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Effect of peat decomposition on the capillary rise in peat-moorsh soils from the Biebrza River Valley**

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A b s t r a c t. The paper shows the application of the steady state soil moisture flow theory for three different peat-moorsh (Ferric Histosols) soil profiles from the Biebrza River Valley. The unsaturated hydraulic conductivity was determined using the 'multi-step' method. The numerical method was used to calculate the height of the capillary rise - pressure head relationship for each profile with several fluxes. The maximum height and intensity of capillary rise in peat-moorsh soil profiles depends on the degree of advance of the moorsh-forming process, as well as the degree of decompositions of peat layers.

K e y w o r d s: capillary rise, peat, moorsh, unsaturated hydraulic conductivity

INTRODUCTION

The Biebrza Wetlands are located in the North-East of Poland in an extensive ice-ringed basin - the Valley of the Biebrza River. The wetlands occupy an area of 116 000 ha with several types of mires. The dominant types are fens, which account for 75.9% of the wetland area. Soils in this area were partially affected by drainage systems which caused the moorshing process [9]. Protection of these soils against the mineralization process requires such water management as would make it possible to keep the moisture content in the root zone of plant communities within the acceptable range. For soils with a shallow groundwater table, the actual moisture content in the root zone depends on the groundwater level position. During the dry summer periods the root zone of different plant communities is supplied by the action of the capillary rise from the groundwater level. Capillary rise can be characterised by the maximum height and its intensity. To estimate these values in peat soil the steady-state soil moisture flow theory can be applied [1,11]. The solution of the theory would be possible with knowledge of only one parameter representing the relationship between unsaturated hydraulic conductivity and the soil water pressure head. Several analytical solutions of the theory have been presented in literature [2]. In most cases however, analytical solutions have limited application to some idealised cases where unsaturated hydraulic conductivity is assumed to be a simple function and soil is assumed to be uniform. For general cases, numerical solutions can be more easily applied [3].

The objective of this paper is to determine the maximum height and intensity of capillary rise, using the steady-state soil moisture flow theory for soil profiles from the Biebrza River Valley. These profiles (Ferric Histosols) are characterised by differing degrees of the advance of the moorsh-forming process.

MATERIAL AND METHODS

Calculations of steady state capillary rise were performed for three soil profiles from the Middle Biebrza Basin. The basic physical properties of the investigated soils and their descriptions are presented in Table 1. The distinguished profiles are characterised by differing degrees of the advance of the moorsh-forming process, ranging from poorly to strongly moorshified soils according to the classifications made by Okruszko [10]. The Toczyłowo profile represents poorly moorshified soil (Mt I aa) and is formed from sedge-moss peat with a low degree of decomposition. In the Jegrznia profile a moderate state of moorshification is observed (Mt II cc) and reed peat with moderate decomposition in the underlying moorsh layer. The Otoczne profile is formed from strongly decomposed reed peat and can be classed as a profile with a profound stage of moorshification (Mt III cb).

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T a b l e 1. Description and some physical properties of fen peat-moorsh soil profiles from the Biebrza River Valley

Depth (cm)	Ash content (% a.d.m.)	Bulk density (kg m^{-3})	Description
		Toczyłowo profile (Mt I aa)[1]	
0-10	17.0	153.0	0-20 peaty moorsh
10-20	10.3	166.0	20-250 sedge-moss peat with low degree of decomposition (R_1)[2]
20-30	8.0	142.0	
30-40	9.4	136.0	
50-60	6.6	100.0	
70-80	8.1	94.0	
90-100	9.0	88.0	
		Jegrznia profile (Mt II cc)	
0-10	20.4	182.0	0-17 humic moorsh
10-20	18.4	211.0	17-30 interlayer
20-30	15.8	191.0	30-96 reed peat with high degree of decompositions (R_3)
30-40	16.0	192.0	
50-60	14.5	170.0	96-180 reed peat with moderate degree of decompositions (R_2)
70-80	14.5	158.0	
90-100	11.8	119.0	
		Otoczne profile (Mt III cb)	
0-10	19.7	312.0	0-25 grainy moorsh
10-20	16.4	308.0	25-35 interlayer
20-30	15.8	252.0	35-55 reed peat with high degree of decompositions (R_3)
30-40	13.1	175.0	
50-60	8.8	131.0	55-180 reed peat with moderate degree of decompositions (R_2)
70-80	8.4	124.0	
90-100	9.1	110.0	

[1] - degree of advance of the moorsh-forming process according to classification of Okruszko [10], [2] - degree of peat decomposition according to classification of Okruszko [10].

