The analysis of shrinkage-swelling behaviour of peat-moorsh soil aggregates during drying-wetting cycles

R. Oleszczuk and T. Brandyk

Department of Environmental Improvement, Warsaw University of Life Sciences (SGGW), ul. Nowoursynowska 159, 02-776 Warsaw, Poland;
e-mail:ryszard_oleszczuk@sggw.pl

Abstract. The aim of this study was to investigate the soil volume changes for moorsh, willow and moss peat layers during drying-wetting cycles. The measurements of soil volume changes were made using the 'saran resin' method. The reversible and irreversible shrinkage coefficient values for each layer were calculated. The relationships between soil moisture contents before and after rewetting were estimated for analysed soil aggregates. The performed research showed that the soil volume changes were relatively small for moorsh and the highest for willow and moss peat. After a few drying-wetting cycles, the moorsh soil aggregates also retained the highest amount of water in comparison with willow and moss peat.

Key words: peat-moorsh soil, drying, shrinkage, rewetting, swelling

INTRODUCTION

The peat-moorsh soils volume changes are the results of the drying and wetting processes. The shrinkage of these soils can be observed durng a drying process. In the natural conditions, vertical shrinkage causes subsidence of the soil surface whereas horizontal shrinkage causes the soil cracks. The rate of peat shrinkage depends on a number of factors, such as rate of decomposition, values of bulk density and ash content for a particular peat type (Ilnicki, 1967). This process has strong influence on chemical and physical properties of the peat-moorsh soils such as subsidence, crack formation, decomposition, mineralization and preferential flow (Olszta, 1975; Okruszko, 1993; Frąckowiak & Feliński 1994; Hendriks, 2004). Several studies on shrinkage characteristics of peat soils due to water losses were reported (Ilnicki, 1967; Pyatt & John, 1989; Szatyłowicz et al., 1996; van den Akker & Hendriks 1997; Oleszczuk, 2001; Brandyk et al., 2002; Oleszczuk et al., 2003; Camporse et al., 2004; Kennedy & Price, 2005). The swelling process takes place due to increasing water content in peat-moorsh soils. In the field conditions, upon wetting, the cracks close again and the rise of the soil surface is observed (Millete & Broughton, 1984; Szuniewicz et al. 1993; Gilmann, 1994; Oleszczuk et al., 1999; Brandyk et al., 2001; 2006; Camporese et al., 2006). In the literature only a limited number of papers reported the swelling phenomena in peat soils. Łacheta & Lipka (1971, 1978) measured the vertical swelling index for highly decomposed peat-moorsh and showed that the values of this parameter were higher for peat soils with a low degree of decomposition at high value of moisture content. Olszta (1975, 1998), Zawadzki & Olszta (1989), Olszta & Jaros (1991) investigated in the laboratory the swelling intensity of carbonated and intensively drained peat-moorsh soils. The values of vertical and horizontal swelling, dynamics of irreversible shrinkage after rewetting and the relationships between the soil moisture content before and after increasing water content were obtained as the results of performed laboratory measurements. Lyon (1995) showed the swelling of peat due to the sorption process in liquid methyl, tetramethylene, propyl sulfoxides and liquid propyl sulfone.

The aim of the present study was to investigate the soil volume changes of peat-moorsh soil layers resulting from drying and wetting processes, estimation of the scale of reversible and irreversible shrinkage coefficients and to present the relationships between soil moisture contents before and after rewetting.

