Contemporary Problems of Management and Environmental Protection
Vol. 1, 2009. Soils of Chosen Landscapes: 51-84

Chapter IV

Sławomir Smólczyński

Physical Properties of Upper Silted Organic Soils in Various Landscapes of North-Eastern Poland

INTRODUCTION

Distinguishing and classification of organic soils is based on the qualitative parameters of organic layer thickness (more than 30 cm) and the content of organic matter (more than 20%) [OKRUSZKO 1976b, SYSTEMATYKA…1989]. Regarding this criteria, upper silted organic soils are the soils which were covered with alluvial and deluvial deposits of a thickness of 10-30 cm. These soils are classified in the Polish soil classification as mucky soils and peat-muck soils. Basing on the admixture of mineral fraction in muck formations, OKRUSZKO [1976b] classified these soils as strongly silted (50-80% of mineral fraction) and slightly silted (50-20% of mineral fraction). According to WRB classification [IUSS WORKING GROUP WRB 2006] organic soils are a reference group of Histosols. Organic formations in these soils may be covered with mineral deposits of thickness of less than 40 cm. The layer of deposits is characterized by the qualifier (Suffix-Qualifier) Novic (Areni-, Clay-, Sillinovic). German soil classification of Moorboden group is based on similar thickness of mineral layer. However the layer of less than 20 cm thick is regarded as a soil substrate and a thickness of 20-40 cm is the basis for determining a variety of soil (Varietet), (AD-HOC-AG BODEN 2005]. The conditions which favor formation of these soils, occur in various landscapes, especially in river valleys [PIAŚCIK, LEMKOWSKA 2001], river deltas [PIAŚCIK et al. 200, SMÓLCZYŃSKI et al. 2000, SMÓLCZYŃSKI et al. 2004] and in young glacial landscape which has diversified relief and in which upper silted soils occur in numerous depressions near the slopes where they are the last chain of eroded and deluvial soils sequence along the slope [PIAŚCIK et al. 2001, PIAŚCIK, SOWIŃSKI 2002]. The processes of upper silting are modifying the morphology, physical and chemical properties of organic soils [ORZECHOWSKI ET AL. 2001, ORZECHOWSKI, SMÓLCZYŃSKI 2002, SOWIŃSKI et al. 2004, SOWIŃSKI et al. 2005]. Properties of upper silted soils, in comparison to proper, not silted organic soils, are insuffiently studied.

The aim of the paper is to present the conditions of formation and location of organic soils modified by alluvial and deluvial processes in various landscapes of north-eastern Poland as well as examination of soil water retention, physical and water properties.

METHODOLOGY OF RESEARCH

For the research, the sites in the following types of landscapes (according to KONDRACKI 1988) were chosen: delta landscape (Jegłownik), riverine landscape (Smolajny), of morainic hills and plains (Reszel II), hummocky lakeland (Lutry I, Lutry II, Prusinowo), (Fig. 1). At the studied sites, along the transects, 19 soil profiles were examined. Additionally, in order to determine the stratigraphy of soil formations, boreholes were drilled. From the soil horizons, soil samples were collected into plastic bags. Samples of undisturbed soil were collected into steel cylinders.

In the laboratory, the following analyses were carried out: loss-on-ignition after combustion in the temperature of 550 °C, soil specific density and soil bulk density (in undisturbed soil samples collected into 100 cm^3 steel cylinders). Total porosity (Po) was calculated on the basis of specific density (S) and bulk density (So) according to the equation: $Po=(S-So)\cdot So^{-1}\cdot 100$. In the soils of young glacial landscape (Reszel, Lutry II, Prusinowo) moisture content in surface horizons and the groundwater level was measured during seven periods (August and December 2007, April, July, October and December 2008, April 2009). In the soils in delta landscape the mentioned measurements were carried out during 5 periods (May and August 2006, May, July, December 2007).

Soil water retention properties were determined using low- and high-pressure chambers [ZAWADZKI 1973]. Water capacities ($W_{vol.}$) were examined at the pressure of 98.1 hPa (pF 2.0), 490.5 hPa (pF 2.7), 981.0 hPa (pF 3.0) and 15 547.9 hPa (pF 4.2). On the basis of total porosity and water capacities, the amounts of following soil pores were calculated: macropores (total porosity-$W_{vol.}$ at pF 2.0), mesopores corresponding to potential useful water retention (PRU) ($W_{vol.}$ at pF 2.0 - $W_{vol.}$ at pF 4.2), effective useful water retention (ERU) ($W_{vol.}$ at pF 2.0 - $W_{vol.}$ at pF 2.7), small pores (DKR) ($W_{vol.}$ at pF 2.7 - $W_{vol.}$ at pF 4.2) and micropores $W_{vol.}$ at pF 4.2.

Age of organic formations underlying alluvial and deluvial deposits was measured by 14C radiocarbon method in Poznań Radiocarbon Laboratory. Statistical analyses were conducted using Statistica 8.0.

DESCRIPTION OF STUDIED SITES AND SOILS

Jegłownik site is situated in the mesoregion of Żuławy Wiślane and represents delta landscape [KONDRACKI 1988]. Organic soils in Vistula delta occur mainly in the depressions. Their development is associated with fluviogenic type of hydrological supply [PIAŚCIK et al. 2000, SMÓLCZYŃSKI et al. 2000, SMÓLCZYŃSKI et al. 2004]. An important role in their origin was played by flooding waters as a result of breaking protective embankments. Consequently, secondary accumulation of alluvial sediments which saturated organic formations or deposited on their surface took place. At the studied site, mucky soils form a mosaic with strongly silted peat muck soils and shallow alluvial soils on peat deposits. For the research two soil profiles, lying 0.5 m below sea level, were chosen. The soils were formed from moderately decomposed reed peats, which at a depth of 60-65 cm were underlain by strongly decomposed alder peats on organic gyttja. Surface layer of mucky soil was composed of mineral-organic deposit of the thickness of 28 cm and containing 15.4% of organic matter (Tab. 1). The age of the deposit was dated to 2740 ±35 years BP. In the profile of strongly silted peat-muck soil, muck horizon had a thickness of 32 cm and contained 68.4% of ash (Tab. 1). The soils at this site are used as arable lands and are classified into periodically drying (BC) prognostic soil moisture complex (PKWG), [OKRUSZKO 1976b].

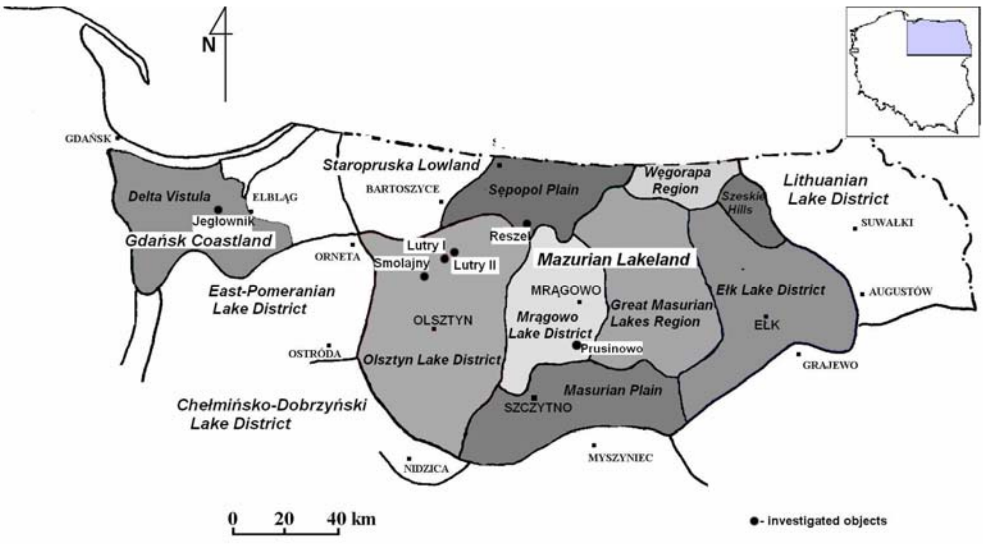


Fig. 1. Location of investigated sites with reference to physico-geographical regionalization of Poland KONDRACKI [1988].

Smolajny site is located at Łyna river valley in Olsztyn Lake District (Fig. 1). Basing on the physico-geaographical conditions and accumulated soil formations in Łyna river valley, three basins were distinguished: post-lacustrine, of ice-dammed lake origin and sedimentary [PIAŚCIK, LEMKOWSKA 2001]. The cross-section through a river valley was carried in the basin of ice-dammed lake origin near Dobre Miasto. Silted peat-muck soils occurred in the valley, at the edge of the upland and towards the river they turn into mucky soils which adjoin shallow humous alluvial soils (Fig. 2). The age of peat which was covered by alluvial deposits of a thickness of 100 cm was dated to 5720 ±40 years BP. Studied peat-muck soils and mucky soils were formed from deep, slightly decomposed reed peats, which in the top (up to 60-65 cm) were strongly decomposed. Underneath, at a depth of 140-170 cm detrital gyttja with mineral layers occurred. Below 220 cm sand deposits were found. In the profile of mucky soil, up to 30 cm, mineral-organic alluvial deposit containing 15.0-17.2% of organic matter occurred (Tab. 1). In peat-muck soil, muck horizon was strongly silted (63.1-65.2% of ash) and had thickness of 33 cm (Tab. 1). The soils at this site are used as grassland and are classified into drying (C) prognostic soil moisture complex.

Reszel II site is situated in the southern part of Sępopol Plain (Fig. 1) and, according to KONDRACKI [1988], represents the landscape of morainic hills and plains. GOTKIEWICZ and SMOŁUCHA [1996], regarding the morphogenesis of the land, type of formations and character of soil cover in young glacial landscape of north-eastern Poland, distinguished three zones and termed them plains of ice-dammed lake origin, morainic uplands and outwash plains. The mesoregion of Sępopol Plain and northern part of Masurian Lakeland is included in the zone of ice-dammed lake origin. Mineral soils occurring in this zone are of high quality and are strongly resistant to changes, which is beneficial for agricultural production, without threats to environment [PIAŚCIK, GOTKIEWICZ 2001]. In this landscape, hydrogenic soils occupy a small area (4% of soil cover) and were formed in the depressions supplied by the waters flowing on impermeable formations [PIAŚCIK, GOTKIEWICZ 2001]. This specific type of hydrologic supply was termed gravity-flow [GOTKIEWICZ et al. 1996].