From characteristic layers of peat in the considered soil profiles, undisturbed soil cores in three replications were collected for measurements of unsaturated hydraulic conductivity. The 'multi-step' method proposed by van Dam *et al*. [4] and validated in moorsh and peat soils by Gnatowski *et al*. [6] was used. The outflow experiments were performed in pressure cells on samples (diameter 5.33 cm and height 3.0 cm) previously saturated with water. The multi-step experiments were conducted by performing three successive steps with pneumatic pressure values: 10, 30 and 50 kPa, respectively. Cumulative outflow volumes were measured using burettes. The procedure of estimating the soil hydraulic parameters from outflow experiments was performed using the MULSTP code [4]. The program uses a Galerkin finite element routine to solve Richards' equation for an unsaturated flow using the Mualem-van Genuchten soil hydraulic functions [5]:

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r) \tag{1}$$

$$h(S_e) = \left[\left(S_e^{-1/m} - 1\right)^{1/n}\right]/\alpha \tag{2}$$

$$K(S_e) = K_s S_e^{\lambda}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2 \tag{3}$$

where S_e is the normalised water content; θ, θ_r and θ_s are the actual, residual and saturated water contents, respectively; h is the pressure head; K and K_s are the unsaturated and saturated hydraulic conductivities, respectively; α, n and λ are empirical parameters; and m=1-1/n.

The unknown soil hydraulic functions are estimated by matching simulated and observed outflow data. Cumulative outflow $Q_c(t, b)$ at time t_i (time corresponding with i-th observation) is calculated for the set of parameters contained in vector $b(\theta_s, \theta_r, \alpha, n, K_s$ and $\lambda)$. The function $O(b)$ describes the difference between observed $Q_0(t_i)$ and predicted $Q_c(t_i, b)$ outflow at time t_i:

$$O(b) = \sum_{i=1}^{N_1}\left\{w_i\left[Q_0(t_i) - Q_c(t_i, b)\right]\right\}^2 \tag{4}$$

where w_i is the weighing factor for individual measurements, N_1 is the number of observations for outflow data.

In the optimisation procedure, values of saturated water content (θ_s) were fixed as a measured value for each samples whereas values of the other parameters describing unsaturated hydraulic function, i.e., θ_r, α, n, K_s and λ were optimised. In calculating the height of capillary rise the average values of the parameters from three replications were used. The parameters of the Mualem-van Genuchten model, describing unsaturated hydraulic conductivity for moorsh layers, were assessed using data published by Gnatowski *et al*. [7].

The height of capillary rise above groundwater table depth (equal to 100 cm) and using different fluxes for considered stratified soil profiles was calculated according to the equation by Brandyk and Wesseling [3]:

$$z = -\int_{0}^{h_1} \frac{dh}{1+q/K_1(h)} - \int_{h_1}^{h_2} \frac{dh}{1+q/K_2(h)} - \ldots - \int_{h_{i-1}}^{h_i} \frac{dh}{1+q/K_i(h)} - \ldots - \int_{h_{n-1}}^{h_n} \frac{dh}{1+q/K_n(h)} \quad (5)$$

where: z - vertical coordinate which is positive in the upward direction (m), h_1, h_2,..., h_i,..., h_n - soil water pressures corresponding to height of z_1, z_2,..., z_i,..., z_n boundaries between neighbouring soil layers (m), q - volumetric moisture flux which is positive in the upward direction (m^3 m^{-2} d^{-1}), $K_1(h)$, $K_2(h)$,..., $K_i(h)$,..., $K_n(h)$ unsaturated hydraulic conductivity functions depending on the soil water pressure head for particular layers (m d^{-1}).

The integration of Eq. (5) was performed numerically using the computer program CAPSEV [13].