MATERIALS AND METHODS

The peat-moorsh soil layers from the soil profile located in Kuwasy drainage sub-irrigation system (Middle Basin of Biebrza river valley, Poland) were investigated in this study. The soils in this area are mainly fen-moorsh soils with a medium degree of decomposition. They are used as meadows with hay production of ca. 8 t ha^{-1}. Undisturbed soil aggregates in five replications were collected from this soil profile from the following layers: 0–20 cm, 60–70 cm and 110–120 cm. These soil layers were classified as a moorsh, willow peat (H_7) and moss peat (H_3) according to Tołpa et al. (1967) classification. The degree of the decomposition of the aggregates was estimated using the van Post scale (Maciak & Liwski, 1996). The volume of soil aggregates ranged from 30 cm^3 to 60 cm^3. The aggregates' volume changes due to the shrinkage process were measured using the 'saran resin' method described by Brasher et al. (1966). Each of the soil aggregates was completely saturated with water and then briefly immersed in a solution of butanone saran resin (solvent ratio 1:4) and allowed to dry at room temperature. The saran resin coating was flexible and semi-permeable for water, i.e. impermeable for water immersion and permeable for water vapour. The coating remained tightly fitted around changing volume soil aggregates. Repeated weighting of the coated soil aggregates in air and immersed in water allowed daily measuring in a non-destructive way both their mass and their volume during shrinkage processes. After a few days the drying process was stopped and the soil samples were again completely saturated with water. After saturation, the increase of the soil aggregates' volumes due to the swelling process were observed. Then the soil samples were dried again in order to reach the next, lower stage of drying. This procedure, including drying and swelling processes, was performed four times for each soil aggregate. During the last phase of the drying process, when the weight and volume losses were negligible, the soil aggregates were dried in the oven at 105°C in order to measure their final dry mass and volume. The procedure proposed by Bronswijk et al. (1997) was used in order to calculate the volume and weight of soil aggregates during shrinkage-swelling processes.

The reversible and irreversible shrinkage coefficients were calculated for the considered soil layers during shrinkage-swelling cycles using the formulas proposed by Ilnicki (1967) and by Maciak & Liwski (1996):

Reversible shrinkage coefficient, **S_{irr}** [%] defined as:

$$S_{irr} = \frac{v_p - v_o}{v_s} 100 \qquad (1)$$

Irreversible shrinkage coefficient, **S_{rev}** [%] defined as:

$$S_{rev} = \frac{v_s - v_p}{v_s} 100 \qquad (2)$$

where:

v_s – the volume of soil aggregate at fully saturation [cm^3],

v_p – the volume of swollen soil aggregate after rewetting [cm^3],

v_o – the volume of soil aggregate dried at the temperature of 105^{o}C [cm^3],

RESULTS AND DISCUSSION

The values of volumetric moisture content (θ_V) and the volume of the soil aggregates (V) at the beginning and the end of each shrinkage-swelling phase for two selected soil aggregates from the considered soil layers are presented in Table 1. The results of the shrinkage-swelling measurements performed for descriptions in Table 1 soil aggregates are plotted in Fig. 1.

Table 1. The changes of the values of the volumetric moisture content (%) and volume (cm^3) during shrinkage-swelling phases for moorsh and peat soil aggregates.

The layer	1 phase		2 phase		3 phase		4 phase	
	θ_V	V	θ_V	V	θ_V	V	θ_V	V
cm	% vol.	cm^3	% vol.	cm^3	% vol.	cm^3	% vol.	cm^3
samp.1	85.88	32.72	78.63	31.94	78.24	32.42	72.86	29.99
0–20	41.81	29.86	31.02	27.05	15.03	21.91	0.00	14.37
(moorsh)	86.84	31.94	78.23	31.02	78.74	31.44	73.79	29.43
samp.2	39.43	27.85	31.03	26.14	15.64	21.98	0.00	14.50
samp. 1	91.43	52.19	79.38	48.19	76.26	46.47	61.31	38.21
60–70	59.82	42.16	45.12	36.11	23.36	27.06	0.00	11.16
(willow peat)	92.58	43.91	80.15	40.07	75.57	37.90	64.82	33.12
samp.2	61.49	34.92	46.94	29.63	30.57	23.97	0.00	7.66
samp. 1	89.40	48.11	74.63	46.21	70.80	43.71	57.52	36.62
110–120	34.88	44.18	12.44	38.95	1.50	27.16	0.00	21.60
(moss peat)	91.93	46.14	73.62	45.16	69.86	42.64	55.91	36.41
samp.2	43.16	36.32	10.20	37.19	0.68	25.43	0.00	20.92

In the moorsh layer (0-20 cm) the values of saturated volumetric moisture content were close to 86% and the corresponding volumes, about 32 cm^3. The first phase of the drying process in this layer was continued until the volumetric moisture content reached about 40% and the volume of soil aggregates decreased to about 29 cm^3.

