Acta Agrophysica, 2000, 26, 85-93

EFFECTS OF SECONDARY TRANSFORMATION OF PEAT-MOORSH SOILS ON THEIR PHYSICAL PROPERTIES

C. Sławiński, Z. Sokołowska, R. Walczak

Institute of Agrophysics, Polish Academy of Science, Doświadczalna 4, 20-290 Lublin 29, Poland

Abstract. Detoriation of water conditions in the peat soils are closely related to the transformations that take place in the structure of organic soil mass. Changes in water relations together with an increased access of air enable various physical, chemical and biological processes to take place. This, in turn, leads to changes in organic soil mass and soil mass transformation into moorsh. The scope of changes and their rate depends also on the properties of the original material. Amorphic peats are most susceptible to secondary transformations, whereas fibrous peats undergo moorshing slower. Peat formations after secondary transformations have been divided into 5 groups assuming numerical values of water absorptivity as the basis for the division. This index expresses the ratio between the lowest water absorptivity of a given formation to its absorptivity in the fresh state.

The aim of the present work was to evaluate in what way type of moorsh and degree of its secondary transformation influence some of its physical properties, i.e., retention curves and water conductivity, absorption level (wetting) and desorption (drying) of steam as well as its specific surface area.

The study object included peaty moorshes and proper moorshs originating from peats formations at various stages of decomposition. The soil material originated from the region of Polesie Lubelskie.

Keywords: agrophysics, peat-moorsh soils, retention curve, unsaturated hydraulic conductivity, sorption and desorption isotherms, specific surface area.

INTRODUCTION

Hydrology plays a key role in the development and maintenance of all peatland systems. Many peatland functions depend on the detail of the water budget, i.e., water input, water output and water storage. The reduction of water capacity of peat soils during the process of their moorshing reflects changes taking place in the structure and chemistry of the raw organic materials. In the changed water conditions soil mass loses its absorption abilities and is transformed into a formation of a hydrophobic character. The mechanism of the above changes was called the process of "secondary transformation [8-10]. On the basis of water holding capacity, Gawlik [3,4] proposed a new classification of secondary transformed peat into six classes characterised by a W_1 index. This index is the ratio of centrifuged moisture equivalent after predrying at 105 °C and one week of rewetting to the moisture level of a fresh sample. The index W_1 ranges from 0.17 to 1.0 and increases with the degree of peat transformation. The value below 0.36 is characteristic for peat formations.

Characteristics of the water content profile of peat reflecting the level of water table is a prerequisite for modelling processes related to soil moisture condition of peatlands. Most models of water movement in porous solids use the moisture retention curve and the relationship between the coefficient of unsaturated hydraulic conductivity and soil water contents or soil water potential. Water retention characteristics of mineral soils have been modelled intensively and several models were presented in last years [13,17,21]. Some of these models were investigated for peat soils by Weiss *et al.* [19]. They developed a semiempirical model with only one shape parameter, which was clearly explained by the peat characteristics and recommended for statistical investigations. The van Genuchten's model is for predicting moisture conditions near saturation. The instantaneous profile method elaborated in the Institute of Agrophysics allows to determine water retention curve and coefficient of unsaturated hydraulic conductivity directly from measurements. Specific surface area of the organic matter is a key parameter for water volumes bound at high tension and is strongly related to decomposition [14].

This work presents laboratory results of water retention curves, unsaturated hydraulic conductivity, water vapour sorption and specific surface area for peat-moorsh soils in relation to their varied state of the secondary transformation.

MATERIALS AND METHODS

The study object included peaty moorshes (Z_1) and proper moorshes (Z_3) originating from peat formations at various stages of decomposition [3,8,9]. Those soils were characterised by the index of the secondary transformation W_1 in the range from 0.44 to 0.82. All the study materials were taken from the Polesie Lubelskie Region and from the Biebrza River Valley. The some selected properties of the investigated peaty moorsh soil samples are collected in Table 1. Szajdak *et al.* [16] and Gawlik [3,4,16] gave a detailed characteristics of the soils and the method used to obtain the W_1 index.