RESULTS AND DISCUSSION

The parameters of the Mualem-van Genuchten model, describing soil moisture retention characteristics and the unsaturated hydraulic conductivity function, obtained as a result of the 'multi-step' method application for characteristic layers in the considered soil profiles, are presented in Table 2. From the data presented in this table it can be seen that the values of saturated moisture content (θ_s) are the lowest in the top moorsh layers and increase with increasing depths in the soil profiles. The highest values of θ_s were observed in the poorly moorshified Toczy³owo profile (Mt I aa) while the lowest values were to be found in the Otoczne profile (Mt III cb), characterised by a profound stage of moorshification. Relatively high values (>0.56 m^3 m^{-3}) of residual moisture content (θ_r) were evaluated for moorsh layers in all considered profiles. In peat layers the values of parameter θ_s are decreasing as the degree of peat decomposition decreases. The lowest θ_s value was measured for sedge-moss peat with a low degree of decomposition in the Toczy³owo profile in the layer 70-100 cm. Parameters describing the shape of the moisture retention functions (i.e., α and n) and the unsaturated hydraulic conductivity functions (i.e., K_s and λ) varied among depths and also peat or moorsh types. The values of parameter λ varied between -4.386 and 4.371 which is in contradiction to the standard practice of using λ=0.5 as proposed by Mualem [8]. Negative values of the λ parameter were found only for sedge-moss peat layers.

The soil moisture retention characteristics together with unsaturated hydraulic conductivity functions for considered soil profiles are shown in Fig. 1. From these figures it can be seen that soil moisture characteristics for moorsh layers differ from those of peat layers, especially regarding the amount of water available for plants (pF range from 1.7 to 4.2). Among the peat layers the curves measured for

T a b l e 2. Values of the Mualem-van Genuchten model parameters describing soil moisture retention characteristic and unsaturated hydraulic conductivity function for characteristic layers in the soil profiles

Depth (cm)	Parameters of the Mualem-van Genuchten model					
	θ_s (cm^3 cm^{-3})	θ_r (cm^3 cm^{-3})	α (cm^{-1})	n (-)	K_s (cm d^{-1})	λ (-)
			Toczyłowo profile			
0-20	0.8553	0.5922	0.0199	2.168	6.700	0.923
20-50	0.9220	0.1670	0.0090	1.427	1.224	1.393
50-70	0.9370	0.1470	0.0110	1.445	1.584	-2.010
70-100	0.9300	0.0360	0.0170	1.389	1.080	-4.386
			Jegrznia profile			
0-25	0.8490	0.5658	0.0169	2.186	10.600	0.507
25-65	0.8770	0.1890	0.0160	1.155	9.384	3.957
65-100	0.9100	0.1390	0.0210	1.188	7.008	0.782
			Otoczne profile			
0-35	0.8173	0.6310	0.0313	1.822	3.840	2.362
35-65	0.8650	0.2300	0.0340	1.125	6.240	4.371
65-100	0.8930	0.1400	0.0140	1.141	6.600	3.172