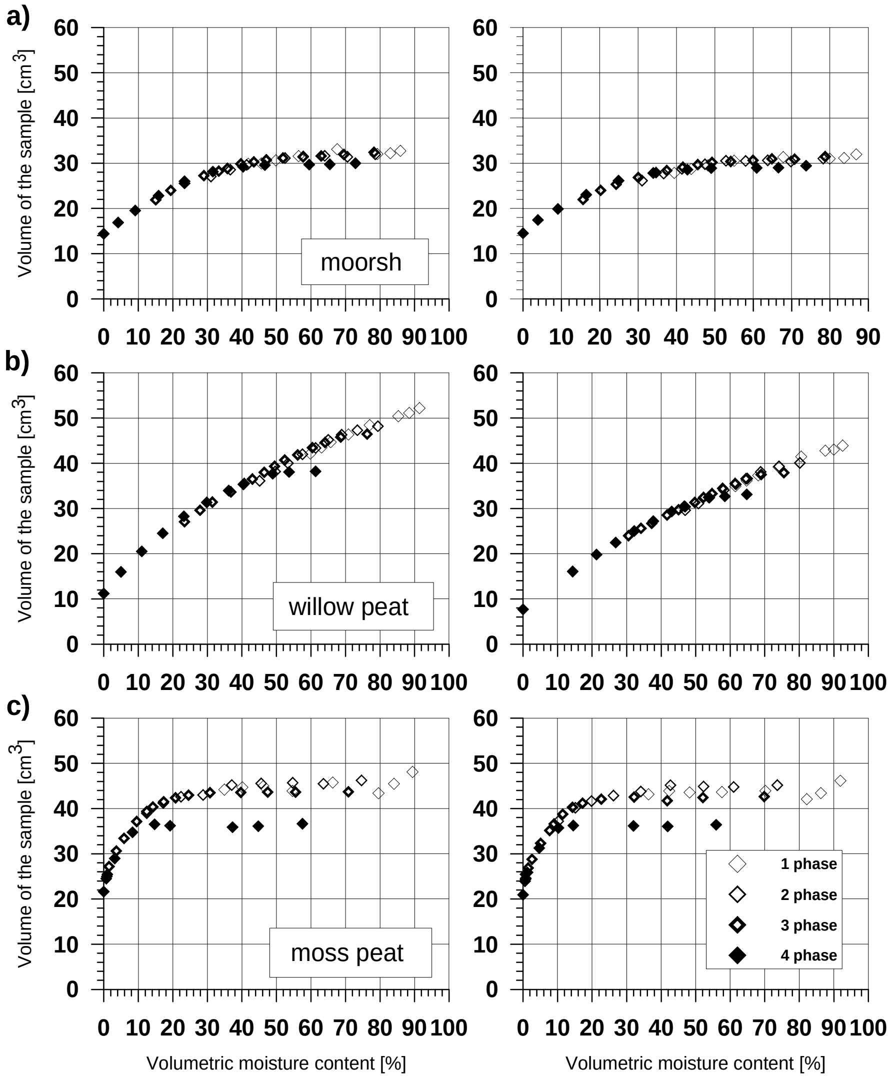

Fig. 1. The soil volume changes during shrinkage-swelling processes for the selected aggregates representing different layers in the soil profile.

After rewetting the aggregates the values of volumetric moisture content were increased to about 78% and the values of the aggregates' volumes were close to the initial volume at the beginning of phase 1. During the second phase the aggregates decreased the values of θ_V to 30% and the volume to the value in the range 26-27 cm^3. Due to the saturation procedure performed after the second phase, the values of moisture content and the values of the volume of the soil aggregates were very close to those obtained at the beginning of the previous (2) phase. The drying process in the third phase was performed until a very low value of volumetric moisture content (15%) was reached and the resulted loss of volume of moorsh aggregates was close to about 22 cm^3. The rewetting after the third phase resulted in the values of the soil aggregates' volume increase to about 30 cm^3, which is relatively close to the initial volume of the soil aggregates. The analysis of the values of volumetric moisture content after the last third rewetting showed that they are lower by about 12% in comparison with the values of the saturated moisture content at the beginning of the measurements (Fig. 1a).

The analysis of the volume changes of the aggregates collected from the willow peat layer (60-70 cm) showed that saturated moisture contents were reached at values about 92% and the initial volume of the willow peat aggregates were in the range from 43 cm^3 to 52 cm^3. At the end of the first drying phase, the decrease of the values of volumetric moisture content to about 60% and volumes of the aggregates from 35 cm^3 to 42 cm^3 were observed. Due to the second rewetting of these aggregates the values of the moisture content increased to about 80% and, after the rewetting, the considered soil aggregates increased their volumes to a range of 40 cm^3–48 cm^3. During the second phase, the drying process was continued until the level of the moisture content ranged between 45% and 46% and the values of the soil aggregates volume were in the range 29-36 cm^3. After the saturation following the second phase, the soil aggregates reached the values of moisture content and volume which were very close to those recorded at the beginning of the second phase. The last fourth phase, after few shrinkage-swelling processes, started with the lowest saturated values of moisture content and volume of the soil samples (Table 1, Fig.1b).