In the studied catena (Fig. 3), on the slopes with the gradient of 7.1%, black-earths occurred. They were formed from heavy loam and clay. In the lower part of the slope, deluvial soils and mucky soils occurred. In mucky soils under mineral-organic deluvial deposit, at a depth of 27-28 cm, a 17-19-cm layer of muck was found. Underneath, moderately decomposed reed peats were underlain by detrital-calcareous gyttja. Below, clay gyttja was found. In the studied transect, the investigated soils occupied a section of 35 m (i. e. 1.5 times shorter than deluvial soils) and turned into strongly silted peat-muck soils formed from reed peats.

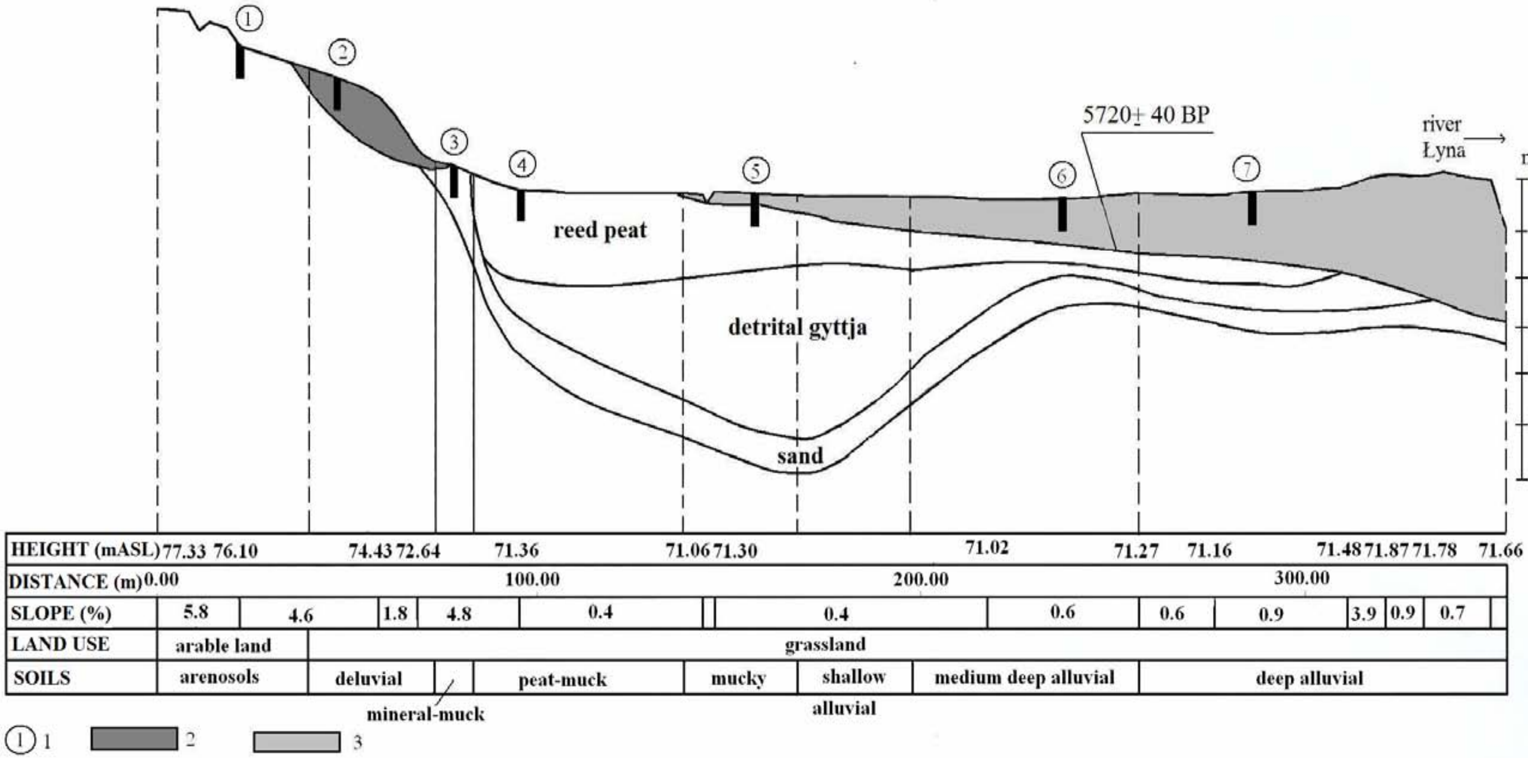
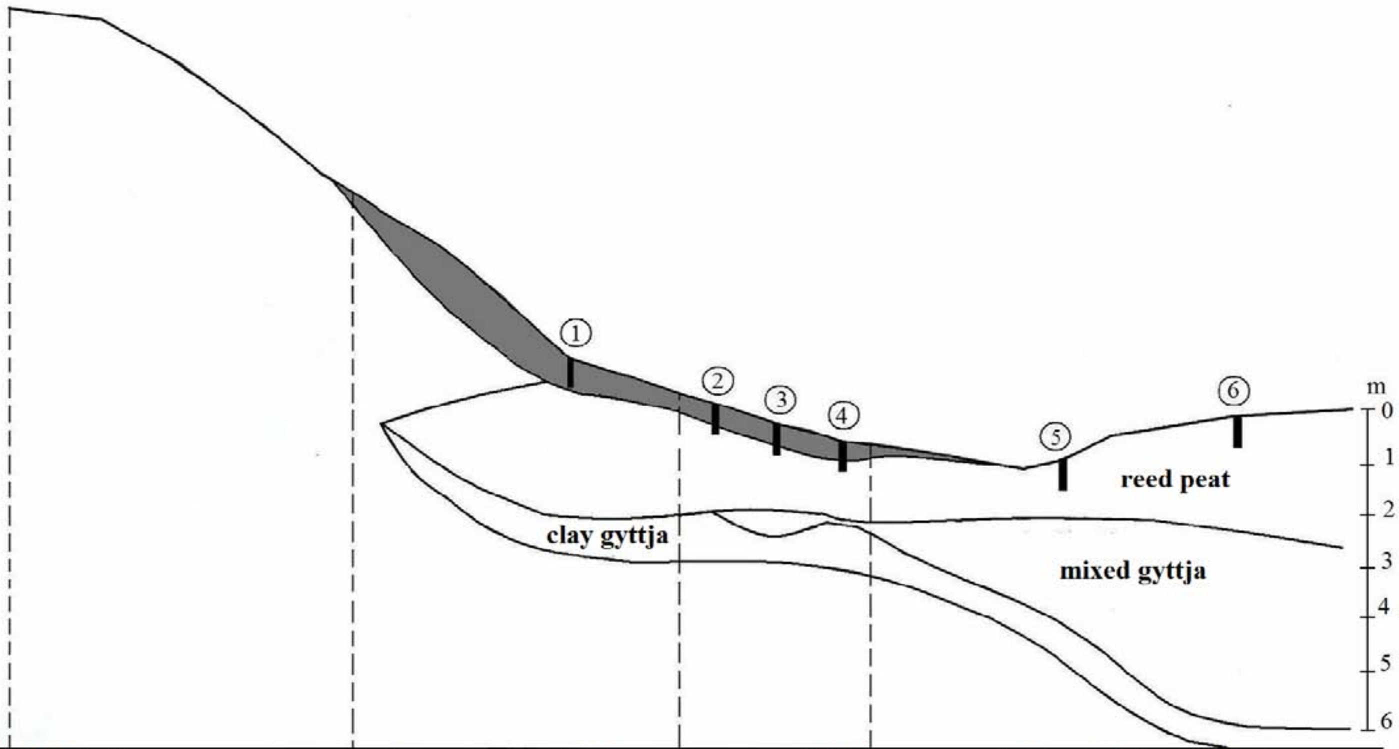


Fig. 2. Catena Smolajny. 1 – profile number. 2 – deluvial deposit, 3 – alluvial deposit



HEIGHT(mASL)	72.43	69.14	66.22	65.18	64.72	65.27	65.59	
DISTANCE (m)			100.00				200.00	
SLOPE (%)	1.6	7.1	8.2	3.3	1.5	3.8	1.6	
LAND USE	arable land				grassland			
SOILS	black earths	deluvial	mucky	peat-muck				