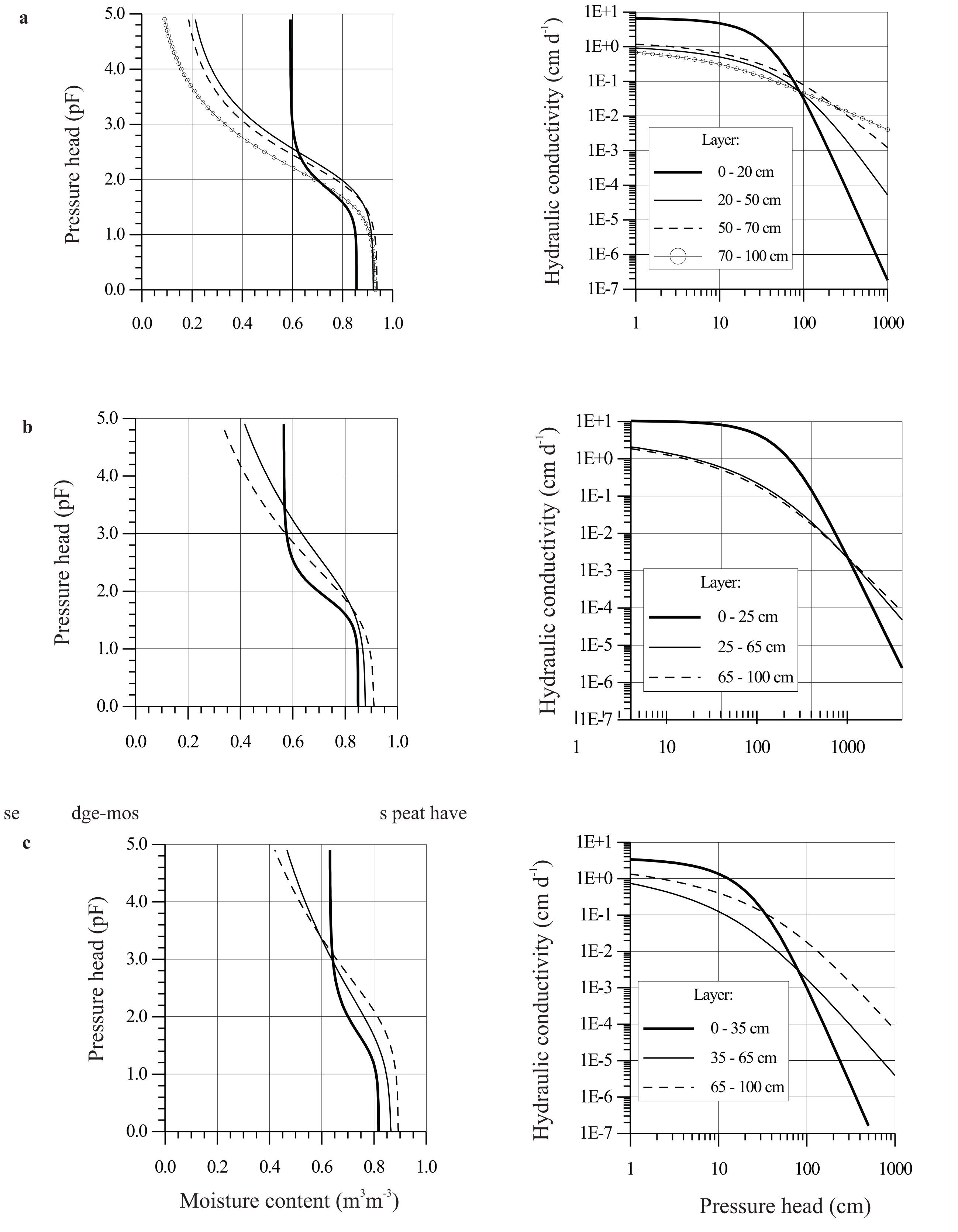

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Fig. 1. Soil moisture retention characteristics and unsaturated hydraulic conductivity functions for different layers in: Toczyłowo (a), Jerzgina (b), and Otoczne (c) soil profiles.

larger values of water available for plants in comparison with reed peat layers. In the range of pressure head from saturation to about -100 cm the unsaturated hydraulic conductivity in moorsh layers was greater than in peat layers. Below this value the slope of the unsaturated hydraulic conductivity function in peat layers was less than that of moorsh layers.

Figure 2 shows the height of capillary rise - pressure head relationship for each peat-moorsh soil profile with volumetric moisture flux rates ranging from 0.0 to 5.0 mm d^{-1} obtained as a result of performed CAPSEV calculations. From this figure it can be seen that the height of capillary rise is limited to a certain maximum value for a given flux rate. It can also be observed that the maximum value depends on the flux rate, i.e., when the flux rate is increasing the maximum value of the height of capillary rise decreases. Assuming a flux rate of 1 mm d^{-1}, the calculated maximum height of capillary rise was equal to 80 cm in the poorly moorshified Toczy³owo profile, 60 cm in the moderate moorshified Jegrznia profile and 38 cm in the strongly moorshified Otoczne profile. With a flux rate of 5 mm d^{-1}, the calculated values of the maximum height of capillary rise were equal to 38, 22 and 20 cm, respectively. These values show that the height and intensity of capillary rise in peat-moorsh soil profiles depends on the degree of advance of the moorsh-forming process as well as on the degree of decomposition of the underlying peat layers. With the advance of the moorsh forming process and peat decomposition the height of capillary rise at a given flux rate decreases. This implicates the necessity to maintain higher groundwater levels in peat-moorsh soil profiles (characterised by a strongly advanced moorshing process in comparison with profiles where this process is less advanced) in order to cover plant water requirements by the action of the capillary rise from the groundwater. These results are in agreement with field data presented by Szuniewicz [12], who found that for soils developed from moderately decomposed peat, the water level should be no lower than 60 cm, whereas for soils developed from strongly decomposed peat, poorly moorshified soil profiles no lower than 40-50 cm and for strongly moorshified soil profiles no lower than 30 cm.