Soil water retention curves and coefficient of unsaturated hydraulic conductivity were determined using a TDR (Time Domain Reflectometry) device for water content, temperature and salinity measurements [6,7]. Soil material was dense to define bulk density standard using a TDR method with steel cylinders 10 cm high

Table 1. Properties of the chosen peat-moorsh soils

No. of soil (study site)	W_I index	Bulk density of solid phase G_o (g cm^{-3})	Porosity ε vol. %	Ash content A % d.m.
1. Kosiły (Z_1)	0.55	0.25	84.6	17.56
3. Gajówka (Z_3)	0.63	0.46	74.9	37.87
5. Modzelówka-Wykowo (Z_3)	0.82	0.39	78.7	22.27
6. Brzeziny Ciszewskie (Z_3)	0.65	0.32	82.5	20.52
8. Szóstka (Z_3)	0.71	0.30	83.6	22.77
12. Sosnowica (Z_1)	0.44	0.21	88.5	22.69

and 5 cm in diameter. TDR probes used for water content measurement and microtensiometers for water potential measurements were installed through the holes in the cylinder walls. Soil column prepared in this way was wetted to saturation by capillary rise [5,15,18]. For the purpose of thermodynamical equilibrium the soil column was covered for 24 h. After that time it was opened and during evaporation process, water content and water potential were monitored at 1,3,5,7, and 9 cm counting from the bottom of the column. The laboratory TDR device for water content and water potential measurement was connected to the computer, so the data measured (moisture and water potential) are gathered automatically on the hard disk.

Data on the dynamics of water content and water potential profiles obtained from the measurements in time and space, enable to plot retention curves and coefficient of unsaturated conductivity as a function of water potential or water content.

Assuming that the soil column is homogenous, water flow is one-dimensional and the process take place in isothermal conditions the one-dimensional Darcy's law and flow equation through the soil column can be used for the calculation of coefficients of unsaturated hydraulic conductivity:

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

$$q(z,t) = -\int_{o}^{z} \frac{\partial\theta(z,t)}{\partial t}\,dz$$

The coefficient of unsaturated hydraulic conductivity can be determined from the equation:

$$k(\theta) = \frac{\int_{o}^{z} \frac{\partial\theta(z,t)}{\partial z}\,dz}{\frac{\partial\psi(z,t)}{\partial z} - 1} \tag{2}$$

where *q(z,t)* - water flux through the chosen surface of the soil column in a define period of time [m s^{-1}]; *k(θ)* - coefficient of unsaturated hydraulic conductivity [m s^{-1}]; θ(z,t) – water content [cm^3 cm^{-3}]; *Ψ(z,t)* - water potential [hPa].

The water sorption-desorption isotherms were measured gravimetrically in static conditions. Soil samples in glass vessels were placed in a vacuum chamber over sulphuric acid solutions. Air was removed. Afterwards equilibration the mass of samples with the sorbed water was measured. After finishing the sorption-desorption measurements, soil samples were dried in an oven at 105 °C and the amount of sorbed water was calculated. The relative water vapour pressures were estimated from the density levels of sulphuric acid solutions. During the experiment, temperature was kept constant at 20 °C. All the measurements were replicated three times. The specific surface areas of peat-moorsh soil samples were obtained from the sorption isotherms using the BET equation, according to the Polish Standard PN-Z-19010-1.

RESULTS AND DISCUSSION

Relationship between soil water content and soil water potential is presented in Fig. 1. Water retention curves of the investigated soils do not, show high differentiation in respect to their shape. For the settled soil water potential the highest amount of water can be retained by the soil number 1 (W_1=0.55) and the soil number 12 (W_1=0.44). These two soils are classified as peaty moorsh (Z_1). The highest amount of water can be retained by the soil number 8 (W_1=0.71) and number 6 (W_1=0.65) classified as proper moorshes (Z_3). The lowest retention properties are represented by the soils number 3 (W_1=0.63) and number 5 (W_1=0.82). These soils are also classified as proper moorshes (Z_3).

Figure 2 presents the relative values of coefficient of unsaturated hydraulic conductivity received from the instantaneous profile method and smoothed using Mualem-van Genuchten's model as a function of water potential. For the settled soil water potential, the lowest decrease of relative water conductivity in unsaturated zone occurred for the soils number 3 (W_1=0.63) and number 5 (W_1=0.82). For the soil water potentials of about -400 hPa, the hydraulic conductivity values of all the soils decrease to zero.

Relationship between the water vapour pressure and the amount of water adsorbed by the soil materials (i.e., adsorption isotherm) is of fundamental importance for the studies of thermodynamics of water adsorption by soil and diffusion of vapour through soil.