① 1 ▬ 2

Fig. 3. Catena Reszel II. 1 – profile number. 2 – deluvial deposit

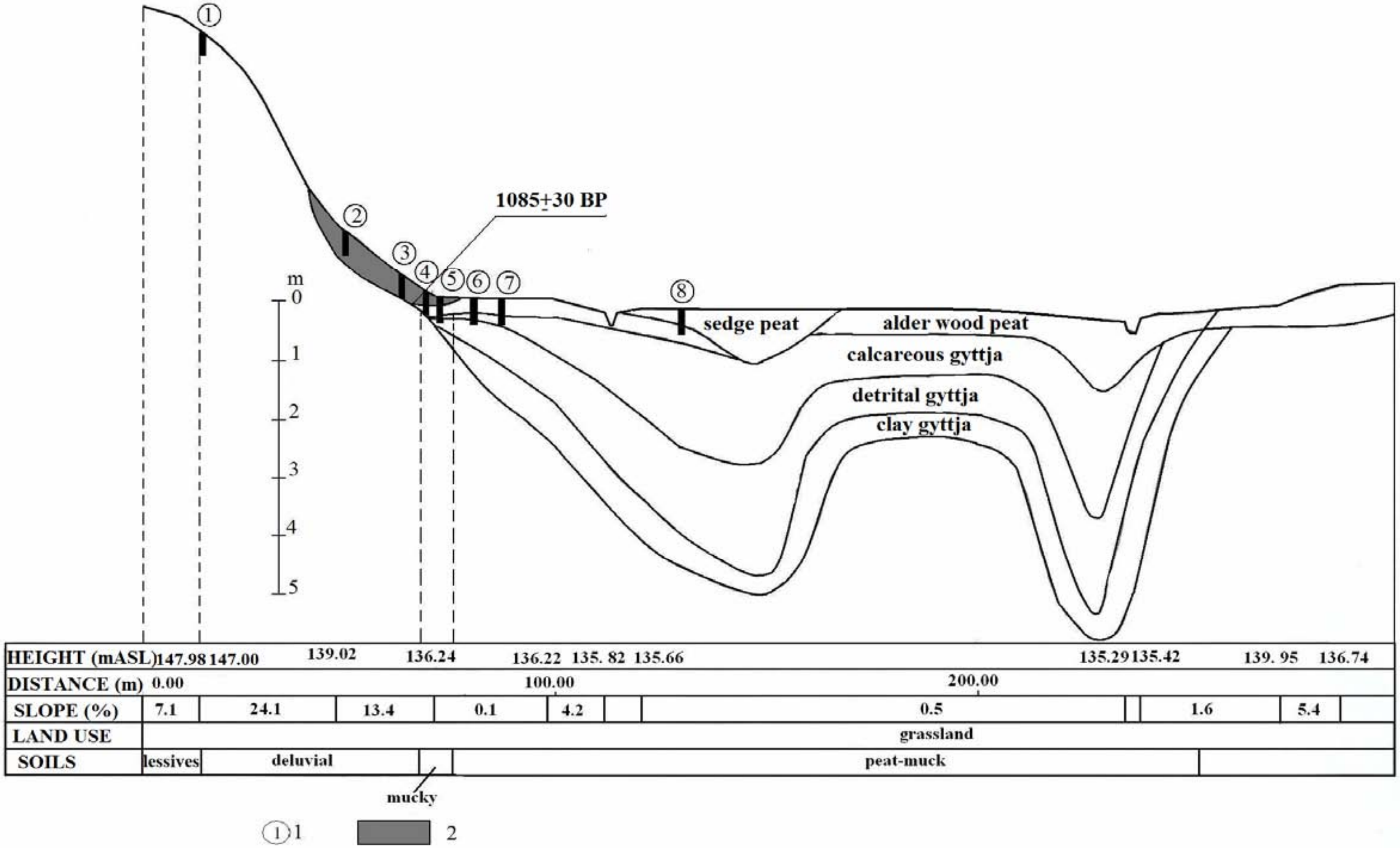


Fig. 4. Catena Lutry II. 1 - profile’s number, 2 – deluvial deposit

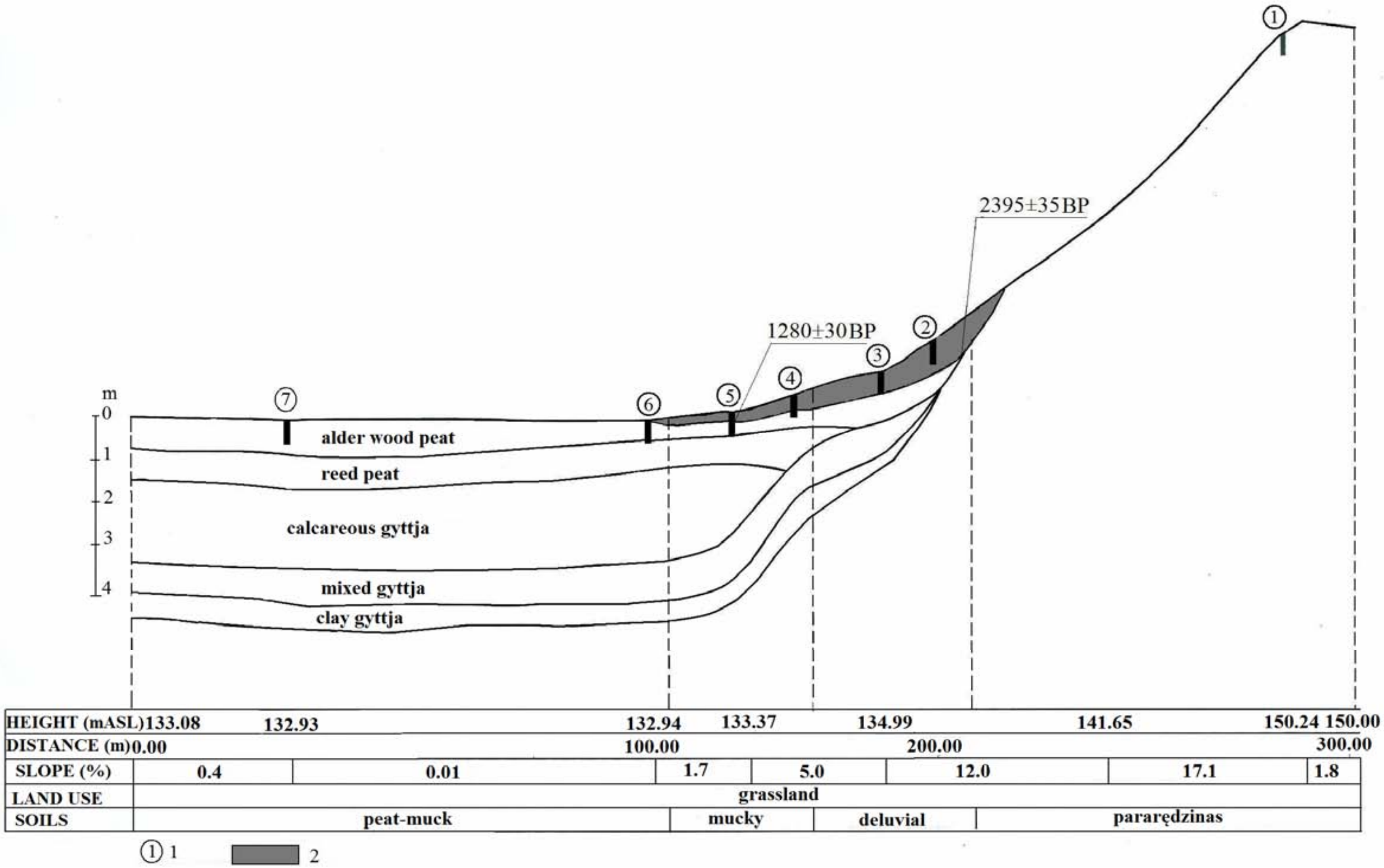


Fig. 5. Catena Prusinowo. 1 – profile number, 2 – deluvial deposit

The peats were underlain by clay-calcareous gyttja at a depth of 93 cm. Underneath, at a depth of 180 cm, clay gyttja occurred. Muck was strongly silted (50.2-54.0% of ash) and had a thickness of 32 cm. Slightly silted peat-muck soils were formed from deep (200 cm) reed peats. Peat formations were lying on detrital-calcareous gyttja which at a depth of 580 cm was underlain by clay gyttja. Mucky soils are used as ploughland and are classified into dry (C) prognostic soil moisture complex. Peat-muck soils are not cultivated. Strongly silted soils are classified into periodically drying complex (BC) and slightly silted into moist complex (B).

Lutry I, Lutry II and Prusinowo sites occur in the macroregion of Masurian Lakeland and represent hummocky lakeland landscape [KONDRACKI 1988]. The characteristic form of relief is hummocky ground moraine with the hills of frontal moraine, which occupies half of the macroregion's area and occurs in the middle part of macroregion [PIAŚCIK 1996]. GOTKIEWICZ and SMOŁUCHA [1996] included this part of Masurian Lakeland into the zone of morainic uplands. It is distinguished by the wide variety of soil formations and diversified soil cover [PIAŚCIK, GOTKIEWICZ 2001]. It has unique natural value [HILLBRICHT-ILKOWSKA 2005]. In this type of landscape, hydrogenic soils play a significantly positive role and occur in irregularly situated depressions [PIAŚCIK, GOTKIEWICZ 2001]. Small depressions with soligenic type of hydrologic supply prevail [GOTKIEWICZ et al. 1996]. Diversified relief favours slope processes which contribute to sedimentation of deluvial deposits, of various thickness and texture, on the surface of hydrogenic soils. Further from the slope, silting of surface layers of soil profile occurs [BIENIEK 1997, ORZECHOWKI, PIAŚCI el al. 2001, SOWIŃSKI, PIAŚCIK 1998, SMÓLCZYŃSKI 2002]. The development of these processes is connected with human activity. Deforestation of slopes and agricultural land use initiated intensive run-off phenomena [SIENKIEWICZ 1998]. Deluvial soils were not found in forests, despite high gradient of slopes [BIENIEK 1997, SMÓLCZYŃSKI 2008]. Slope processes termed by SIENKIEWICZ [1998] anthropogenic denudation, cause a differentiation of soil cover in particular sections of the slope and in adjacent depressions [SOWIŃSKI, PIAŚCIK 1998]. Consequently, in areas with diversified relief, under agricultural use, typical catenal sequences of soils were formed [PIAŚCIK, SOWIŃSKI 2002].

Lutry I and Lutry II sites were situated in the mesoregion of Olsztyn Lake District (Fig. 1) in the area of Pomeranian phase of Vistulianum Glaciation.

At Lutry I site, on the slopes with the gradient of 12%, surrounding the min-moraine depression, lessive soils occurred. Lessive soils turned into deluvial soils at the bottom of the slope. The studied soils were used as arable fields. The peatland in the depression was covered with reed vegetation. In the central part of the depression strongly silted peat-muck soils occurred.

These soils were formed from strongly decomposed alder peats which at a depth of 90-100 cm were underlain by stratified gyttja formations (detrital gyttja, calcareous gyttja, mixed gyttja). Beneath, at a depth of 290-500 clay gyttja occurred. The thickness of muck horizons amounted to 22-25 cm and ash content was increasing from 58.2% to 76.4% towards the depression. Peat-muck soils were surrounded by mucky soils formed from alder peats with layers of calcareous gyttja at a depth of 74-130 cm. The surface layers of the soil profiles consisted of mineral-organic formation containing 19.2% of organic matter. The soils at this site are included in drying (C) prognostic soil-moisture complex.

At Lutry II catena, the gradient of the slopes was 24.1% and the soils on the slope and in the depression were used as pastures (Fig. 4). The beginning of deposition of peat formation was dated to 1085 ±30 years BP, which, according to SINKIEWICZ [1998], was the period of Middle Age agricultural expansion into the uplands. Central part of the depression was filled with slightly silted peat-muck soils formed from sedge peats overlying alder peats at a depth of 52 cm. Underneath, from 80 cm to 260 cm, calcareous gyttja and to a depth of 420 cm, organic gyttja occurred. Clay gyttja lay underneath. Muck horizon contained 31.1-37.2% of ash and had thickness of 23 cm (Tab. 1) Along the slope, the content of mineral fraction in muck horizons increased up to more than 50% and the soils were strongly silted. Peat-muck soils were formed from shallow (up to 34-48 cm), strongly decomposed alder peats and were lying on calcareous and organic gyttja. Underneath, at a depth of 62 cm, clay gyttja occurred. In the studied soils, the thickness of muck horizons amounted to 25-26 cm and ash content amounted to 50.6-72.7%. In the soil profile of mucky soil, below the mineral-organic deposit (ash content 84.4%) at a depth of 20 cm, shallow strongly decomposed alder peats occurred. Calcareous and organic gyttja lay at a depth of 59 cm and clay gyttja underneath. In the studied catena, mucky soils occupied a short section (10 m), several times shorter than deluvial soils. Stratified soil profile of mucky and peat-muck soils shows that during the formation of these soils water conditions were changing. As a result of increasing thickness of mineral deposits in mucky soils, shallow humous deluvial soils were formed. On the slopes lessive soils occurred. They were formed from light loam.

