Int. Agrophysics, 2002, 16, 313–318

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Water-air properties in peat, sand and their mixtures

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Received July 9, 2002; accepted October 11, 2002

Abstract. This paper presents the results of the investigations of water-air relations in peat, sand and their mixture. It was stated that the addition of sand into peat radically changes its water-air characteristics, i.e., causes a considerable decrease of water amount bound in the mixture with different potentials and at the same time the increase of the soil air content. The analysis of ODR and Eh values lets us state that the addition up to 60% of sand into peat does not cause a significant improvement of the conditions of oxygen availability for plant roots.

Keywords: mixtures of peat and sand, ODR, Eh

INTRODUCTION

The intensity of biological processes of oxygen absorption and carbon dioxide emission in the soil environment as well as the physical processes of gas exchange between the soil and the atmosphere determine the state of soil aeration. The movement of gases in the soil directly depends on the diffusion coefficient, determined by the number, tortuousness and continuity of the pores filled with air and indirectly on the bulk density (porosity) of the soil, the distribution function of the soil pores and the amount of the soil watering. The time of the exhaustion of the oxygen in the soil depends on the amount of its accumulation and the speed of the actual consumption. A consequence of the molecular oxygen insufficiency in the soil are the reduction processes which firstly manifest through the reduction of nitrates. The oxidation-reduction status of the soil is expressed by the redox potential (Eh), while the value describing the potential flux density of the oxygen in the soil, signed as ODR (oxygen diffusion rate) is an indicator of the soil ability to maintain oxygen on an appropriate level. Thus, ODR can be treated as a measure of the oxidation-reduction resistance of the soil. Therefore, ODR can be of high practical importance when choosing the kind of cultivation treatments or when trying to maintain the biological equilibrium in the environment [9–12,15,20,23,24].

Peat soils, being potentially fertile, have a number of adverse chemical, hydrophysical, heat and mechanical properties as mineral soils. They are stipulated quite unfavourable ecological conditions to cultivate of agrophytocenoses [2,6–8,23,28]. 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. 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) or 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 [3,13,14, 22,29]. 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 agromelioration methods [21,26,27,30]. A knowledge of organic soils' hydro-physical properties is necessary to develop a useful resource management plan for peat-land areas. It is also necessary for the evaluation of the efficiency of improving sandy soil fertility by the admixture of various organic substances.

The purpose of the present study was to investigate the oxygen diffusion rate (ODR) and the oxydo-reduction potential (Eh) characteristics of peat-sand mixtures as model systems of peat soils enriched with mineral matter.

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MATERIAL AND METHODS

The influence of the addition of sand on the water retention curves of peat soils was studied in laboratory experiments. The mixtures, based on peat and sand, were used as model systems of soil 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%), 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 [19]. The ash content was expressed as a percentage of the ignition residue to the total amount of dry material.

The peat-sand 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.

The water retention curves, i.e., soil water potential – moisture characteristics of peat-sand mixtures were determined in the range from 981 to 100 kJ m^{-3} at points corresponding to the pF values of 0, 1, 1.5, 2, 2.2 and 3 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). After extraction at the chosen pressure levels, the samples were dried at 105°C to a constant weight [16]. The water content was determined gravimetrically at each suction level. The bulk density of the peat was determined for the samples pretreated 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. Peat and sand mixtures pore size distribution was measured by using water retention at different matrix potentials. The border values between macropores and mesopores were taken as 30 μm (pF 2). Quantity of easy available water for plants was calculated as the difference of water content at pF 2 and pF 3, i.e., it is quantity of water which is bound in pores with diameter between 30 and 3 μm (Table 1).

When the equilibrium between the soil water potential and the water content was reached at the chosen soil water potential ODR and Eh were measured. The measurements of electrochemical indices of soil aeration were performed with the use of a measuring set produced by Easy Test Ltd. Firstly, the oxidation-reduction potential (Eh) measurements were done. The indicator electrode was a platinum wire of 0.5 mm diameter and 5 mm length. The complementary electrode was a saturated calomel electrode NEK. After each readout of Eh, the measurement of ODR was performed. The circuit for ODR measurement consisted of a platinum cathode (the same as in ODR measurement) and of steel anode (1mm diameter, 10 mm length). The cathode potential was set to –650 mV (in reference to NEK) with the use of the potentiostat system [17,18].

