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Water retention characteristics of peat and sand mixtures

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A b s t r a c t. The water retention characteristics of peat, sand and their mixtures has been investigated. The results obtained showed that the hydro-physical properties of the mixtures investigated depended on the relation between organic and mineral parts. The greatest changes in bulk density / total porosity, water retention and differential water capacity were observed within the range 0.1-23% of organic matter content in the systems.

K e y w o r d s: peat - sand mixtures, water retention

INTRODUCTION

Peat soils, being potentially fertile, have a number of adverse chemical, hydrophysical, heat and mechanical properties as mineral soils. They are stipulated quite unfavorable ecological conditions to cultivate of agrophytocenoses. An increase in their fertility can be achieved by a physical method of optimising water-air and heat conditions. The above task can be executed in practice by various melioration methods.

Draining melioration changes natural peat soil evolution characterised by the processes of peat accumulation; it becomes an anthropogenic evolution characterised by the processes of an organogenic layer destruction due to the mineralisation of organic matter and erosion. It causes a decrease in the humus content and changes its quality and release of ash elements. The above processes lead to changes in the morphological, chemical, biological and physical properties of peat soils. New evolution stages begin in the shallow drained peat soils when the arable peat layer starts to mix with the underlying mineral bed rocks. Then large territories of peat soils transform into anthropogenic organic-mineral soils and their formation process continues [3,14, 17,24]. This last statement requires special investigation as to the methods of utilisation. So far this stage of evolution has been studied less frequently than others. That is why the qualitative estimation of soil properties in this case require additional research.

To improve agricultural properties and to protect cultivated peat soils from rapid destruction and degradation, methods of land improvement known as the German method of sand-admixture (Sandmischkultur) and covering with sand with deep-ploughing (Sanddeckultur) are widely applied. Both of these methods consist in the addition of sand to arable horizons of peat soils [2,5,10-12,16,25].

Even though the above methods have been known in many countries for a long time there are only few publications on the hydro-physical properties of soils formed by agro-melioration methods [5,7,19,20,26,27].

A knowledge of organic soils' hydro-physical properties is necessary to develop a useful resource management plan for peatland areas. It is also necessary for the evaluation of the efficiency of improving sand-soil fertility by the admixture of various organic substances.

The hydro-physical characteristics of organic and mineral soils have been investigated quite intensively [1,4,6,8,18, 21-23]. There are no detailed investigations on the properties of anthropogenically transformed peat soils in which the content of organic matter ranges from several to many score percent.

The purpose of the present study was to investigate the hydro-physical characteristics of peat-sand mixtures as model systems of peat soils enriched with mineral matter.

MATERIAL AND METHODS

The influence of the addition of sand on the water retention curves of peat soils was studied in laboratory

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experiments. The mixtures, based on peat and sand, were used as model systems of soils samples corresponding to various stages of peat layer enrichment (intermixing) with mineral materials. The following materials were used for the preparation of mixtures:

– shallow dried peat soil from a typical landscape of Polesie (Rogóźno, the Lublin Region) formed on sedge peat with a medium degree of decomposition (35-40%) [15]; ash content - 42.6%, pH_{KCl} - 4.6,
– medium quartz sand; organic matter content - 0.1%, pH_{KCl} - 4.0.

The determination of the organic matter content in the sand was carried out by the Tiurin method. The ash content in the peat soil was determined by igniting dried peat in a muffle furnace at about 550°C until a constant weight was reached [18]. The ash content was expressed as a percentage of the ignition residue to the total amount of dry material.

The samples were prepared by the hand mixing of the fixed quantities of peat and sand material. The resulting peat weight (which equals dry peat mass in the whole sample mass, in %) in the peat - sand mixtures was 5, 20, 40, 60 and 80%. The physical properties of the samples investigated are given in Table 1.

T a b l e 1. Physical properties of peat, sand and their mixtures

Sample No.	Composition	Organic matter	Mineral matter	Bulk density (g cm^{-3})	Total porosity (%)	Content of different sizes pores (%, m^{3}m^{-3})		
		Content in % dry matter				Macropores >30 μm	Mezopores 30-0.2 μm	Micropores <0.2 μm
1.	Peat	57.4	42.6	0.33	90	37	9	44
2.	80% of peat + sand	45.9	54.0	0.41	88	37	8	43
3.	60% of peat + sand	34.5	65.5	0.51	87	38	7	42
4.	40% of peat + sand	23.0	77.0	0.68	84	38	7	39
5.	20% of peat + sand	11.6	88.4	1.05	75	40	5	30
6.	5% of peat + sand	3.0	97.0	1.57	55	39	3	13
7.	Sand	0.1	99.9	1.86	38	31	2	5