The soils in the depression were drained with open ditches. Slightly silted peat-muck soils are included in drying (C) prognostic soil-moisture complex whereas strongly silted peat-muck soils in periodically dry (CD).

Prusinowo site is situated in the southern part of Mrągowo Lake District, between the I and II ridge of frontal moraines, in the area of phase of Vistulianum Glaciation [KONDRACKI 1972]. In detailed geological maps, this area is marked as the older phase of Leszno - Pomeranian stadial [LISICKI 1995]. At Prusinowo site, the peatland was formed as a result of terrestrialisation of part of meltwater lake Nawiady bay and adjoins the hills of dead-ice moraines [LISICKI 1995]. In the catena, slope gradient amounted to up to 17.1% and the soil sequence was as follows: on the top of the slope and on the slope pararendzinas, in the lower part of the slope medium deep deluvial soils which turned into shallow humous deluvial soils. In the depression, mucky soils as well as slightly and strongly silted peat-muck soils occurred (Fig. 5). Mucky and peat-muck soils were formed from strongly decomposed alder peats overlying moderately decomposed reed peats at a depth of 60 cm. Deposits of calcareous gyttja occurred at a depth of 140 cm and clay gyttja lay underneath. Strongly silted mucks had thickness of 22 cm and contained 67.0-68.1% of ash. Slightly silted mucks had thickness of 33 cm and contained 29.7-46.4% of ash (Tab. 1). In mucky soils, the surface layer of thickness amounting to 27-29 cm was composed of mineral-organic deposit containing 13.5-17.8% of organic matter. In the studied catena, these soils occupied a section (40 m) similar to deluvial soils (42 m). The soils were used as grasslands and were drained with open ditches. The drying prognostic soil-moisture complex occurs in the studied soils. According to radiocarbon age, the beginning of sedimentation of deluvial deposits on peats was dated to 2395 ±35 years BP (Fig. 5). This age correlated with radiocarbon dating reported by SIENKIEWICZ [1998] in buried soils in Chełmno Upland and was the first stage of intense denudation, related to the period of early agriculture, from early neolith to Roman times. The top of peat deposits in mucky soils was dated to 1280 ±30 years BP (Fig. 5).

To sum up, upper silted soils, in the zone of ice-dammed lake origin and morainic uplands of young glacial landscape, occurred in the depressions near the slope. They were adjacent to shallow deluvial soils and formed a typical toposequence of mucky, strongly and slightly silted peat-muck soils. These soils are a typical element of soil cover in agricultural land and their development depends on the manner and intensity of agricultural management on the slopes and depressions. In young glacial landscape, upper silted soils form the ecotone zones between wetlands and mineral soils which surround the slopes. HILLBRICHT-ILKOWSKA [2005] stressed that these zones are particularly important for the stability and functooning of hummocky lakeland landscape of north-eastern Poland. In riverine landscape, mucky soils occupied an area between shallow alluvial soils and silted peat-muck soils situated at the edge of the valley. In delta landscape, the regularity in spatial distribution of soils was not found. Mucky soils formed a mosaic with shallow alluvial soils on peats and strongly silted peat-muck soils.

Studied soils had multi-modular soil profile. It was expresses by various thickness and type of organic formations, various degree of their transformation by soil processes and by different types of subsoil. It was particularly apparent in morainic landscape, in the marginal zone of wetlands adjoining the slopes (Lutry II catena). It led to differentiation of water conditions which are expressed by prognostic soil-moisture complexes. Presence of mineral-organic deposit containing 10-20% of organic matter in the top (0-30 cm) was a characteristic feature of the soil profile of mucky soils at each studied site. Mineral-organic deposits are of heterogenous origin. Mineral fraction is of allochthonous origin (alluvial and deluvial) whereas the derivation of organic matter is complex. Part of organic matter could be deposited with alluvial and deluvial sediments. However the majority is of autochthonous origin. During the sedimentation, mineral deposits were saturating organic formations which accumulated earlier or when they were deposited simultaneous enrichment in organic matter during humus-forming process on grasslands occurred. Additional factor modifying the content of organic matter was arable use of mineral deposits. During plowing organic formations (peats, mucks) may be mixed with mineral deposits, which consequently led to a homogenization of humus horizon (according to oral information, soils at Jegłownik, Reszel and Prusinowo sites were used as arable fields in the 80s. of 20th century). The processes of homogenization and humification in anthropogenically modified peat soils through sanding and long-term use, were described by KUNTZE [1987]. It should also be stressed that the presence of mineral or mineral-organic formation on the surface of organic soils was beneficial taking into consideration both soil use and soil protection [OKRUSZKO 1976c]. These deposits diminish the process of mineralization of organic nitrogen compounds and weaken transformations of underlying peat formations [GOTKIEWICZ et al. 1996, SMÓLCZYŃSKI 2009].

Datings of deluvial deposits on peat formations (Prusinowo and Lutry II catenas) indicate that the age of deposits varies and that the processes of surface flow in Masurian Lakeland had occurred locally, which was also noted by BIENIEK [1997].

On the basis of the thickness of deluvial deposits and differences in time between the sedimentation of deposits on organic formations in deluvial soils and mucky soils (Prusinowo catena) it can be stated that mucky soils are a younger stage of the deluvial process.

THE DYNAMICS OF GROUNDWATER LEVEL AND SOIL MOISTURE

In the soils of delta landscape, the groundwater level was low. In mucky soils it ranged from 0.85 m to 0.95 m below land surface (BLS). In strongly silted peat-muck soils, the groundwater was at a depth of 0.75-1.1 m BLS

(Fig. 6). According to SZUNIEWICZ et al. [1991], the maximum depth of drainage in these soils (PKWG BC) should not exceed 0.9 m. In the periods of low groundwater level in 2006, the moisture content in the studied soils was within the range of water hardly available for plants (Fig. 10).

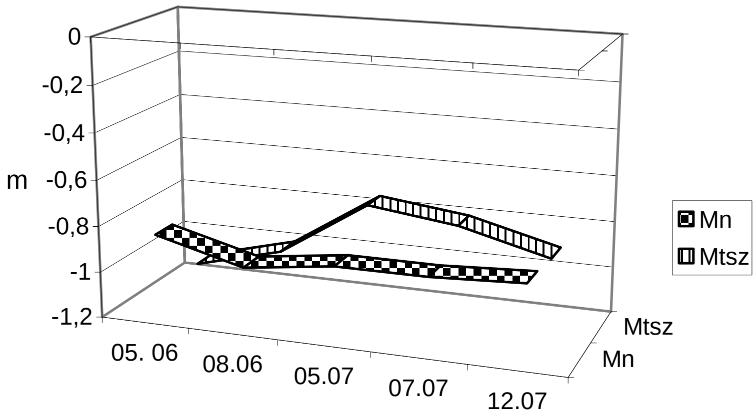


Fig. 6. Groundwater level in mucky soils (Mn) and strongly silted peat muck soils (Mtsz), (Jegłownik site)

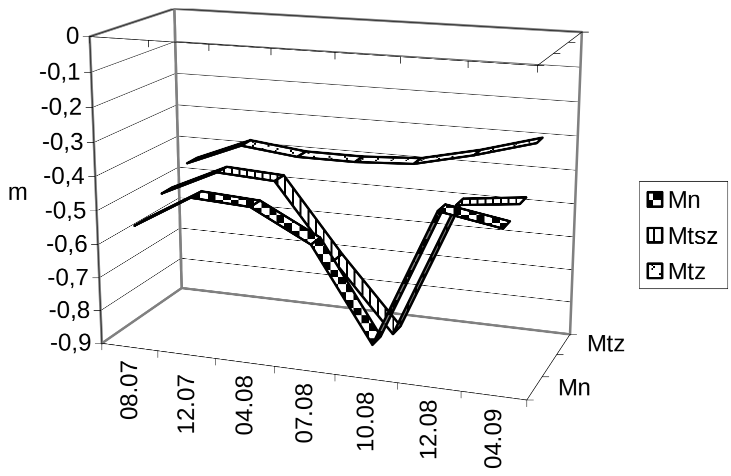


Fig. 7. Groundwater level in mucky soils (Mn), strongly silted peat muck soils (Mtsz) and slightly silted peat muck soils (Mtz), (Reszel II site)

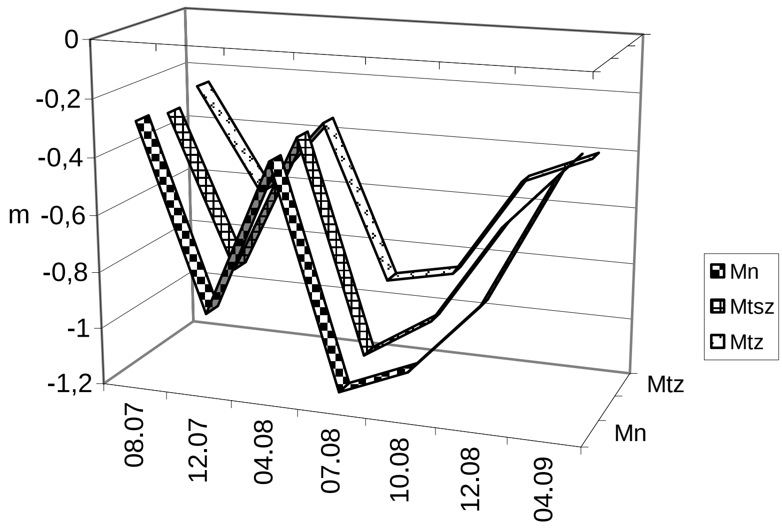


Fig. 8. Groundwater level in mucky soils (Mn), strongly silted peat muck soils (Mtsz) and slightly silted peat muck soils (Mtz), (Lutry II site)

