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Estimation of the optimal depth of the groundwater level for a layered peaty-mucky soil profile using a steady state moisture flow solution.

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CONTENTS

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Introduction

The purpose of this paper is to show the results of an application of the theory on steady-state capillary rise. The aim of the investigations was to find the optimal groundwater level yielding an adequate supply of water to the root zone of a soil covered by meadows. In the first chapter the methods used in the calculations are described. The second chapter deals with the soil physical parameters. In the last chapter some results are presented.

1. Theory

Water movement in a soil may be described by the following partial differential equation:

$$\frac{\partial\theta}{\partial t} = -\nabla(k\nabla H) = -\left(\nabla(k\nabla h) + \frac{\partial k}{\partial z}\right) \qquad (1)$$

where

θ = volumetric moisture content ($cm^3.cm^{-3}$)
t = time (d)
H = hydraulic head (cm)
k = hydraulic conductivity ($cm.d^{-1}$)
z = vertical coordinate with origin at the soil surface directed positive upward (cm)
h = pressure head (cm)

To solve equation (1) for any given boundary condition, knowledge of the relation between k, h and θ is required. For steady state one-dimensional vertical flow ($\frac{\partial\theta}{\partial t}=0$) integration of eq. (1) yields

$$-k\left(\frac{dh}{dz}+1\right)=q \qquad (2)$$

where q is a constant representing the soil moisture flux density ($cm^3.cm^{-2}.d^{-1}$). Rearranging eq. (2) gives

$$\frac{dz}{dh}=\frac{-1}{1+q/k} \qquad (3)$$

A method to calculate the height of capillary rise corresponding to a specified pressure head for a non-homogeneous soil profile was described by WESSELING, BLOEMEN and KROONEN (1984).

2. Materials and methods.

Calculations were performed for a layered peaty-mucky soil profile which is typical for drainage-subirrigation open ditch systems at Solec (near Warsaw) in Poland. The soil water management system may be described as presented in fig. 1. This figure shows schematically the division of the soil system into three parts: the ditch system, the subsoil and the root zone. Steady state soil moisture flow was assumed between these three components. Table 1 shows some physical properties and the degree of decomposition of every layer in the soil profile.