The water retention curves, i.e., soil water potential - moisture characteristics of peat - sand mixtures were determined in the range from 981 to $15 \cdot 10^5$ MJ m^{-3} at points corresponding to the pF values of 1, 1.5, 2, 2.2, 3, 3.7 and 4.2 in the drying process. They were obtained by using pressure plate extractors (Catalogue No. 1500 and 1600, Soil Moisture Equipment Corp., Santa Barbara, CA, USA). When the equilibrium between the soil water potential and the water content was reached, the samples were weighed. After extraction at the chosen pressure levels, the samples were dried at 105°C to a constant weight [15]. The water content was determined gravimetrically at each suction level. The bulk density of the peat was determined for the samples pre-treated in pressure chambers on the basis of their saturated volume and dry weight. The total porosity was considered as equal to the water content at saturation. The border values between macropores and mesopores were taken as 30 μm (pF 2) and between mesopores and micropores as 0.2 μm (pF 4.2) [17,18].

RESULTS AND DISCUSSION

The soil water properties were determined by the physical and chemical soil characteristics, mainly bulk density (porosity) and organic matter content. The relations between these properties have been shown in Fig 1. It can be seen that an increase in organic matter content leads to a decrease in bulk density and an increase in the total porosity of the materials investigated. An increase in the organic matter content from 0.1 to 57.4% caused a decrease in the bulk density from 1.86 g cm^{-3} (sample No. 7) to 0.33 g cm^{-3} (sample No. 1); and a similar increase in the total porosity from 38 to 90%, respectively. The influence of the organic matter content in the range from 0.1 to 23% on the level of bulk density and porosity was especially obvious, i.e., when the bulk density decreased from 1.86 to 0.68 g cm^{-3}, porosity increased from 38 to 84%. Relations between bulk density and porosity in the soil materials investigated have been shown in Fig. 2. It can be seen that an increase in the bulk density from 0.33 to 0.68 g cm^{-3} caused only slight changes in porosity (from 90 to 84%); whereas an increase in the bulk density from 0.68 to 1.86 g cm^{-3} caused a rapid decrease in porosity (84 to 38%). The relation presented showed that the addition of sand to peat soils resulted in great changes in their bulk density (porosity), especially when the sand addition was higher than 40%.

The results of the present research on the soil water potential - water content characteristics in the process of the drying of peat-sand mixtures have been shown in Figs 3 and 4. Water retention curves were presented in two versions as the respective characteristics differed in their courses. This

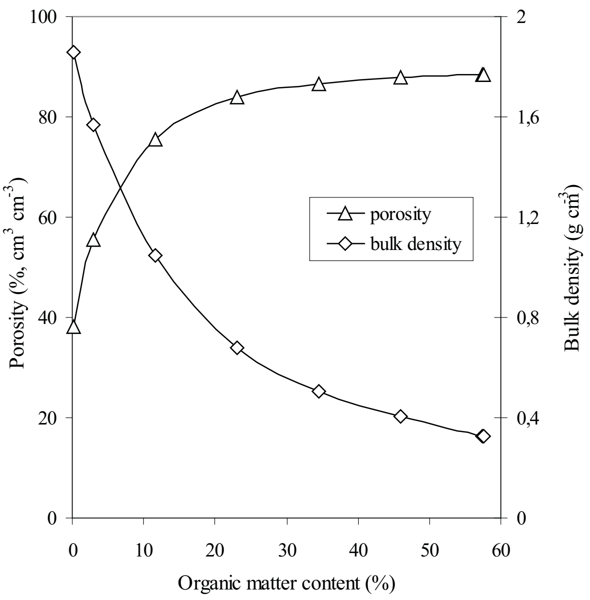

Fig. 1. Relations between organic matter content and bulk density /total porosity of the soil material investigated.

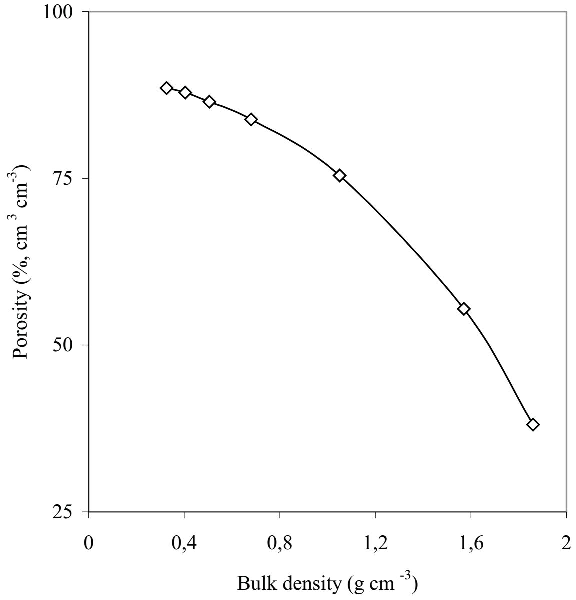

Fig. 2. Relations between bulk density and total porosity of the soil material investigated.