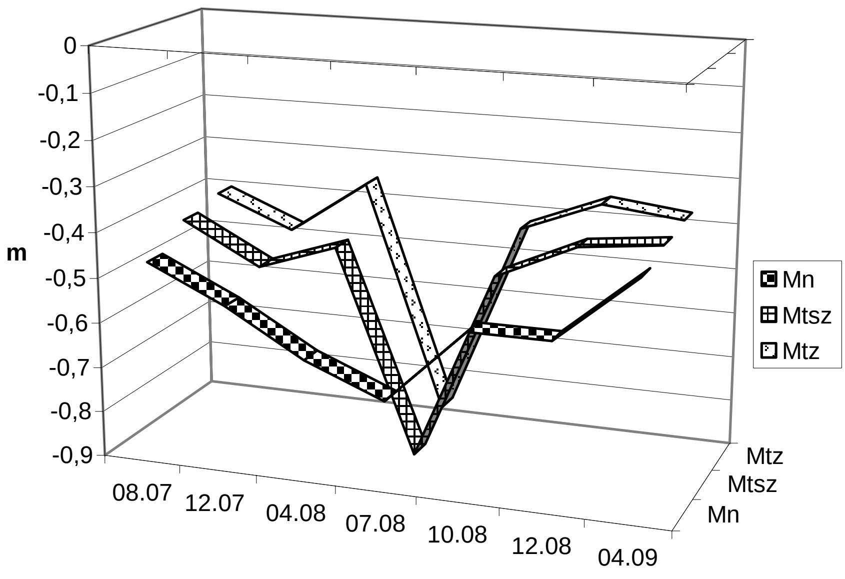
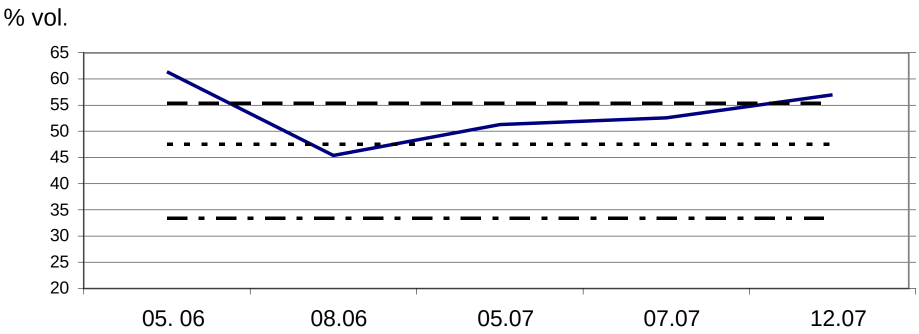


Fig. 9. Groundwater level in mucky soils (Mn), strongly silted peat muck soils (Mtsz) and slightly silted peat muck soils (Mtz), (Prusinowo site)

In the landscape of ice-dammed lake origin, in slightly silted peat-muck soils the groundwater level was the highest and hardly changeable.

In the studied periods, the groundwater level fluctuated between 0.3 m and 0.45 m below land surface (Fig. 7) and provided moisture content in surface layers higher than field capacity (Fig. 11). Small amplitude of fluctuations of groundwater level and high moisture content was affected by permanent, equal supply of water. In mucky soils, the groundwater table was similar to the level recorded in strongly silted peat-muck soils. The lowest level of groundwater (0.85 m BLS) in these soils was noted in autumn 2008 (Fig. 7) and was accompanied by a decrease of moisture content below the content of hardly available water (Fig. 11).

a)



b)

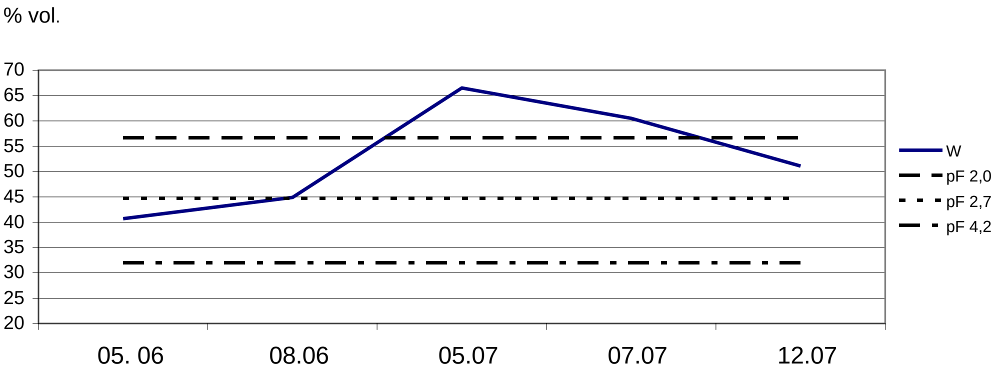
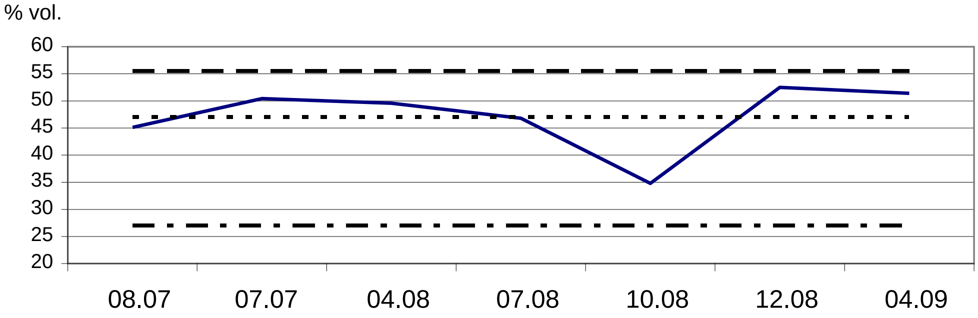
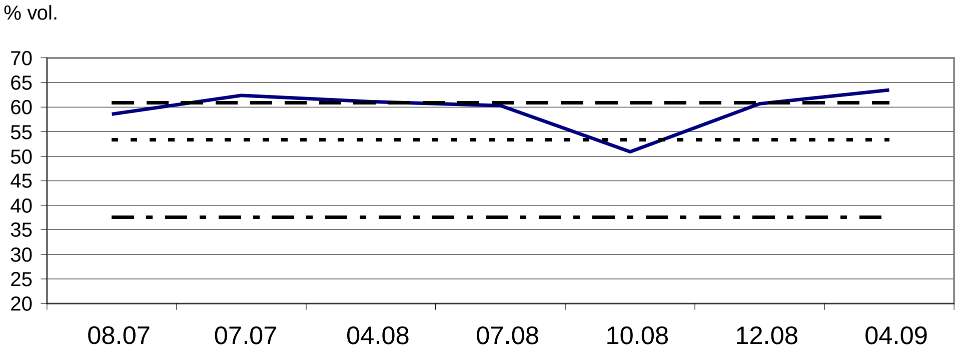


Fig. 10. Actual moisture in relation to water capacity at pF 2,0, pF 2,7, pF 4,2 (Jegłownik site): a) horizon AO mucky soils, b) horizon Mt strongly silted peat-muck soils

In the soils in morainic landscape, the fluctuations of groundwater level were the highest. At Lutry II site, the highest level of groundwater was noted during summer 2007 (Fig. 8). It fluctuated between 0.25 m BLS in slightly a)



b)



c)

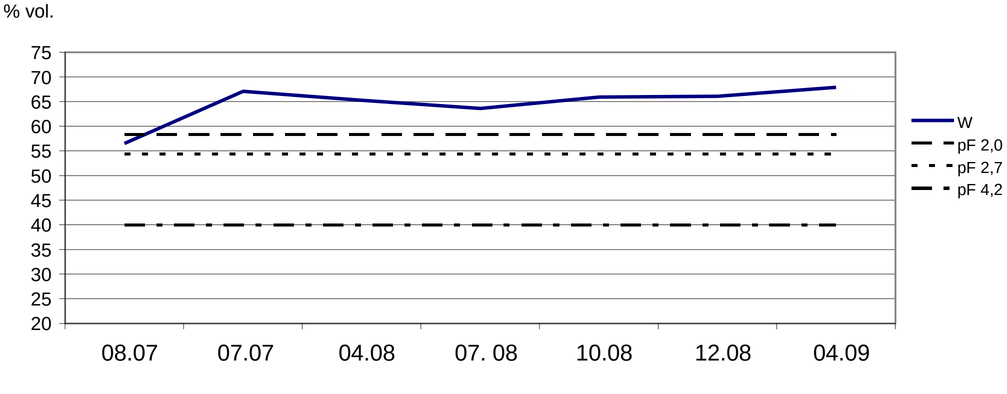


Fig. 11. Actual moisture in relation to water capacity at pF 2,0, pF 2,7, pF 4,2 (Reszel II site):

a) horizon AO mucky soils,
b) horizon Mt strongly silted peat-muck soils,
c) horizon Mt slightly silted peat-muck soils.

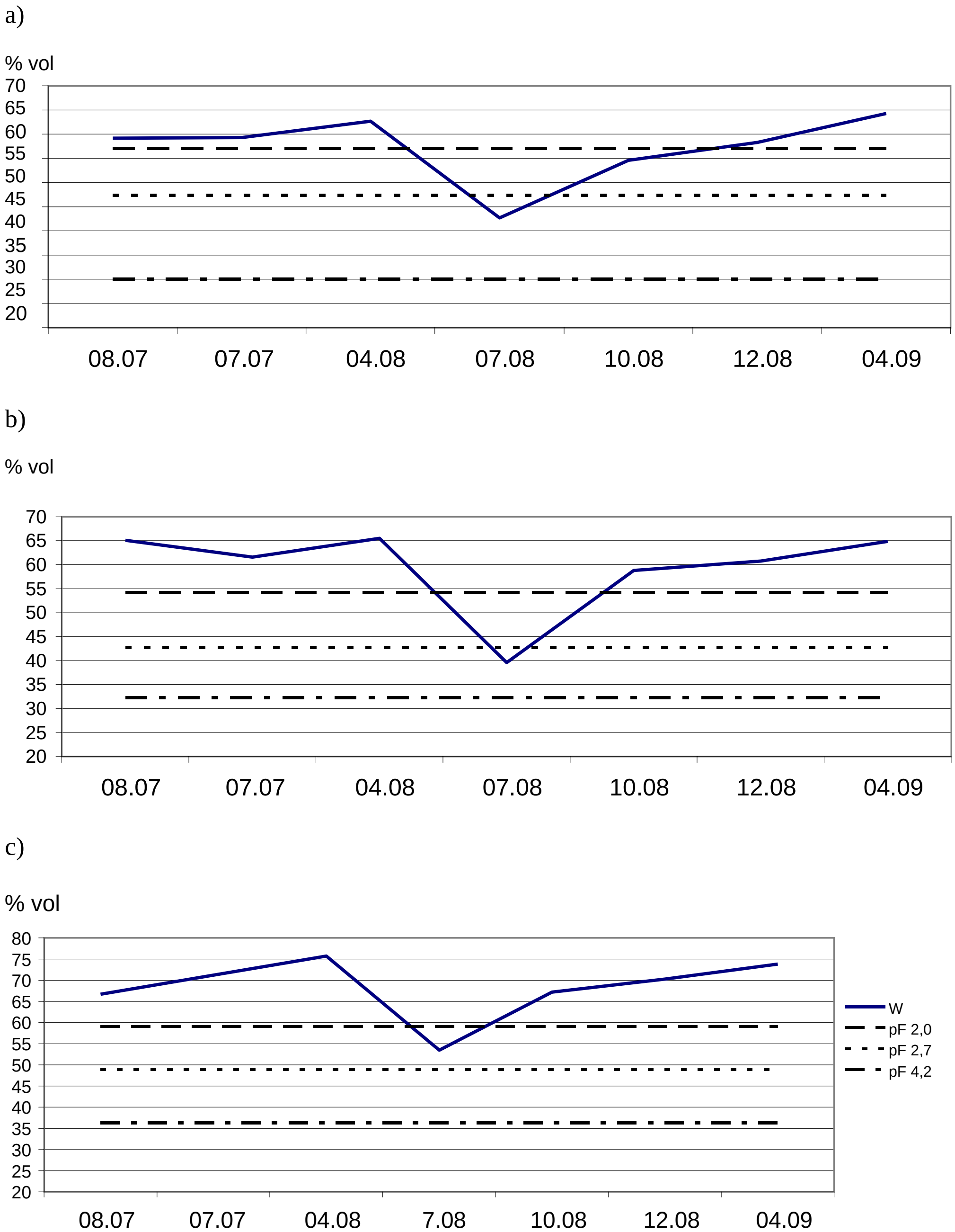


Fig. 12. Actual moisture in relation to water capacity at pF 2,0, pF 2,7, pF 4,2 (Lutry II site):
a) horizon AO mucky soils,
b) horizon Mt strongly silted peat-muck soils,
c) horizon Mt slightly silted peat-muck soils.