Figure 3 shows adsorption isotherms for the investigated peat-moorsh soils. Qualitative interpretation of the isotherms obtained permits to provide information

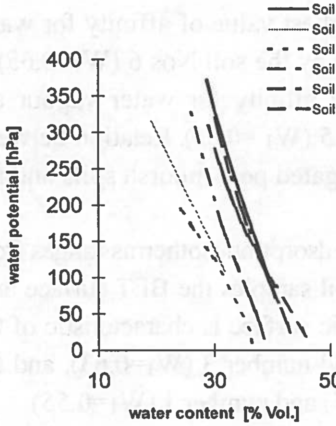

Fig. 1. Retention curves.

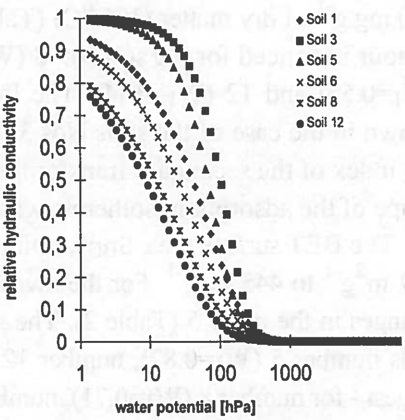

Fig. 2. Relative values of coefficients of unsaturated hydraulic conductivity.

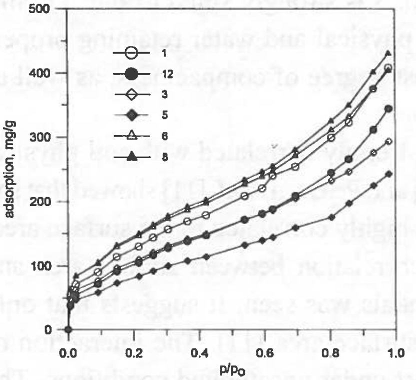

Fig. 3. Water vapour sorption isotherms for the state of secondary transformation transformed peat-moorsh soils.

for on the structure of adsorbents. Adsorption isotherms belong to the type II of the BET classification or to the type IV of the IUPAC, which points out a non-porous character of the adsorbents.

The knees of the isotherms are rounded and are associated with a low value of the C_{BET} constant, or with a low net heat of adsorption. The shape of all the curves is similar; however, a detailed course of the curves and the amount of sorbed water vary from sample to sample, which is obviously connected with different basic properties of particular samples (Table 1). The pF curves and sorption isotherms indicate that the amount of sorbed water increase according to the following series 5<3<12< 1<6<8. The soil samples labelled 3,12 and 6, 8 are of a very similar shape, especially in the range of low relative water pressures. Samples Nos 6 and 8 are characterised by similar values of bulk density and total porosity, whereas samples Nos 3 and 12 shaw extremely different values of these parameters and, additionally, also the value of ash content (Table 1). The investigated soils characterised by different values of affinity with water vapour. For the relative pressure of about 0.93 the amount of water vapour sorbed in the process of sorption (wetting) and desorption (drying) ranges from about 200 to

400 mg g^{-1} of dry matter (105 °C) (Table 2). The highest value of affinity for water vapour is noticed for the soil No. 8 (W_1=0.71), then by the soil Nos 6 (W_1=0.65), 1 (W_1=0.55) and 12 (W_1=0.44). The lowest values of affinity for water vapour are shown in the case of the soils Nos 3 (W_1=0.63) and 5 (W_1 =0.82). Relation between the index of the secondary transformation of investigated peat-moorsh soils and the shape of the adsorption isotherms was not found.

The BET surface area, S_{BET}, estimated from the adsorption isotherms ranges from 257 m^2g^{-1} to 445 m^2g^{-1}. For the investigated peat soil samples the BET surface area changes in the order 5 (Table 2). The smallest specific surface is characteristic of the soils number 5 (W_1=0.82), number 12 (W_1=0.44) and number 3 (W_1=0.63), and the largest - for number 8 (W_1=0.71), number 6 (W_1=0.65) and number 1 (W_1=0.55)

In general, the value of peaty moorsh surface area of soil samples increases according to the W_1 index, which characterises the state of secondary transformation (Fig. 4).

Samples Nos 3 and 5 have lower values of surface area (Table 2). Sample No. 5 shows the highest W_1 index, while sample No. 3 is strongly silted (Table 1). Silting-up process has a significant effect on the physical and water retaining properties of hydrogenic soils. They show the highest degree of compactness, as well as the lowest total porosity [12].