SUMMARY AND CONCLUSIONS

The maximum height and intensity of capillary rise in peat-moorsh soil profiles depends on the degree of advance of the moorsh-forming process as well as the degree of decompositions of peat layers forming the profile. The decrease of the height of the capillary rise at a given flux rate is observed with the advance of the moorsh forming process and peat decomposition. The capillary rise-pressure head relationships, obtained as a result of the steady state moisture flow theory application for three different peat-moorsh soil profiles from Biebrza River Valley, can be used to determine the desired groundwater level to supply water,

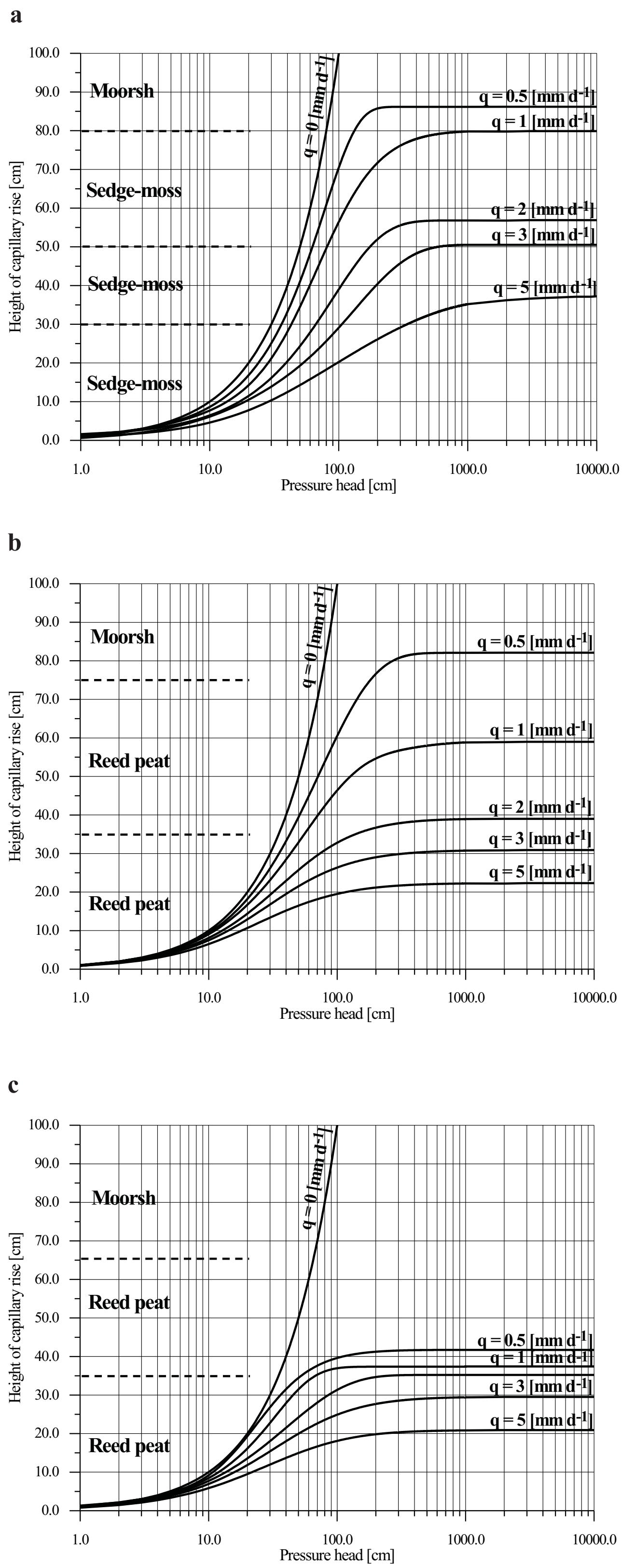

Fig. 2. Height of capillary rise at different fluxes (q) for: Toczyłowo (a), Jegrznia (b), and Otoczne (c) soil profiles.

using the action of capillary rise, to the crop root zone at specified evapotranspiration rates. The groundwater level in the peat-moorsh soils during intensive evapotranspiration should be maintained in proportion to the degree of decomposition of the peat formation underneath the moorsh layer, and to the advance of moorshing process. In profoundly transformed soils comprising grainy moorsh, the water table should occur immediately below the moorsh layer in order to ensure a sufficient supply of water to the plants.

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