The three phases of the shrinkage-swelling process caused gradually decreasing values of moisture content and the volume of the moss aggregates (110–120 cm) similar to those observed for moorsh and willow peat. After the last rewetting, the moss peat samples were able to increase their moisture content to 57–55% and swell only to the volume of 36 cm^3.

The reversible and irreversible shrinkage coefficients for each soil layer were calculated using equations 1 and 2. The relationships between shrinkage coefficient and volumetric moisture content in form of linear regression were presented in Table 2.

Table 2. The linear correlation equation between shrinkage coefficients (S_{rev} and S_{irr}) and volumetric moisture content (θ_V) for considered soil layers.

Layer (cm)	Linear equation	Coefficients of determination R^2
	Reversible shrinkage	
0–20	S_{rev}=0.2922θ_V+43.928	0.3094
60–70	S_{rev}=0.5894θ_V+38.320	0.9162
110–120	S_{rev}=0.4244θ_V+36.846	0.7936
	Irreversible shrinkage	
0–20	S_{irr}=-0.1415θ_V+8.2861	0.3887
60–70	S_{irr}=-0.562θ_V+41.118	0.9200
110–120	S_{irr}=-0.3456θ_V+18.153	0.5129

The measured and fitted reversible and irreversible shrinkage coefficient versus moisture content for analysed soil layers were plotted in Fig. 2. In all considered soil layers, the values of the reversible coefficient were decreasing with the water loss. In analysed soil aggregates, the swelling after rewetting was gradually lower corresponding to the decrease of moisture content.