Table 1. Physical properties of peat, sand and their mixtures

Sample number	Composition	Content in % dry matter		Bulk density (g cm^{-3})	Total porosity (%)	Content of different sizes pores (%, m^3 m^{-3})		
		Organic matter	Mineral matter			> 30 μm	30-3 μm	< 3 μm
1.	Peat	57.4	42.6	0.33	90	37	5	48
2.	80% of peat + sand	45.9	54.0	0.41	88	37	4	47
3.	60% of peat + sand	34.5	65.5	0.51	87	38	3	46
4.	40% of peat + sand	23.0	77.0	0.68	84	38	4	42
5.	20% of peat + sand	11.6	88.4	1.05	75	40	3	32
6.	5% of peat + sand	3.0	97.0	1.57	55	39	1	15
7.	Sand	0.1	99.9	1.86	38	31	2	5

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 Table 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 (sample No. 7) to 0.33 g cm^{-3} (sample No. 1); and an 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%.

The results of the present research on the soil water potential-water content characteristics in the process of drying of peat-sand mixtures have been shown in Fig. 1. Water retention curves were presented in volume units (cm^3 cm^{-3}), because the change in the amount of soil in a volume unit 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 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 bulk density caused by the organic matter content (Table 1) were very clear. In all cases investigated, peat soils had the highest water retention capacity. At saturation, organic soils con- tained about 90% of water, sand – 38%, and at pF 3–50% and 5%, respectively.

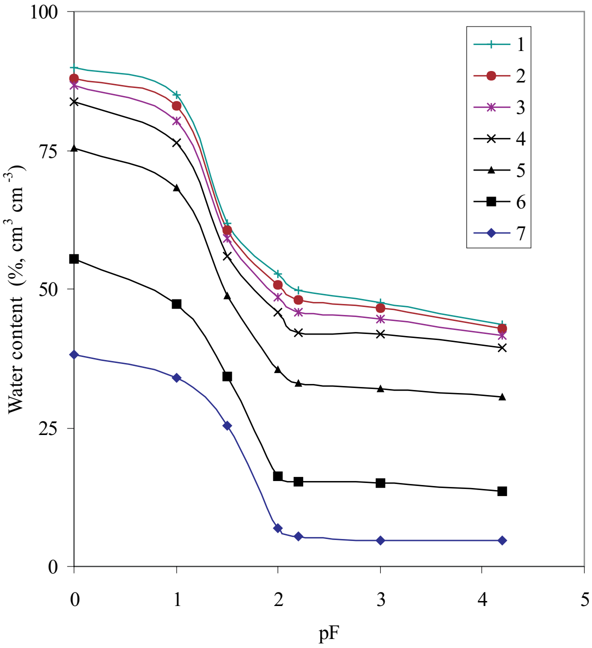

Fig. 1. Soil water potential (pF) – water content characteristics in samples Nos 1-7.

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 [11]. 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. Peat soil, as a matrix for hydro-physical phenomena, is characterised by a very high quantity of small pores (< 3 m), high amount of large pores (> 30 m) and very low amount of medium pores. The pore size distribution is caused by the state of decomposition [1,6–8]. In peat soil with higher state of decomposition, pore size distribution is more uniform. In presented investigations it was stated that the addition up to 60% of sand to the peat did not cause the important changes in its porosity and pore distribution. The most significant changes in the porosity and pore size distribution take place scarcely under its height amount, i.e., in the range of 0.1–23% of the organic matter content.