a)

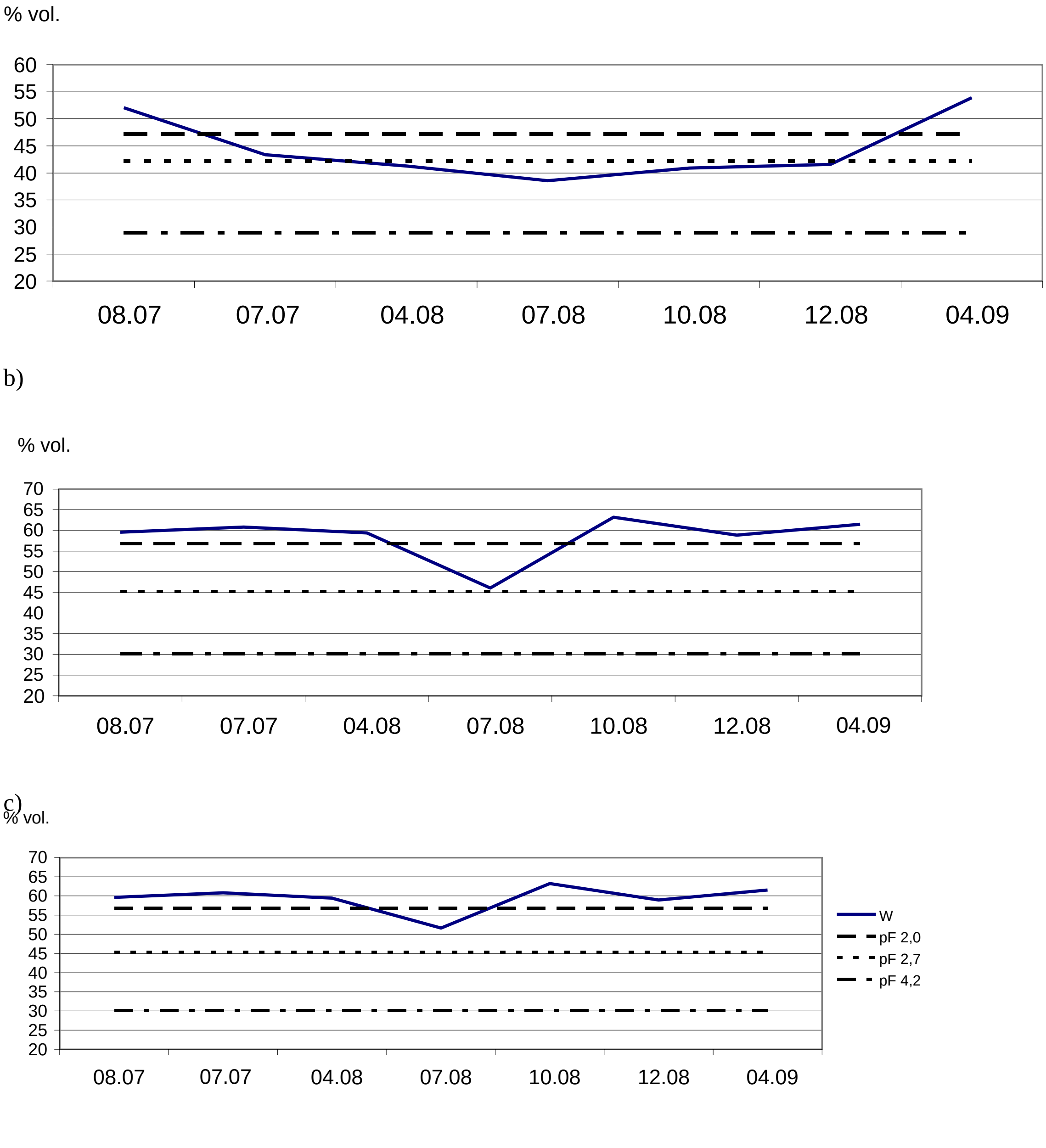


Fig. 13. Actual moisture in relation to water capacity at pF 2,0, pF 2,7, pF 4,2 (Prusinowo site):

a) horizon AO mucky soils,
b) horizon Mt strongly silted peat-muck soils,
c) horizon Mt slightly silted peat-muck soils.

silted peat-muck soils and 0.3 m BLS in strongly silted peat-muck soils. The lowest groundwater table was in July 2008 and oscillated between 0.9 m BLS in slightly silted peat-muck soils and 1.15 m BLS in mucky soils, i.e. lower than peat formations. The groundwater level in these soils should not be lowered below 0.8 m (PKWG – C) and 0.6 m (PKWG – CD) [SZUNIEWICZ et al. 1991]. In the studied period, the moisture content in surface layers of mucky and strongly silted peat-muck soils was within the range of water hardly available for plants and in slightly silted peat-muck soils within the range of water easily available for plants (Fig. 12).

In the soils at Prusinowo site, the fluctuations of groundwater level were smaller than in the soils at Lutry II. The lowest groundwater table was in summer 2008 in strongly silted peat-muck soils (0.9 m BLS) and in slightly silted peat-muck soils (0.85 m BLS), (Fig. 9).

In mucky soils, the water level was higher (0.72 m BLS) which resulted from the inflow of water from morainic slopes. According to SZUNIEWICZ et al. [1991], in the soils of drying prognostic soil-moisture complex (C), in the periods of atmospheric draughts, the lowest groundwater level should not be below 0.8 m. In other studied periods, the highest groundwater level was noted in slightly silted peat-muck soils (0.35-0.47 m BLS) and the lowest in mucky soils (0.4 m BLS), (Fig. 9). Moisture content in muck horizons of strongly and slightly silted peat-muck soils was parallel to field capacity or fell within the range of easily available water (Fig. 13). In Mucky soils, during the studied periods of 2008, moisture content was within the range of hardly available water (Fig. 13).

PHYSICAL AND WATER RETENTION PROPERTIES

Alluvial and deluvial processes decreased the content of organic matter in soil solid fraction through sedimentation of mineral fractions on surface horizons of organic soils. It influenced basic physical properties and led to changes in the amount of soil pores which determine the ability of water conductivity and water retention. The results of ash content in chosen soil profiles are presented in Table 1. Mean content of organic matter in soil surface formations was calculated on the basis of loss-on-ignition and is presented in Table 3. The data in the table suggest that the amounts of organic matter in the studied groups of soil formations (mineral-organic, strongly silted mucks, slightly silted mucks) in morainic landscape were statistically significantly different. Whereas in the landscape of ice-dammed lake origin, the differences between strongly and slightly silted mucks were small and statistically insignificant.

Among the studied soils, surface horizons of mucky soils had the highest compaction (0.561-1.284 $Mg \cdot m^{-3}$), (Tab. 1). These values were 2-7 times higher in comparison to underlying peat layers. Bulk density in AO horizons in morainic landscape was significantly higher than in muck horizons (Tab. 3). Total porosity was inversely related to bulk density. It was decreasing together with the content of organic matter and was significantly lower in surface horizons of mucky soils than in mucks (Tab. 3).

In riverine landscape, delta landscape and landscape of ice-dammed lake origin, the amount of water at pF 2.0 corresponding to field capacity in mineral-organic formations of mucky soils, fluctuated between 55.4 and 62.3% vol. (Tab. 1). In the zone of morainic uplands, in mucky soils mean values of water content at pF 2.0 were the lowest and amounted to 47.9% (Tab. 3). Field capacity in mucks was statistically significantly higher (Tab. 3) and positively correlated with the content of organic matter and negatively correlated with bulk density (Tab. 6).

In the landscape of ice-dammed lakes origin and in morainic landscape, mean water capacity at pF 2.7, which is assumed as the down limit for easily available water in organic soils [OKRUSZKO 1976], was significantly higher in mucks than in surface horizons (AO) of mucky soils (Tab. 3).

In delta and riverine landscapes, mucky soils and peat-muck soils had similar amounts of unavailable water (pF 4.2), (Tab. 1). In the soils of morainic landscape and landscape of ice-dammed lake origin, mean content of water at wilting point corresponding to the volume of micropores, increased together with organic matter increase (Tab. 3). These values were the highest in muck horizons in the landscape of ice-dammed lakes origin (38.6-38.7%). A proportion of micropores in total porosity ranged from 51.1% in slightly silted mucks to 52.7% in strongly silted mucks (Tab. 3). High amount of micropores can be explained by the fact that in organic soils, the amount of water at pF > 4.2 comprises water in micropores and water absorbed by organic matter (MACLAY et al. 1992). It can also be affected by silting of muck formations with swelling clay minerals which occur in black earths on surrounding slopes.

AO horizons of mucky soils had small volume of macropores. In delta landscape, the volume of macropores amounted to 6.2-7.2% and in riverine landscape the amount of macropores fluctuated between 10.5% and 18.4% (Tab. 2). In the landscape of ice-dammed lake origin, the volume of macropores amounted to 10.9% and was similar to the amounts reported in morainic landscape (10.3%), (Tab. 3). In slightly silted muck formations, mean volume of air pores was approximately twice higher and statistically significant (Tab. 3).