Specific surface area of organic matter is strongly correlated with soil physical properties. For mineral soils Zawadzki *et al.* [20] and Petersen *et al.* [11] showed that soil water content at -15 bars (the wilting point) was highly correlated to the surface area. However, a steadily decre-asing degree of correlation between surface area and water contents at seven increasing matrix potentials was seen. It suggests that only tightly bound water is directly related to the surface area [11]. The interaction of water with organic soils is of particular interest under unsaturated conditions. The specific surface area is directly correlated to the volume of water bound at high

Table 2. Some chosen parameters of peat-moorsh soils

Soil No.	Z	W_1	S (m^2g^{-1})	N_{ads} (mgg^{-1})	N_{des} ($mg\ g^{-1}$)	$\Delta=N_{des}-N_{ads}$ ($mg\ g^{-1}$)
12	Z_1	0.44	324.1	270.59	311.17	40.60
1	Z_1	0.55	399.3	335.65	375.32	39.67
3	Z_3	0.63	334.8	245.86	275.70	29.84
6	Z_3	0.65	444.9	333.53	375.98	42.44
8	Z_3	0.71	457.7	356.20	401.14	44.93
5	Z_3	0.82	257.8	199.40	225.00	25.60

Abbreviations: Z - kind of moorsh, according to Okruszko; W_1 - secondary transformation index according to Gawlik; S - specific surface area from the BET equation, N_{ads} , N_{des} - amount of water vapour sorbed at p/p_o=0.93 during adsorption and desorption, respectively; Δ - difference between the amount of water vapour sorbed and desorbed at p/p_o=0.93.

tensions. Decomposition of organic material increases the specific surface area, thus strongly reducing hydraulic conductivity [1,2,14,22]. Ryden [14] analysed different factors that determine unsaturated hydraulic conductivity of organic soils. Characterisation and occurrence of changes in organic material, strong water binding to soil, interaction between dipole molecule and ions, the surface area and surface charge, formation of water films on organic material and internal character of Diffuse Double Layer were applied as parameters for modelling unsaturated conductivity in the dry range. Microscopic properties that are fundamental for most hydrological processes in natural soils begin at the atomic level and proceed to the field scale.

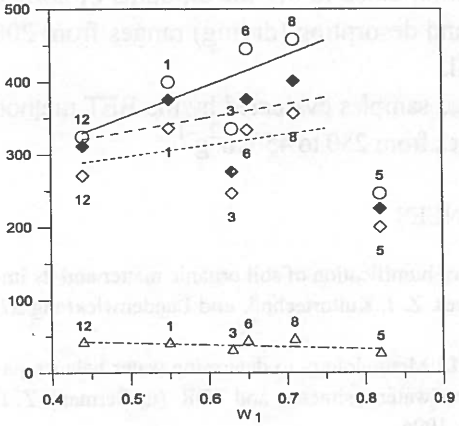

Fig. 4. Relation between W_1 and specific surface area (open circle) and the amount of water sorbed at p/p_0=0.93 during saturation (black squares) and during drying (open squares), as well as the amount of permanently sorbed water (open triangles).

CONCLUSIONS

1. Water retention curves of the investigated peat-moorsh soils do not show high differentiation in respect to their shape.

2. For the soil water potentials of about -400 hPa, hydraulic conductivity values of all the soils decrease to zero.

3. Soils: Nos 3 (W_1=0.63) and 5 (W_1=0.82) characterised as proper moorsh (Z_3), have the smallest specific soil surface, the smallest porosity characterised by the smallest affinity to water vapour, indicate the lowest retention properties and the smallest decrease of the relative water conductivity in unsaturated zone.

4. Relation between retention properties of the investigated soils and kind of moorsh characterised by Z indicator was determined. Peaty moorshes (Z_1) indicate better retention properties.

5. Unequivocal relation between the kind of moorsh characterised by the Z indicator and the shape of soil water retention curves, soil water vapour sorption and the value of specific surface area was not determined.

6. Kind of the moorsh and its secondary transformation does not influence the shape of water vapour isotherms.

7. The investigated samples are characterised by different affinity to water vapour. For the relative water vapour saturation close to 0.9 the amounts of sorbed water measured during sorption (wetting) and desorption (drying) ranges from 200 to 400 mg per 1 gram of dry (at 105 ^{o}C) soil.

8. Specific surface area of the investigated samples evaluated by the BET method with water vapour isotherms is high and ranges from 250 to 450 m^2g^{-1}.