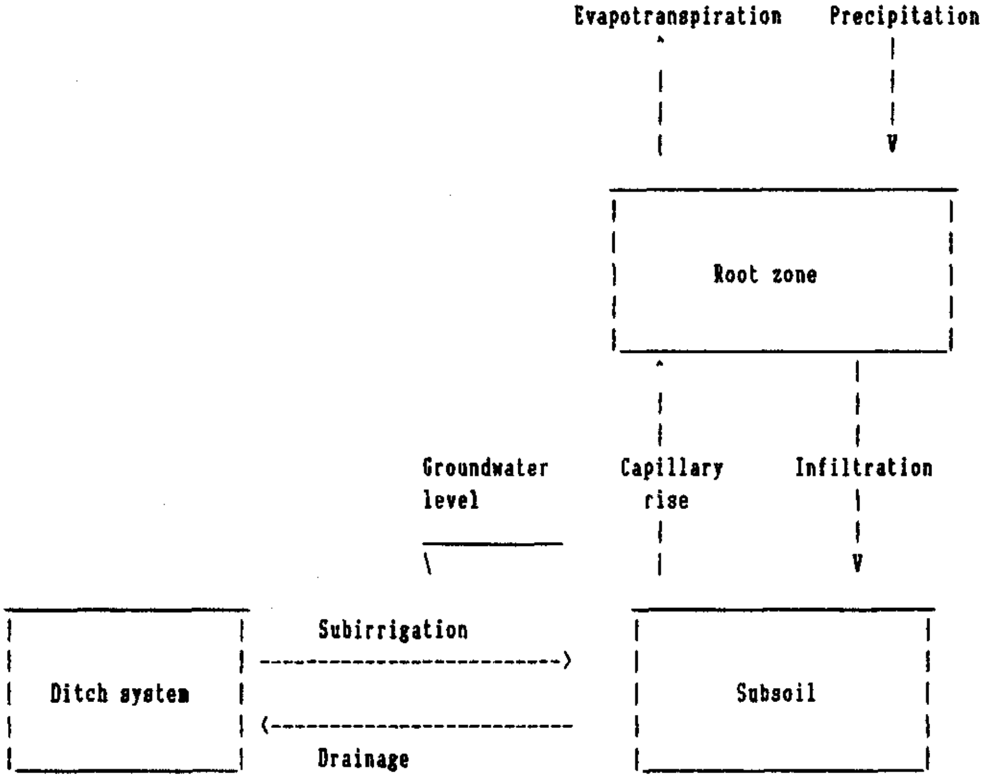

Fig. 1. Schematic representation of the soil water management system at Solec (Poland).

Table 1. Degree of decomposition and physical properties of the Solec peaty-mucky soil.

Layer	Depth (cm)	Decomp. (%)	Density (kg.m^{-3})	Spec. grav. (kg.m^{-3})	Porosity (%)	Vert.perm. (cm.d^{-1})	Hor.perm. (cm.d^{-1})
1	0-10	25	0.364 10^{-3}	1.76 10^{-3}	79.4	77.8	30.2
2	10-20	60	0.240 10^{-3}	1.65 10^{-3}	85.4	121.0	51.8
3	20-35	50	0.176 10^{-3}	1.67 10^{-3}	89.5	13.8	38.0
4	35-40	40	0.168 10^{-3}	1.58 10^{-3}	89.4	-	-
5	40-50	50	0.175 10^{-3}	1.63 10^{-3}	89.3	19.9	58.7
6	50-60	35	0.184 10^{-3}	1.74 10^{-3}	89.4	-	-
7	60-70	30	0.183 10^{-3}	1.70 10^{-3}	89.2	28.5	-
8	70-80	45	0.174 10^{-3}	1.66 10^{-3}	89.5	-	-

The presented data show a higher degree of decomposition in the upper soil layers than in the lower ones, which is caused by mineralisation of organic matter. Analysis of the data shows that the profile may be divided into 3 essential layers: 0 - 10 cm muck, 10 - 20 cm peat with a relatively high degree of decomposition and below 20 cm peat with a relatively low degree of decomposition. For every layer of the soil profile desorption curves were measured according to the method presented by STAKMAN et al. (1969). Fig. 2 shows the soil moisture retention curves for each essential layer.

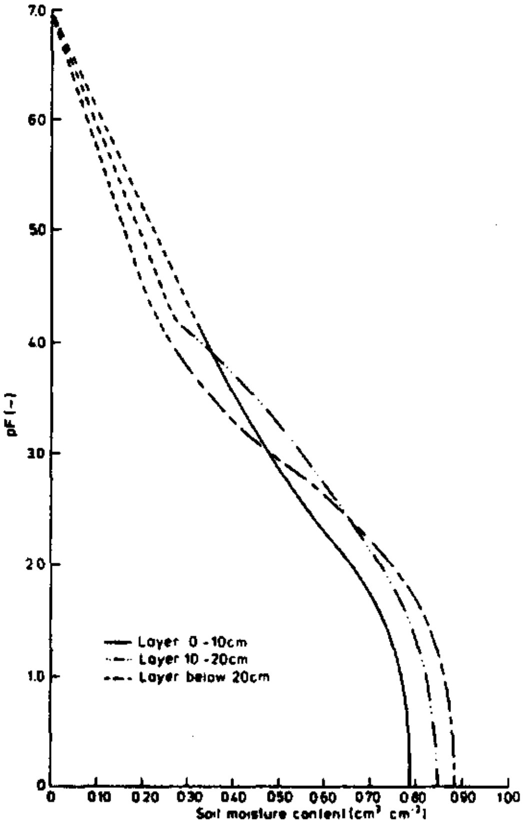

Fig. 2. The soil moisture retention curves for the Solec peaty-mucky soil profile.