Table 1

Physical porperties in some selected soil profiles

Profile No	Soil horizon	Depta cm	Soil formation	Ash content	Specific density	Bulk density	Total porosity	Water capacity at pF		
								2.0	2.7	4.2
				%	$Mg \cdot m^{-3}$		% vol.			
1	2	3	4	5	6	7	8	9	10	11
Delta landscape (Jegłownik site) Mucky soil										
1	AO	0-18	mineral-organic formation	84.6	2.382	0.892	62.6	55.4	47.5	33.4
	AO	18-28	mineral-organic formation	83.2	2.366	0.871	63.2	57.0	47.6	33.0
	$OtniszR_2$	28-60	reed peat R_2	14.8	1.614	0.181	88.8	66.1	48.9	28.2
	$OtniolR_3$	60-150	alder wood peat R_3	32.1	1.804	0.156	91.4	68.7	50.6	24.6
Peat muck soil strongly silted										
2	Mt	0-20	strongly silted muck	68.4	2.203	0.551	74.9	56.7	44.7	32.0
	Mt	20-32	strongly silted muck	63.5	2.149	0.564	73.8	58.0	45.0	33.0
	$OtniszR_2$	32-65	reed peat R_2	15.8	1.625	0.191	88.3	72.1	53.4	26.4
	$OtniolR_3$	65-150	alder wood peat R_3	36.7	1.855	0.164	91.7	70.5	51.3	28.7
Riverine landscape (Smolajny site) Mucky soil										
5	AO	0-15	mineral-organic formation	82.8	2.362	0.561	76.3	57.9	45.3	27.9
	AO	15-30	mineral-organic formation	85.0	2.386	0.829	65.3	54.8	45.3	29.6
	$OtniszR_3$	30-60	reed peat R_3	47.9	1.978	0.178	91.0	79.3	56.1	26.4
	$OtniszR_2$	60-150	reed peat R_2	38.3	1.872	0.163	91.3	77.2	54.3	25.6
Peat muck soil strongly silted										
4	Mt	0-15	strongly silted muck	63.1	2.145	0.413	80.7	59.6	40.2	27.7
	Mt	15-33	strongly silted muck	65.2	2.168	0.514	76.3	54.5	44.4	30.2
	$OtniszR_3$	33-65	reed peat R_3	46.7	1.965	0.172	91.2	80.1	57.2	27.1
	$OtniszR_2$	65-150	reed peat R_2	36.4	1.851	0.159	91.4	78.9	55.5	26.9

Table 1. continued.

1	2	3	4	5	6	7	8	9	10	11
Ice-dammed lakes (Reszel II site) Mucky soil										
2	AO	0-15	mineral-organic formation	84.5	2.345	0.796	66.1	55.5	47.0	27.0
	AO	15-28	mineral-organic formation	84.6	2.343	0.685	70.8	60.3	46.2	30.5
	Mt	28-52	strongly silted muck	56.8	2.109	0.565	73.2	57.0	46.0	33.2
	$OtniszR_2$	52-150	reed peat R_2	12.7	1.638	0.124	92.4	62.0	49.6	17.4
Peat muck soil strongly silted										
5	Mt	0-24	strongly silted muck	54.0	2.045	0.573	72.0	60.9	53.4	37.6
	Mt	24-32	strongly silted muck	50.2	2.003	0.512	74.4	62.4	55.0	39.5
	$OtniszR_2$	32-60	reed peat R_2	13.9	1.604	0.167	89.6	63.3	52.7	28.6
	$OtniszR_2$	60-93	reed peat R_2	16.0	1.627	0.157	90.4	62.2	48.9	26.0
Peat muck soil slightly silted										
6	Mt	0-15	slightly silted muck	47.9	1.978	0.526	73.4	58.3	49.8	40.0
	Mt	15-29	slightly silted muck	49.0	1.990	0.454	77.2	57.2	50.8	37.4
	$OtniszR_2$	29-150	reed peat R_2	23.6	1.711	0.138	91.9	63.7	49.9	17.8
Morainic landscape (Lutry I site) Mucky soil										
5	AO	0-15	mineral-organic formation	82.3	2.419	1.284	46.9	38.7	34.2	23.1
	AO	15-28	mineral-organic formation	80.8	2.340	0.722	63.5	54.6	48.2	28.5
	$OtniolR_3$	28-74	alder wood peat R_3	18.4	1.653	0.190	88.5	61.0	52.6	27.0
	Dgy_{Ca}	74-130	calcareous gyttja	79.4	2.329	0.294	87.3	57.8	47.5	32.0
Peat muck soil strongly silted										
6	Mt	0-15	strongly silted muck	71.3	2.239	0.511	77.2	64.6	53.9	34.8
	Mt	15-25	strongly silted muck	76.4	2.291	0.556	75.7	63.2	50.7	30.7
	$OtniolR_3$	25-100	alder wood peat R_3	28.3	1.762	0.249	85.9	70.1	57.0	31.0
Morainic landscape (Lutry II site) Mucky soil										
5	AO	0-20	mineral-organic formation	84.4	2.379	0.636	73.3	57.1	47.4	30.1
	$OtniolR_3$	20-45	alder wood peat R_3	28.4	1.763	0.345	80.4	61.2	49.7	33.6
	$OtniolR_3$	45-59	alder wood peat R_3	24.2	1.717	0.238	86.1	66.2	53.8	36.5

Table 1. continued.

1	2	3	4	5	6	7	8	9	10	11
Peat muck soil strongly silted										
6	Mt	0-10	strongly silted muck	71.7	2.240	0.480	78.6	58.9	43.1	29.6
	Mt	10-25	strongly silted muck	72.7	2.251	0.621	72.4	55.8	46.8	33.5
	OtniolR_3	25-48	alder wood peat R_3	33.7	1.822	0.329	81.9	64.0	51.2	32.1
	Dgy_{Ca}	48-74	calcareous gyttja	87.3	2.411	0.469	80.5	45.8	37.9	11.3
	OtniolR_3	74-100	alder wood peat R_3	29.6	1.777	0.204	88.5	69.2	55.7	29.8
Peat muck soil slightly silted										
8	Mt	0-10	strongly silted muck	31.1	1.793	0.344	80.8	59.1	48.9	36.4
	Mt	10-23	strongly silted muck	37.2	1.860	0.336	81.9	62.5	54.6	37.8
	OtnituR_2	23-52	sedge peat R_2	21.8	1.691	0.152	91.0	67.5	48.9	23.2
	OtniolR_3	52-68	alder wood peat R_3	12.5	1.589	0.170	89.3	68.6	51.5	27.6
Morainic landscape (Prusinowo site) Mucky soil										
4	AO	0-15	mineral-organic formation	82.4	2.357	0.946	59.9	47.4	42.2	29.0
	AO	15-29	mineral-organic formation	86.6	2.403	1.048	56.4	47.5	43.4	28.5
	OtniolR_3	29-60	alder wood peat R_3	26.1	1.738	0.220	87.4	61.7	54.0	27.4
	OtniszR_2	60-150	reed peat R_2	17.4	1.642	0.197	88.0	64.2	47.8	24.2
Peat muck soil strongly silted										
6	Mt	0-15	strongly silted muck	67.0	2.188	0.706	67.7	56.8	45.3	30.1
	Mt	15-22	strongly silted muck	68.1	2.200	0.624	71.6	58.1	47.2	29.7
	OtniolR_3	22-55	alder wood peat R_3	30.6	1.787	0.351	80.3	63.4	55.4	26.6
	OtniszR_2	55-130	reed peat R_2	17.8	1.646	0.199	87.9	64.8	50.3	24.3
Peat muck soil slightly silted										
7	Mt	0-18	slightly silted muck	46.4	1.961	0.471	76.0	55.9	43.0	29.5
	Mt	18-33	slightly silted muck	29.7	1.778	0.318	82.1	58.4	44.2	30.1
	OtniolR_3	33-60	alder wood peat R_3	18.4	1.653	0.223	86.5	62.8	54.2	26.5
	OtniszR_3	60-90	reed peat R_3	16.2	1.692	0.195	88.5	63.2	51.5	27.0
	OtniszR_2	90-137	reed peat R_2	17.5	1.643	0.135	91.8	65.4	48.7	25.4

* Explanation: R_2 – medium decomposed peat, R_3 –strongly decomposed peat

Table 2

Volume of soil pores in some selected soil profiles

Profile No	Soil horizon	Depht cm	Soil formation	Macro-pores	Mesopores PRU*	Mesopores ERU*	Mesopores RDK*	Micro-pores	Macro. / P	PRU / P	ERU / P	Micro. / P
				% vol.					%			
1	2	3	4	5	6	7	8	9	10	11	12	13
Delta landscape (Jegłownik site) Mucky soil												
1	AO	0-18	mineral-organic	7.2	22.0	7.9	14.1	33.4	11.5	35.2	12.6	53.3
	AO	18-28	mineral-organic	6.2	24.0	9.4	14.6	33.0	9.8	37.9	14.9	52.2
	OtniszR$_2$	28-60	reed peat R$_2$	22.7	37.9	17.2	20.7	28.2	25.6	42.7	19.4	31.7
	OtniolR$_3$	60-150	alder wood peat R$_3$	22.7	44.1	18.1	26.0	24.6	24.8	48.2	19.8	26.9
Peat muck soil strongly silted												
2	Mt	0-20	strongly silted muck	18.7	24.7	12.0	12.7	32.0	24.3	33.0	16.0	42.7
	Mt	20-32	strongly silted muck	15.8	25.0	12.0	13.0	33.0	21.4	33.9	16.3	44.7
	OtniszR$_2$	32-65	reed peat R$_2$	16.2	45.7	18.7	27.0	26.4	18.3	51.8	21.2	29.9
	OtniolR$_3$	65-150	alder wood peat R$_3$	21.2	41.8	19.2	22.6	28.7	23.1	45.6	20.3	31.3
Riverine landscape (Smolajny site) Mucky soil												
5	AO	0-15	mineral-organic	18.4	30.0	12.6	17.4	27.9	24.1	39.3	16.5	36.6
	AO	15-30	mineral-organic	10.5	25.2	9.5	15.7	29.6	16.1	38.6	14.5	45.3
	OtniszR$_3$	30-65	reed peat R$_3$	11.7	52.9	23.2	29.7	26.4	12.9	58.1	25.5	29.0
	OtniszR$_2$	65-150	reed peat R$_2$	14.1	51.6	22.9	28.7	25.6	15.4	56.5	25.1	28.0
Peat muck soil strongly silted												
4	Mt	0-15	strongly silted muck	21.1	31.9	19.4	12.5	27.7	26.1	39.5	24.0	34.3
	M2t	15-30	strongly silted muck	21.8	24.3	10.1	14.2	30.2	28.6	31.8	13.2	39.6
	OtniszR$_3$	30-65	reed peat R$_3$	11.1	53.0	22.9	30.1	27.1	12.2	58.1	25.1	29.7
	OtniszR$_2$	65-150	reed peat R$_2$	12.5	52.0	23.4	28.6	26.9	13.7	56.9	25.6	29.4

Table 2. continued.