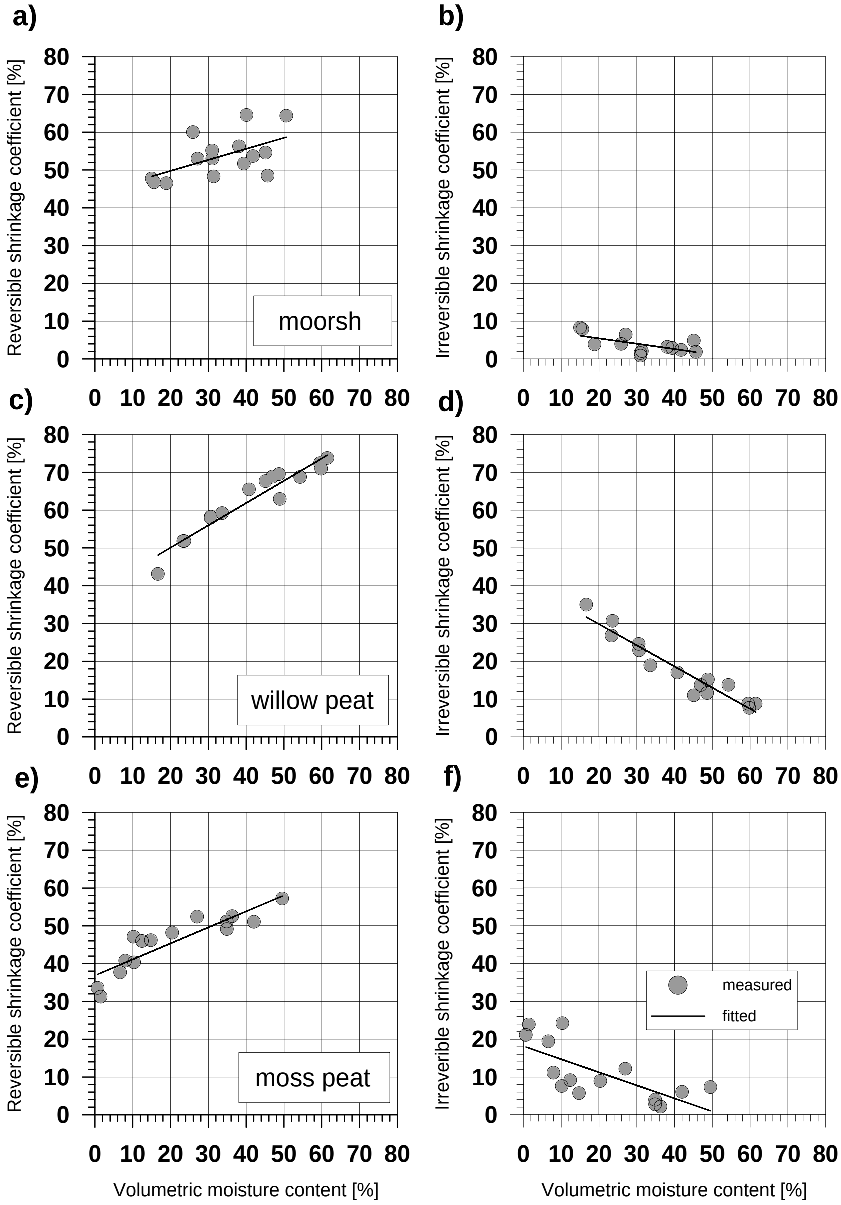

Fig. 2. The dynamics of reversible and irreversible shrinkage coefficient as depending on soil moisture content for considered soil layers.

Olszta & Jaros (1991) obtained similar relationships for alder, sedge, reed and moss peats. From the analysis of the data presented in Fig. 2 it can be seen that the highest possibility to swell was observed for the aggregates collected from the moorsh layer (0–20 cm) and the lowest ability to increase their volume was found for the aggregates of willow peat (60–70 cm). These observations were confirmed by the values of the slope coefficient presented in Table 2.

The analysis of the irreversible shrinkage coefficient values showed that this parameter was increasing its values with decreasing moisture content values for all considered soil layers. The lowest value of irreversible shrinkage coefficient was determined for the moorsh layer and the highest value was estimated for willow peat.

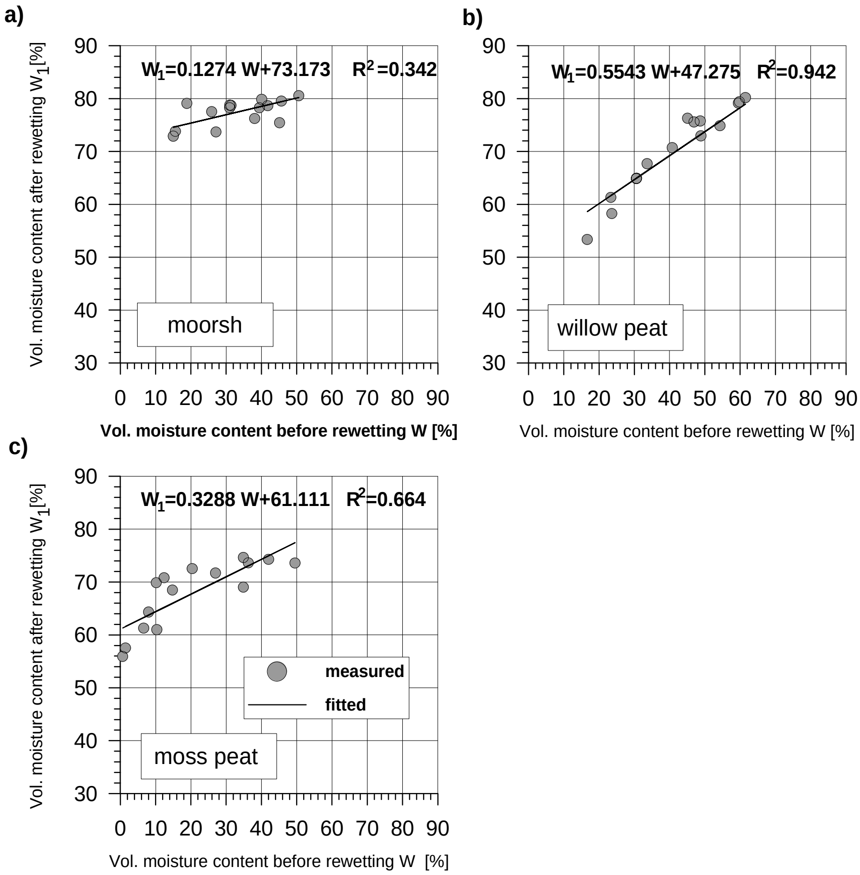

Fig. 3. The relationships between soil moisture content after rewetting (W_1) and before rewetting (W) for considered soil samples.