The unsaturated hydraulic conductivity for every layer was computed from the retention curves and the averages of the measured values of vertical soil permeability. These calculations were performed according to the formula proposed by KUNZE et al. (1968) which states:

$$k(\theta)_i = \frac{k_s \cdot 43200 \cdot \gamma^2 \cdot \theta}{k_{sc} \cdot \rho \cdot g \cdot \eta \cdot n^2} \cdot \sum_{j=i}^{n} \left[(2j + 1 - 2i) \cdot \frac{1}{h_j^2}\right] \qquad (4)$$

where

$k(\theta r)_i$ = calculated conductivity for a specified moisture content or pressure class ($cm.d^{-1}$)

k_s/k_{sc} = matching factor (measured saturated conductivity divided by calculated saturated conductivity (-)

γ = surface tension of water ($dynes.cm^{-1}$)

ρ = density of water ($g.cm^{-3}$)

g = gravitational constant ($cm.sec^{-2}$)

η = water viscosity ($g.cm^{-1}.s^{-1}$)

θ = water filled porosity ($cm^3.cm^{-3}$)

n = total number of pore classes

h = pressure head (cm)

Calculations according to eq. (4) require only standard determinations of the pF-curve (to find the pressure head for every pore class) and the saturated conductivity. This latter value is used to adjust the calculated unsaturated conductivity. Eq. (4) yields a good agreement between the measured and the calculated hydraulic conductivities for this peaty-mucky soil, as was shown by Brandyk (1981).

Using the method described above, the unsaturated conductivity was calculated for every soil layer. The values were computed from a completely dry soil up to saturation, with steps of 1% soil moisture content. To simplify the description of the k(h)-relation it was decided to describe the function by three straight line pieces as shown in fig. 3. This may be done using an optimisation technique, as used by e.g. ALIVERTI-PIURI and WESSELING (1979) or WESSELING (1981).

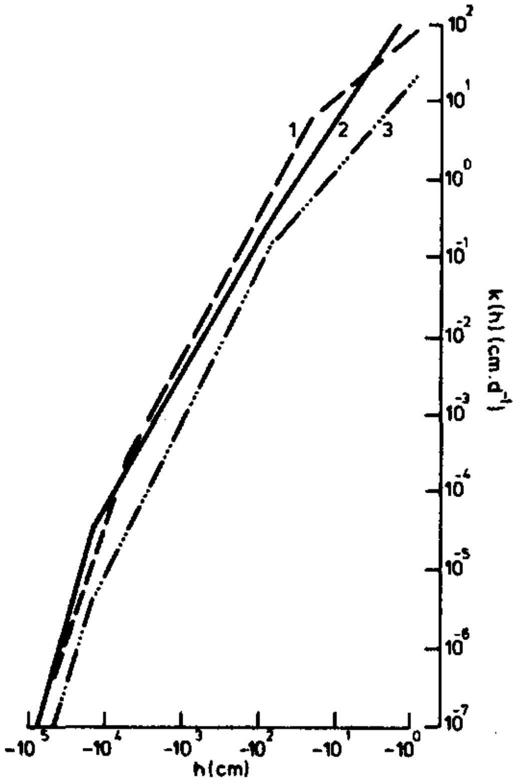

Fig. 3. The hydraulic conductivity function for the characteristic layers in the Solec soil profile.

3. Results and discussion

Calculations of pressure head distributions for the soil described in the previous chapter were performed for both infiltration and capillary rise at different fluxes starting from 0 to 0.5 $cm.d^{-1}$. These values were taken from evapotranspiration rates