REFERENCES

1. **Bachmann J.:** Wettability related to the degree of humification of soil organic matter and its impact on infiltration and soil water retention curves. Z. f. Kulturtechnik und Landenwicklung 37, 190-196 (in German), 1996
2. **Bohl H., Facklam M., Marschall S, Renger M.:** Methodology to determine water balance parameters of peat soils using easy installable groundwater lysimeters and TDR (in German). Z. f. Kulturtechnik und Landenwicklung 37, 185-189, 1996.
3. **Gawlik J.:** Water holding capacity of peat formation as an index of the state of their secondary transformation. Polish J. Soil Sci., 25, 121-126, 1992.
4. **Gawlik J.:** The usefulnes of water holding capacity index for evaluation of the state of secondary transformation of the peat soils (in Polish). Wiad. IMUZ, 18, 198-216, 1996.
5. **Malicki M.A., Plagge R., Renger M., Walczak R.:** Application of time-domain reflectometry (TDR) soil moisture miniprobe for the determination of unsaturated soil water characteristics from undisturbed soil cores. Irrigation Sci., 13, 65-72, 1992.
6. **Malicki M.A., Skierucha W.:** A manually controlled TDR soil moisture meter operating with 300 ps. rise time needle pulse. Irrigation Sci., 10, 153-163, 1989.
7. **Malicki M.A., Walczak R.T.:** Evaluating soil salinity status from bulk electrical conductivity. European Journal of Soil Sci. 50, 505-514, 1999.
8. **Okruszko H.:** Classification principles of organic soils (in Polish). Wiad. IMUZ, 12, 19-38, 1974.
9. **Okruszko H.:** Keys to hydrogenic soil investigation and classification for reclamation purposes (in Polish). Bibl. Wiad. IMUZ, 52, 7-54, 1976.
10. **Okruszko H., Piaścik H.:** Comparative characteristics of peat soil classification (in Polish). Prace Komisji Nauk. PTG, Warszawa, V-43, 47-53, 1981.
11. **Petersen L.W., Moldrup P., Jacobsen O.H., Rolston D.E.:** Relations between surface area and soil physical and chemical properties. Soil Sci., 161, 9-20, 1996.
12. **Piaścik H., Smólczyński S., Orzechowski M.:** Physical, water and retaining properties of hydrogenic soils of the Vistula Delta. Polish J. Soil Sci., XXXI, 9-14, 1998.
13. **Ross P.J., Smettem R.J.:** Describing soil hydraulic properties with the sums of simple functions. Soil Sci. Soc. Am. J., 57, 26-29, 1993.
14. **Ryden B.E.:** Double layer and specific surfaces of organic soils for modeling the unsaturated hydraulic conductivity. Proc. Inter. Workshop on Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils. Riverside, California, October 11-13, 1989, Ed. Van Genuchten M. Th. and Leij F. J. 693-706, 1989.
15. **Sobczuk H.A., Plagge R., Walczak R.T., Roth Ch.H.:** Laboratory equipment and calculation procedure to rapidly determine hysteresis of some soil hydrophysical properties under nonstady flow conditions. Z. Pflanzen. Bodenkd. 155, 157-163, 1992.

16. **Szajdak L., Matuszewska T., Gawlik J.:** Effect of secondary transformation state of peat-moorsh soils on their amino acid content. Inter. Peat J., 8, 76-80, 1998.
17. **Van Genuchten M.T.:** A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J., 44, 892-898, 1980.
18. **Walczak R.T. Sławiński C., Malicki M., Sobczuk H.:** Measurement of water characteristics in soil using TDR technique: water characteristics of loess soil under different treatment. Int. Agrophysics, 7, 175-182, 1993.
19. **Weiss R., Alm J., Laiho R., Laine J.:** Modeling moisture retention in peat soils. Soil Sci. Soc. Am. J., 62, 305-313, 1998.
20. **Zawadzki S., Michałowska K., Stawiński J.:** The application of surface measurements of soils for determination of the content of water unavilable for plants. Polish J. Soil Sci., IV, 89-92, 1971.
21. **Zhang R., Van Genuchten M.T.:** New models for unsaturated soil hydraulic properties. Soil Sci., 158, 77-85, 1994.
22. **Żółcik M.:** Relationship between pF value and water content in peat soils with different moorshing grade (in Polish). Wiad. IMUZ, VII, 153-161, 1968.