The relationships between volumetric moisture content of soil aggregates after rewetting (W_1) and before rewetting (W) were presented in Fig. 3. Analysis of the data presented in this figure shows that, after few shrinkage-swelling cycles, the strongly decomposed top layer still retained water. Soil moisture content of this layer after drying to volumetric moisture content W=40% increased after rewetting to the value W_1=80%. In the layers of willow and moss peat the drying process caused the decrease of the soil moisture contents after rewetting (W_1). The analysis of the data presented in Fig. 3 and Table 2 showed that the drying process influences soil moisture retention after rewetting (W_1). Olszta (1998) reported similar observations for other moorsh and peat layers: after drying process they were not able to retain the same amount of water as at the beginning of the experiments.

CONCLUSIONS

1. The performed analysis of the volume changes of the soil aggregates collected from the moorsh layer (0-20 cm) after three phases of shrinkage-swelling cycles showed that the volume changes were relatively small, ranging from 32.77 cm^3 at the beginning of the experiment to 29.43 cm^3 at the beginning of the fourth phase. For the less decomposed willow and moss peat the soil volume changes were much higher, ranging between 52.19 cm^3 to 33.12 cm^3 for willow peat and from 48.11 cm^3 to 36.41 cm^3, for moss peat, respectively.
2. The analysis of the variation of reversible and irreversible shrinkage coefficients showed the much higher values of reversible shrinkage coefficient in comparison with the values of the irreversible shrinkage coefficient. The values of the reversible shrinkage coefficient were decreasing during the drying process for all considered soil layers, while the values of irreversible shrinkage coefficient were increasing with the water losses.
3. The established relationships between volumetric moisture content of soil aggregates after (W_1) and before rewetting (W) showed that strongly decomposed moorsh layer after three shrinkage-swelling cycles still retained almost the same amount of water. In the layers of willow and moss peat the drying process caused significant decrease in the soil moisture content after rewetting.

ACKNOWLEDGEMENT. The study was supported by Polish Ministry of Science (project no. 2 P06S 029 30, 2006–2008).

REFERENCES

Brandyk, T., Oleszczuk, R. & Szatyłowicz J. 2001. Investigation of soil water dynamics in a fen peat-moorsh soil profile. *Inter. Peat J.* **11**, 15–24.

Brandyk, T., Oleszczuk, R. & Szatyłowicz J. 2006. Comparison of different methods of water storage determination in peat-moorsh soil profile used as a meadow. *Acta Agrophysica* **8**(1), 11–21.

Brandyk, T., Szatyłowicz, J., Oleszczuk, R. & Gnatowski, T. 2002. Water-related physical attributes of organic soils. In Parent, L.E. & Ilnicki P. (eds): *Organic soils and peat materials for sustainable agriculture*. CRC Press and International Peat Society, Boca Raton, Florida, USA, pp. 33–66.

Brasher, B. R., Franzmeier, D. P., Valassis, V. & Davidson, S. E. 1966. Use of Saran resin to coat natural soil clods for bulk density and water – retention measurements. *Soil Sci.* **101**, 108.

Bronswijk, J. J. B., Evers-Vermeer, J. & van den Akker, J. J. H. 1997. Determination of the shrinkage characteristic of clay soil aggregates. In Stolte, J. (ed.): *Manual for soil physical* *measurements*. Tech. Document 37 ver. 3, DLO Winand Staring Centre, Wageningen, The Netherlands, pp. 71–77.

Camporese, M., Ferraris, M., Putti, M., Salandin, P. & Teatini P. 2006. Hydrological modeling in swelling/shrinking peat soils. *Water Resour. Res*. **42**, doi:10.1029/2005WR004495.

Camporese, M., Putti, M., Salandin, P. & Teatini P. 2004. 2004. Modeling peatland hydrology and related elastic deformation. In Miller, C. (ed.): *Computational Methods in Water Resources XV*. Elsever, New York, USA, vol. 1, pp. 1453–1465.

Frąckowiak, H. & Feliński, T. 1994. The lowering of organic soil surface during intensive drainage under meadow use. *Wiadomości IMUZ* **17**(2), 29–35 (in Polish).

Gilman, K. 1994. *Hydrology and Wetland Conservation*. Wiley, J & Sons (eds), 101 pp.

Hendriks, R. F. 2004. An analytical equation for describing the shrinkage characteristics of peat soils. In: Paivanen, J. (ed.): *Proc. of the 12th International Peat Congress*, Tampere, Finland, vol. **2,** pp. 1343–1348.