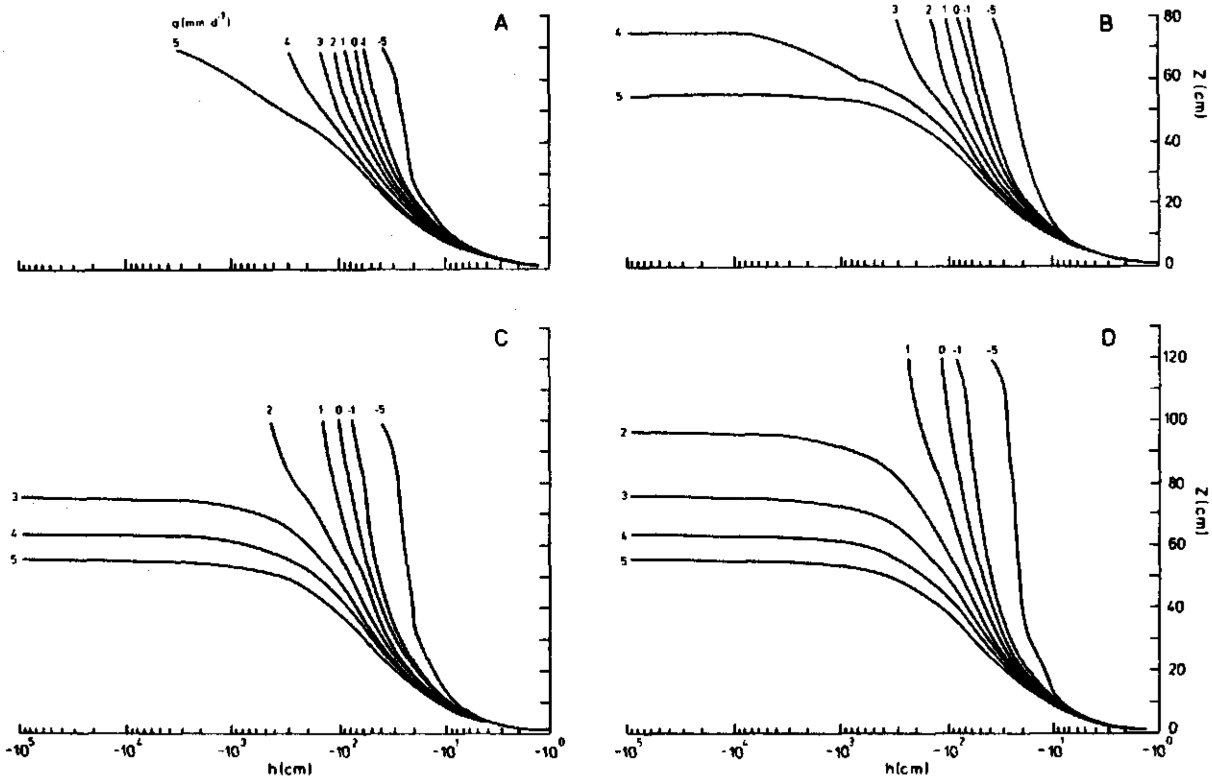

Fig. 4. Pressure head distributions in the Solec peaty-mucky soil profile for capillary rise and infiltration at different groundwater levels. a: 70 cm, b: 80 cm, c: 100 cm and d: 120 cm below the soil surface.

measured in the field. Several groundwater levels from 50 to 150 cm below the soil surface (with increments of 10 cm) were considered. Some of the results are shown in fig. 4. As described by BRANDYK (1981) the depth of the root zone for this soil is limited to 20 cm. The maximum allowed pressure head in the root zone was assumed to be -500 cm.

Fig. 4. shows that a groundwater level between 70 and 80 cm below the soil surface provides sufficient

capillary rise to support the root zone with moisture. Data from the experimental field at Solec show that the measured pressure heads in the root zone are slightly higher than -500 cm (pF 2.7), even in dry periods, as long as the groundwaterlevel remains above 80 cm. This agrees with the calculated data. Fig. 4 also shows some pressure heads in case of infiltration. Comparison of these results with data presented by RENGER et al. (1976) for similar peaty soils yields good agreement.

As a conclusion it may be seen that with relatively simple steady state methods and with only 2 standard soil characteristics (saturated hydraulic conductivity and the soil moisture retention curve) a good estimation of the optimal depth of the groundwater level may be found for certain crops.

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