The process of soil aeration is an important determinant of soil productivity, because plant roots absorb oxygen and release carbon dioxide in the vital function of respiration. Adequate root respiration generally requires that the soil itself be aerated, i.e., that gaseous exchange take place between soil air and the atmosphere at such a rate as to prevent a deficiency of oxygen and an excess of carbon dioxide from developing in the root zone. The rate of gas transfer in the air phase is generally much greater than in the water phase, hence soil aeration is dependent largely on the volume fraction of air-filled pores.

The degree of aeration can be determined using different methods [9]. However, the methods which base on registration and processing of electrical signals are of the greatest practical importance because they enable automatic data acquisition. In reference to the measurement of soil aeration, the potential flux of oxygen and oxidation-reduction potential are such methods. The determination of the potential oxygen flux in the soil which enables to evaluate the actual oxygen availability for the plant roots can be realised using the amperometric or voltammetric methods [4,17]. From the physical point of view both methods lead to determination of the same quantity. To distinct which method has been used, the results obtained with the use of the amperometric method are indicated as ODR (oxygen diffusion rate) and these, obtained using the voltammetric method as OFD (oxygen flux density). The voltammetric method is more time consuming but it enables to obtain more reliable results. This fact is less important in case of the field measurements. In controlled laboratory conditions the use of the amperometric method is fully justifiable [4].

The oxidation-reduction potential informs about the mutual relation of oxidised and reduced forms (ions and organic substance) being the base for evaluation of aeration history. It is possible because oxygen is one of the main factors influencing the redox relations in the soil and also the actual state of equilibrium. This state however is set on the base of the water-air conditions which occurred before.

The relation between soil water potential (pF) and ODR for the investigated soil samples is presented in Fig. 2. It comes from the plots that under low values of the soil water potential (pF0 and pF1), i.e., under high saturation with water, not matter what was the composition of the peat-sand mixture, the ODR values were small and included in the range 12–27 μg $s^{-1}m^{-2}$. Together with drying of the soil samples (pF >1) the ODR values increase. It can be observed that for the samples with smaller contribution of peat in the mixture (samples 6 and 7) the maximum of the ODR=f(pF) function occurs for pF 1.5 and it equals 93 and 74 μg $s^{-1}m^{-2}$, respectively. In case of the samples with bigger contribution of peat in the mixture the maximum ODR values occur under pF 2 and they change within the range of 85–101 μg $s^{-1}m^{-2}$. However, for the higher soil water potential (pF>2) the ODR values decrease for all the investigated samples. It can be stated, that the favourable oxidation conditions take place in the majority of investigated mixtures only at pF 2 (ODR >70 g $s^{-1}m^{-2}$) and for sample 5 at pF 1.5 – pF 2.2. The unfavourable oxidation conditions appear between pF 0 and pF 1 (ODR < 35 g $s^{-1}m^{-2}$) in the all investigated samples.

Obtained results of ODR for the investigated mixtures are in good correlation with the results published for the mineral soils [4,5]. The occurrence of the maximum of the ODR=f (pF) function can be explained by the phenomena of tearing off the water film in the dry soils on the surface of platinum cathode [25]. It results in the decrease of the current in the system (measured with amperometric method), although the amount of oxygen reaching the cathode surface by diffusion increases.

Obtained various values of soil water potential (pF) at which the maximum of the ODR=f (pF) function occurs for different composition of the peat-sand mixture is compatible with results of the other authors [4,5].

The value of the soil water potential (pF) and/or soil water content, at which the maximum of the ODR=f (pF) function occurs is recognised as the limit of amperometric and voltammetric methods applicability. It means that above a certain value of the soil water potential (pF) the measured current values cannot be interpreted in terms of a potential oxygen flux density in the soil. Thus, it is important from a methodological point of view to determine the boundary values for various soils.

When analysing the courses of the curves presented in Fig. 2 it is not possible to determine univocally the limits of applicability of the investigated soil samples. However, it is possible to state that for the investigated mixtures of peat and sand, in case when the sand content does not exceed 80%, a safe range, from the point of view of the results reliability, is from pF 0 to pF 1.5, whereas for the soil samples in which sand content exceeds 80% this range is limited to pF 0 –pF 1.