Ilnicki, P. 1967. The shrinkage of peat soils during drying as dependent on soil structure and physical properties. *Zesz. Prob. Post. Nauk Rol.* **76**, pp. 197–311 (in Polish).

Kennedy, G.W. & Price J. S, 2005. A conceptual model of volume-change controls on the hydrology of cutover peats. *J. Hydrol*. **302**, 13–27.

Lyon, W. G. 1995. Swelling of peats in liquid methyl, tetramethylene and propyl sulfoxides and in liquid propyl sulfone. *Environ. Toxicol. and Chem*. **14**(2), 229–236.

Łacheta, S. & Lipka K. 1978. Laboratory research on peat swelling capability. *Zeszyty Naukowe Akademii Rolniczej w Krakowie, ser. Melioracje* **9**, 145–155 (in Polish).

Łacheta, S. & Lipka, K. 1971. Swelling capacity of muck-peat soils in the light of laboratory experiments. *Zesz. Nauk. Akad. Rol. im. Hugona Kołątaja w Krakowie, ser. Melioracje* **5**, 151–165 (in Polish).

Maciak, F. & Liwski S. 1996. *Practical peatlands guidelines*. Warsaw Agricultural University Press, 159 pp. (in Polish).

Millete, J.A, & Broughton, R.S. 1984. The effect of water table in organic soil on subsidence and swelling. *Can. J. Soil Sci*. **64**, 273–282.

Okruszko, H. 1993. Transformation of fen-peat soil under the impact of draining. *Zesz. Prob. Nauk Rol,* **406**, 3–73.

Oleszczuk, R., Bohne, K., Szatyłowicz, J., Brandyk, T. & Gnatowski, T. 2003. Influence of load on shrinkage behaviour of peat soils. *J. Plant Nutr. and Soil Sci*. **166**, 220–224.

Oleszczuk, R., 2001. Shrinkage characteristics of peat-moorsh soil. *Annals of Warsaw Agricultural Universty - SGGW, Land Reclamation* **31**, 13–21.

Oleszczuk, R., Szatyłowicz, J. & Brandyk T. 1999. Prediction of vertical peat-moorsh soil profile movements caused by moisture content changes. *Rocz. Akad. Rol. w Poznaniu CCCX, Melior. Inż. Środ*. **20**(1), 139–150.

Olszta, W. 1975. Overdrying effect on changes of physical and hydrological properties of hydrogenic carbonate formations. *Roczniki Nauk Rolniczych* ser. F, t.**79**, z. 1, 57–69 (in Polish).

Olszta, W. 1998. Influence of intensive drainage on water retention capacity and capillary conductivity of hydrogenic soils. *Wiadomości IMUZ*, t. **19**(3**)**, 25–39 (in Polish).

Olszta, W., Jaros H. 1991. Influence of intensive drainage on water retention capacity, shrinkage and capillary rise of peat-moorsh soils. *Wiadomości IMUZ* **16**(3), 37–55 (in Polish).

Pyatt, D.G. & John, A. L. 1989. Modelling volume changes in peat under conifer plantations. J. Soil. Sci. **40**, 695–706.

Szatyłowicz, J., Oleszczuk R. & Brandyk T. 1996. Shrinkage characteristic of some fen fen peat soil. In Luttig, G., W (ed.): *Proc. Of 10th International Peat Congress*. Bremen, Germany, vol. **2**., pp, 327–338.

Szuniewicz, J., Churski, T. & Szajda J. 1993. The surface level movements and water storage in peat-moorsh soil. *Wiadomości IMUZ* **17**(3), 191–205 (in Polish).
Tołpa S., Janowski M. & Pałczyński A. 1967. System der genetischen Klassifizierung der Torfe Mittleeuropas. *Zesz. Prob. Post. Nauk Rol.* **76**, 9–99 (in German).
Van den Akker, J. J. & Hendriks R., F. 1997. Shrinkage characteristics of Dutch peat soil. In Schmilewski, G. (ed.): *Peat in Horticulture*. Proc. Int. Peat Conf. The Netherlands, pp. 156–162.
Zawadzki, S. & Olszta, W. 1989. The changes of physico-water properties of excessively dried hydrogenic soils. *Pol. J. Soil. Sci.,* **22**(1), 1–9.