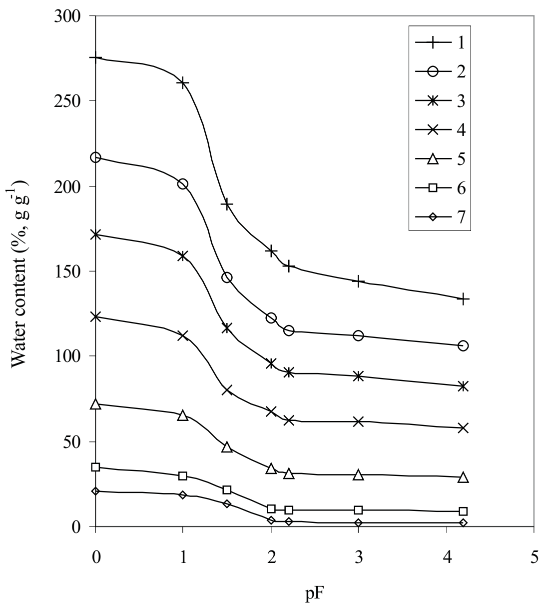

Fig. 3. Soil water potential (pF) - water content characteristics in mass units (g g^{-1}) in samples Nos 1-7.

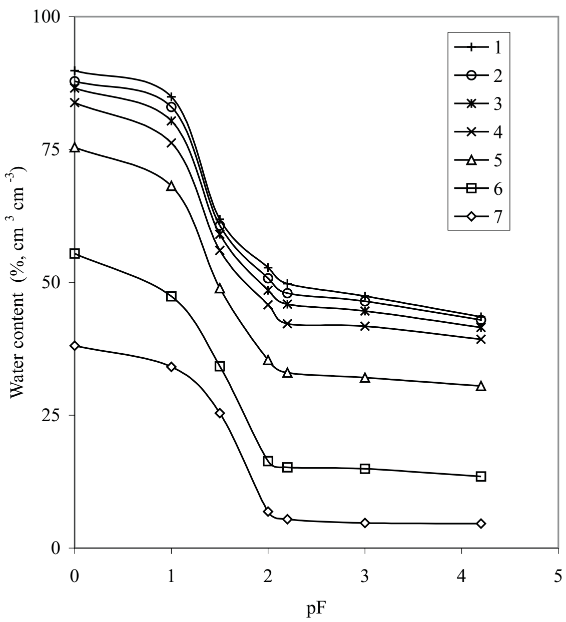

Fig. 4. Soil water potential (pF) - water content characteristics in volume units (cm^3 cm^{-3}) in samples Nos 1-7.

resulted from fact that in the case of expressing water content in g g^{-1} (mass unit), the amount of water retained by the unit of soil mass at a given potential is determined. The amount of water in this case depends only on the changes in the volume of pores and their distribution. When expressing water content in m^3 m^{-3} (volume unit). the change in the amount of soil in a unit volume depending on its bulk density is also considered. The use of volume units enables, simultaneously, both the amount of water in the soil space around the plant root system and the balance of water reserves in the soil profile and its individual layers to be determined. The water retention curves presented in Fig. 3, showed that the addition of sand to the peat soil caused an abrupt proportional decrease in the quantity of water retained at all pF points. The addition of sand to peat soil influenced the retention curves shown in Fig. 4 in a different way. The shapes of the water retention curves are nearly the same, however the addition of sand up to 60% influenced water content at all pF points to a small degree. On the other hand, changes in soil compaction caused by the organic matter content (Fig. 1) were very clear. In all cases investigated, peat soils had the highest water retention capacity. At saturation, organic soils contained about 90% of water, sand - 38%, and at pF of 4.2 - 43.5% and 4.6%, respectively.

Soil water potential - moisture characteristics gives us important information on differential water capacity. The slope of the soil water potential - moisture characteristics expressing changes in the water content per potential unit, is generally defined as differential water capacity [9]. It is an important property affecting soil water storage and availability for plants. The relation between differential water capacity and water potential characterises the soil quality as a source and storage unit for water. It also defines the potential ability and stability of water supply to the soil. Sand, as compared to peat, has low differential water capacity. The differential water capacity of peat-sand mixtures takes an intermediate position between peat and sand in accordance with the relation of the content of the organic and the mineral parts.

