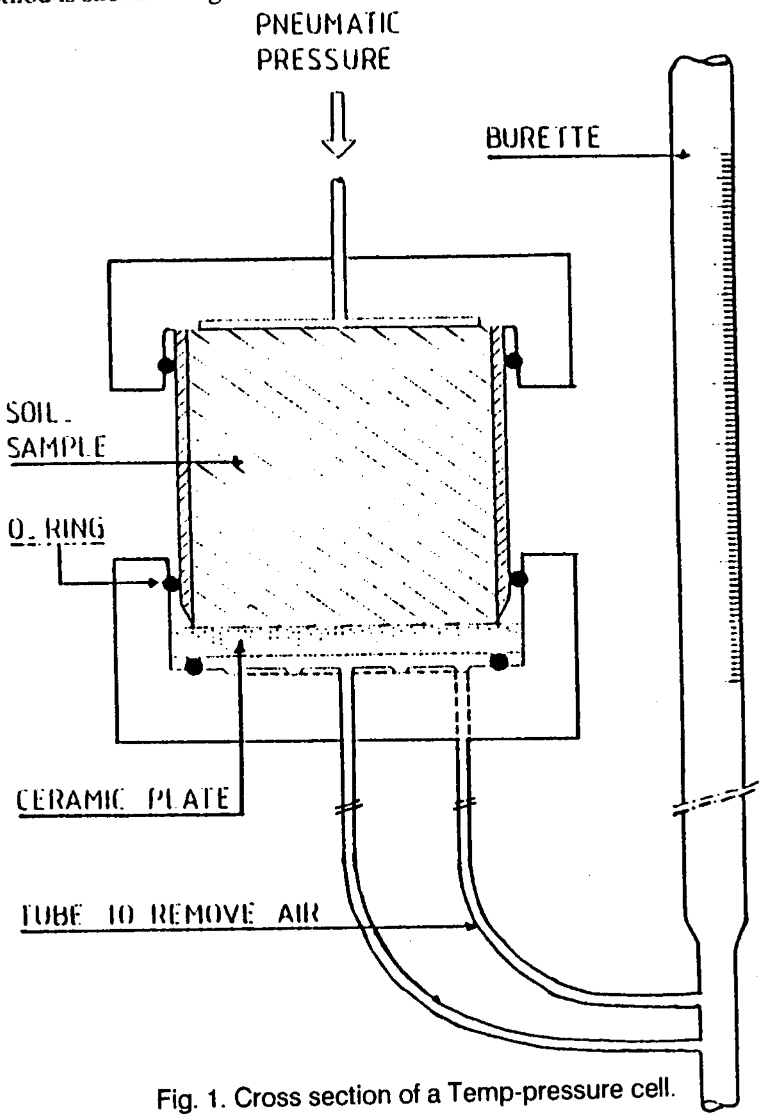

Fig. 1. Cross section of a Temp-pressure cell.

saturation, all samples were subjected to an initial pressure of 3 kpa until equilibrium was reached in order to start the experiment from unsaturated initial conditions as the more homogeneous flow occurs under these conditions (Van dam, 1990). The 3 kpa equilibrium pressure was used as initial value of the outflow experiment. After equilibrium at the initial pressure, 5 small successive increments (i.e. 6, 10, 20, 40 and 80 kpa) were applied and to prevent time related errors, each pressure increment was given after 24 hours. Cumulative outflow against time was measured with short time intervals.

In order to get the unique solution of the optimization procedure, the number of unknown parameters were kept minimum (Maulem, 1976) and the parameters having little effect on calculations of outflow (Ks, Θm and Θr) were determined in the laboratory independently. The saturated hydraulic conductivity (Ks) of soil samples and of the plates was measured by constant head method. The saturated hydraulic conductivity of ceramic plate used was 0.0039 cm/h. Θm was determined by adding the cumulative outflow to the soil water content at the end of the experiment and Θr was approximated by the determination of 'Θ' at pF 4.2 by pressure membrane method.

Data analysis: A computer programme SFIT (Kool and Parker, 1987 b) was used to analyze the outflow data by optimizing the Van Genuchten (1980) equation parameters i.e. saturated soil water content ($cm^3\ cm^{-3}$), residual soil water content ($cm^3\ cm^{-3}$), saturated hydraulic conductivity ($cm\ d^{-1}$), α, L and n. The parameters α, L and n are empirical or shape parameters. Input data to the programme consist of a description of the experimental conditions of hysteresis, initial parameter estimates, a code determining whether the parameter is optimized or fixed and prescription of top and boundary conditions.

In this experiment, outflow against time Q (t) and a time step of 0.01 hr is used for calculations. Effect of hysteresis and air entrapment was not observed during the parameter estimation. The code for initial condition (K0D1) was taken as 1, i.e. pressure heads were specified.

Conclusions:

1. The pressure outflow method in combination with SFIT computer model can give relatively quick, good description of the hydraulic behaviour of soil.
2. The measurements are simple and soil moisture contents and unsaturated hydraulic conductivity relations with suction can fit simultaneously over a wide range.
3. The method is more flexible in boundary condition; the measurements are simple.

REFERENCES

Hendrickx, J.M.H., M.A. Mughal, R. Wahid, J. Akhtar and S.H. Ali. 1990. Field methods for determination of water retention and unsaturated area. Draft Report NRAP, Lahore, Faisalabad.

Klute, A. and C. Dirksen, 1986. Hydraulic conductivity and diffusivity. Laboratory Methods. Agron. J. 9: 687-734.

Kool, J.B. and C.J. Parker. 1987 b. Estimating soil hydraulic properties from transient flow experiments. SFIT User Guide. Report submitted to Electric Power Res. Inst., Palo Alto, California, USA.

Maulem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Amer. J. 44: 892-898.

Van dam. 1990. From one step to multi-step determination of soil hydraulic functions by pressure outflow experiment. Lecture Notes. Wageningen Agri. Univ., The Netherlands.

Van Genuchten, M. Th. 1980. A closed farm equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.

Wosten, J.H.M. 1987. Description of the water retention and hydraulic conductivity characteristics from the staring series with analytical functions. Soil Survey Inst., STIBOKA, Wageningen, The Netherlands. Report No. 2019.