It is very difficult to interpret univocally the obtained results in reference to the oxidation-reduction potential Eh (Fig. 3). It is because all the samples were prepared artificially in laboratory. Due to this the history of their

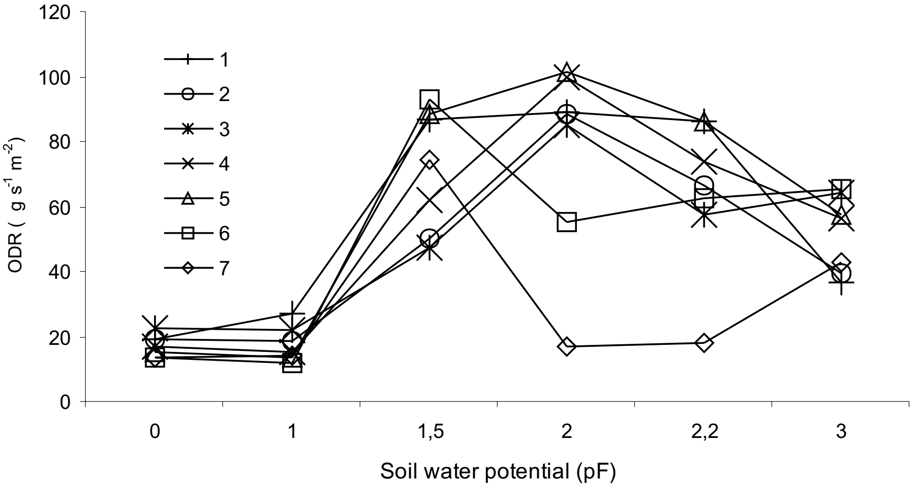

Fig. 2. Relationship between soil water potential (pF) and ODR.

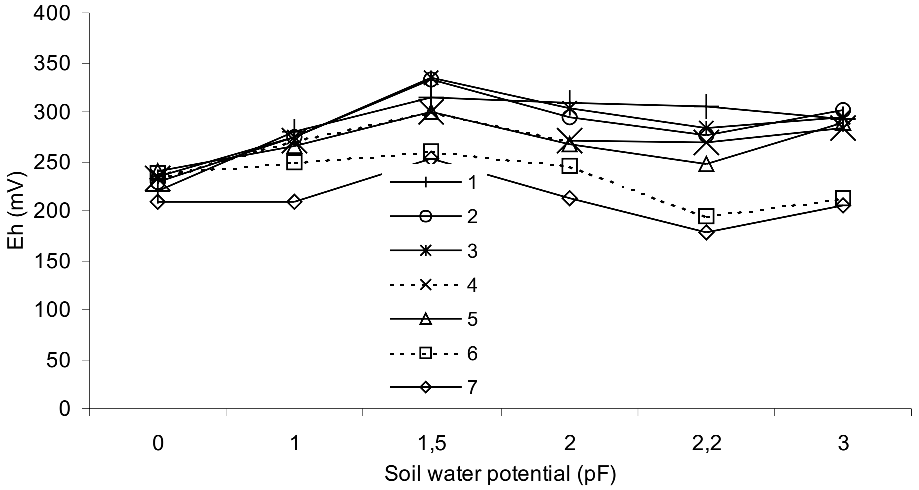

Fig. 3. Relationship between soil water potential (pF) and Eh.

aeration was the same, i.e., the air dry mixture of the soil materials was watered with a fully oxygen saturated water. Furthermore, the cylinders filled with the mixture had an unlimited contact with atmosphere. Therefore, the courses of the curves in Fig. 3 have a similar shape and the values of Eh change from 178 mV at pF 0 to 335 mV at pF 1.5. However, it should be noticed that Eh values for the samples with sand content higher than 80% are lower than for the others.

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. A decrease in the organic matter content resulted in a decrease in water retention.

3. 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.

4. The process of addition of sand up to 60% to the peat does not lead to a distinct improvement of the condition of oxygen availability for the plant rooting system.

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