The hydrological characteristics of soils, such as water retention and the rate of water movement, depend, to a large degree on the total porosity and pore-size distribution of the material [13]. The soil water potential - moisture characteristics allow the calculation of effective pore size distribution. Water retention curves make it possible to determine the amount of strongly bound water (pF higher than 4.2), which is an indicator of the presence of micropores in soil. The volume of mesopores can be calculated as a difference between water content at pF 2 and 4.2. The mesopore content in the soil corresponds to the content of water available for plants and the water content at pF 2.0 - 2.7 and 2.7 - 4.2 represents easily available and poorly available water respectively. The water content between saturation and pF 2 indicates the presence of macropores. In macropores, a rapid gravitational efflux of water takes place. It is called soil aeration capacity. Water capacity between pF 2.0 and 4.2 is called potentially useful retention, but below pF 4.2 water is unavailable for plants [17].

Peat and sand mixture pore size distribution was measured by using water retention at different matrix potentials (Table 1). The percentage of pores in various sizes was calculated from the volume of water at saturation assumed to be equal to total porosity. Peat soil, as a matrix for hydrophysical phenomena, is characterised by a high proportion of small pores and a very heterogeneous pore structure. It is related to particle size distribution and soil structure. In peat, particle size, structure and porosity are determined by the state of decomposition [1,6,18]. The peat soil investigated is characterised by a higher content of micropores (44%) as compared with sand (5%). The presence of a great quantity of micropores in peat tells us of the high content of unavailable water for plants. Hence, most pores are relatively large in sandy soil, and when these large pores are wet, only a small amount of water is retained. In peat soil, pore size distribution is more uniform and water is adsorbed to a much higher degree. Then an increase in the matrix potential causes a more gradual decrease of moisture content. An increase in the organic parts in the peat - sand mixtures leads to changes in pore size distribution, which in turn, increases micropore and mesopore content and decreases macropore content. The most significant changes in pore distribution take place in the range of 0.1 - 23% of the organic matter content. An increase in organic matter content above 23% does not cause any significant changes.

The relation between water content in a unit volume of the soil at various potentials (pF) and organic matter content is given at Fig. 5. It is shown that an increase in organic matter content up to 23% in the mixtures investigated had a more pronounced effect on water retention at all levels of soil water potential than its increase from 23 to 57.4%. Thus, the increase of organic matter content from 0.1 to 23% causes an increase in moisture from 38 to 84% at pF 0, from 5.4 to 42% at pF 2.2 and from 4.6 to 39 % at pF 4.2; whereas

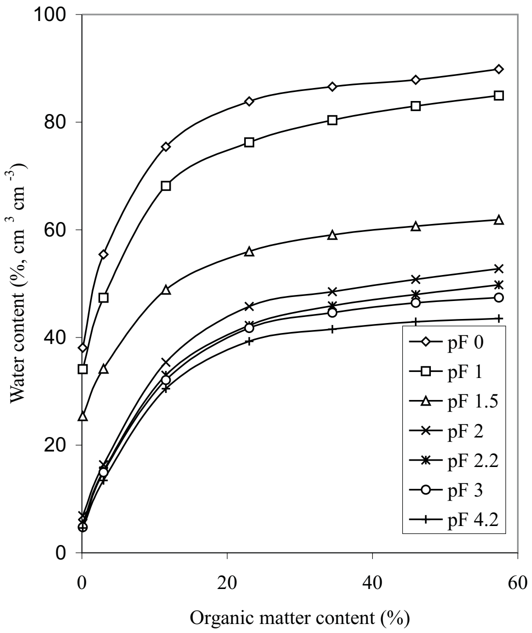

Fig. 5. Relations between organic matter content and water content (cm^3 cm^{-3}) for some chosen soil water potentials (pF) of the soil material investigated.

an increase in organic matter content from 23 to 57.4% changes the water content from 84 to 90% at pF 0, from 42 to 50% at pF 2.2 and from 39 to 44% at pF 4.2.

Adding sand to the peat soil (samples Nos 2-6) increased the amount of macropores from 42 to 70% and decreased the amount of mesopores from 9 to 5%, and the micropores from 49 to 24%.

CONCLUSIONS

The results obtained from the present research led to the following conclusions:

1. The physical properties (bulk density, total porosity, water retention, differential water capacity) of peat - sand mixtures depend to a large extent on the relation between their organic and mineral parts.

2. The greatest changes in the bulk density (total porosity) and water retention of the mixtures investigated were observed in the range of 0.1 - 23% of the organic matter content in the systems.

3. An increase in the organic matter content resulted in an increase in water retention.

4. Relations between the organic and mineral parts determined the size of pore distribution in the systems; an increase in the level of the organic part of the content resulted in an increase in the amount of micropores and mesopores and a decrease in the amount of macropores.

5. The amount of water available for plants in peat - sand mixtures increased with the increasing amount of organic matter.

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