1	2	3	4	5	6	7	8	9	10	11	12	13
Ice-dammed lakes (Reszel II site) Mucky soil												
2	AO	0-15	mineral-organic	10.6	28.5	8.5	20.0	27.0	16.0	43.1	12.8	40.8
	AO	15-28	mineral-organic	10.5	29.8	14.1	15.7	30.5	14.8	42.1	19.9	43.1
	Mt	28-52	strongly silted muck	16.2	23.8	11.0	12.8	33.2	22.1	32.5	15.0	45.4
	$OtniszR_2$	52-150	reed peat R_2	30.4	44.6	12.4	32.2	17.4	32.9	48.3	13.4	18.8
Peat muck soil strongly silted												
5	Mt	0-24	strongly silted muck	11.1	23.3	7.5	15.8	37.6	15.4	32.4	10.4	52.2
	Mt	24-32	strongly silted muck	12.0	22.9	7.4	15.5	39.5	16.1	30.8	9.9	53.1
	$OtniszR_2$	32-60	reed peat R_2	26.3	34.7	10.6	24.1	28.6	29.4	38.7	11.8	31.9
	$OtniszR_2$	60-93	reed peat R_2	28.2	36.2	13.3	22.9	26.0	31.2	40.0	14.7	28.8
Peat muck soil slightly silted												
6	Mt	0-15	slightly silted muck	15.1	18.3	8.5	9.8	40.0	20.6	24.9	11.6	54.5
	Mt	15-29	slightly silted muck	20.0	19.9	11.0	8.8	37.4	25.9	27.6	14.2	48.4
	$OtniszR_2$	29-150	reed peat R_2	28.2	35.9	13.8	22.1	27.8	30.7	39.1	15.0	30.3
Morainic landscape (Lutry I site) Mucky soil												
5	AO	0-15	mineral-organic	8.2	15.6	4.5	11.1	23.1	18.0	33.2	9.6	49.2
	AO	15-28	mineral-organic	8.9	26.1	6.4	19.7	28.5	14.0	41.1	10.1	44.9
	$OtniolR_3$	28-74	alder wood peat R_3	26.9	34.0	8.4	25.6	27.0	33.7	42.5	10.5	33.8
	Dgy_{Ca}	74-130	calcareous gyttja	29.8	25.8	10.3	15.5	32.0	36.4	31.5	12.6	39.1
Peat muck soil strongly silted												
6	Mt	0-15	strongly silted muck	12.6	29.8	10.7	19.1	34.8	16.3	38.5	13.8	45.1
	Mt	15-25	strongly silted muck	12.5	32.5	12.5	20.0	30.7	16.5	42.9	16.5	40.5
	$OtniolR_3$	25-100	alder wood peat R_3	15.8	39.1	13.1	26.0	31.0	18.4	45.5	15.2	36.1
Morainic landscape (Lutry II site) Mucky soil												
5	AO	0-20	mineral-organic	16.2	27.0	9.7	17.3	30.1	22.1	36.8	13.2	41.1
	$OtniolR_3$	20-45	alder wood peat R_3	19.2	27.6	11.5	16.1	33.6	23.9	34.3	14.3	41.8
	$OtniolR_3$	45-59	alder wood peat R_3	19.9	29.5	12.4	17.1	36.7	23.1	34.3	14.4	42.6

Table 2. continued.

1	2	3	4	5	6	7	8	9	10	11	12	13
Peat muck soil strongly silted												
6	Mt	0-10	strongly silted muck	19.7	29.1	15.8	13.5	29.6	25.1	37.0	20.1	37.9
	Mt	10-25	strongly silted muck	16.6	22.3	9.0	13.3	33.5	22.9	31.6	12.4	46.3
	$OtniolR_3$	25-48	alder wood peat R_3	17.9	31.9	12.8	19.1	32.1	21.9	38.9	15.6	39.2
	Dgy_{ca}	48-74	calcareous gyttja	28.6	34.5	7.9	26.6	11.3	35.5	42.9	9.8	14.0
	$OtniolR_3$	74-100	alder wood peat R_3	19.3	39.4	13.5	25.9	29.8	21.8	44.5	15.3	33.7
Peat muck soil slightly silted												
8	Mt	0-10	slightly silted muck	21.7	22.7	10.2	12.5	36.4	26.9	28.1	12.6	45.0
	Mt	10-23	slightly silted muck	19.4	24.7	7.9	16.8	37.8	23.7	30.2	9.6	46.1
	$OtnituR_2$	23-52	sedge peat R_2	23.5	44.3	18.6	25.7	23.2	25.8	48.7	20.4	25.5
	$OtniolR_3$	52-68	alder wood peat R_3	20.7	41.0	17.1	23.9	27.6	23.2	45.9	19.1	30.9
Morainic landscape (Prusinowo site)												
Mucky soil												
4	AO	0-15	mineral-organic	12.4	18.4	9.0	9.4	29.0	20.8	30.7	15.0	48.5
	AO	15-29	mineral-organic	8.9	19.0	7.7	11.3	28.5	15.8	33.7	13.7	50.5
	$OtniolR_3$	29-60	alder wood peat R_3	25.7	34.3	7.7	26.6	27.4	29.4	39.2	8.8	31.4
	$OtniszR_2$	60-150	reed peat R_2	23.8	40.0	16.4	23.6	24.2	27.0	45.4	18.6	27.6
Peat muck soil strongly silted												
6	Mt	0-15	strongly silted muck	10.9	26.7	11.5	15.2	30.1	16.1	39.4	17.0	44.5
	Mt	15-22	strongly silted muck	13.5	29.4	10.9	17.5	29.7	18.9	41.1	15.2	41.5
	$OtniolR_3$	22-55	alder wood peat R_3	16.9	36.8	12.0	24.8	26.6	21.1	45.8	14.9	33.1
	$OtniszR_2$	55-130	reed peat R_2	23.1	40.5	14.5	26.0	24.3	26.3	46.1	16.5	27.6
Peat muck soil slightly silted												
7	Mt	0-18	slightly silted muck	20.1	26.4	12.9	13.5	29.5	26.4	34.7	16.9	38.9
	Mt	18-33	slightly silted muck	23.7	28.3	14.2	14.1	30.1	28.9	34.5	17.3	36.6
	$OtniolR_3$	33-60	alder wood peat R_3	23.7	36.3	8.6	27.7	26.5	27.4	41.9	9.9	30.7
	$OtniszR_3$	60-90	reed peat R_3	25.3	36.2	11.7	24.5	27.0	28.6	40.9	8.7	30.5
	$OtniszR_2$	90-137	reed peat R_2	26.4	40.0	16.7	23.3	25.4	28.7	43.6	18.2	27.7

* Explanation: PRU – potential useful water retention, ERU-effective useful water retention, RDK – small pores retention

Table 3

Physical properties in surface horizons of studied soils (mean values)

Properties	Value	1AO	2Mtsz	3Mtz	4AO	5Mtsz	6Mtz	Statistically significant differences
		Morainic landscape			Ice-dammed lakes			
Organic matter	X	15,9	34,1	63,9	17,9	47,9	51,6	1<2<3
	S	2,37	8,71	7,63	2,20	2,69	0,78	4<5,6
	CV	14,9	25,5	11,9	12,3	5,6	1,5	
Specific density	X	2.385	2.175	1.848	2.340	2.024	1.984	1>2>3
	S	0.03	0.10	0.08	0.004	0.03	0.008	1>4
	CV	1.3	4.6	4.3	0.2	1.5	0.4	4>5
Bulk density	X	0.975	0.509	0.367	0.791	0.542	0.490	1>2.3
	S	0.23	0.12	0.07	0.16	0.04	0.05	
	CV	23.6	23.6	19.1	24.0	7.4	10.2	
Total porosity	X	58.3	76.7	80.2	66.2	73.2	75.3	1<2.3
	S	8.47	5.15	2.86	6.70	1.70	2.69	
	CV	14.5	6.7	3.6	10.1	2.3	3.6	
pF 2.0	X	47.9	60.8	59.0	55.2	61.5	57.8	1<2.3
	S	6.25	4.31	2.72	6.65	1.06	0.78	
	CV	13.0	7.1	4.6	12.0	1.7	1.3	
pF 2.7	X	42.8	47.2	47.7	42.3	54.2	50.3	1<2<5
	S	4.62	3.73	5.27	4.03	1.31	0.71	4<5.6
	CV	10.8	7.9	11.0	9.5	2.4	1.4	
pF 4.2	X	27.6	31.4	33.5	29.2	38.6	38.7	1<2.3
	S	2.42	1.77	4.26	2.24	1.34	1.84	2<5
	CV	8.8	5.6	12.7	7.7	3.5	4.8	4<5
Macrpores	X	10.3	15.8	21.2	10.9	11.6	17.6	1<2<3
	S	2.94	3.36	1.91	1.73	0.64	3.46	4>6
	CV	28.5	21.3	9.0	15.9	5.5	19.7	
PRU	X	20.3	29.5	25.5	26.1	23.1	19.1	1<2>3
	S	4.39	4.40	2.39	8.72	0.28	1.13	3.5>6
	CV	21.6	14.9	9.4	33.4	1.2	5.9	
ERU	X	6.6	13.6	11.3	13.0	7.5	9.8	1<2.3.4
	S	2.24	3.07	2.81	5.51	0.07	1.77	2>5
	CV	33.9	22.6	24.9	42.4	0.9	18.1	
RDK	X	13.7	15.8	14.2	13.1	15.7	9.3	3>6
	S	3.68	3.35	1.84	5.90	1.34	1.84	5>6
	CV	26.9	21.2	13.0	45.0	8.5	19.8	
Macropores·P^{-1}	X	20.7	19.9	26.5	16.6	15.8	23.3	2<3
	S	5.26	4.48	2.14	2.81	0.49	3.75	4<6
	CV	25.4	22.5	8.1	16.9	3.1	16.1	
PRU·P^{-1}	X	29.7	38.9	31.9	38.7	31.6	26.3	1<2>3
	S	9.71	4.80	3.26	10.35	1.13	1.91	
	CV	32.7	12.3	10.2	26.7	3.6	7.3	
ERU·P^{-1}	X	18.3	17.8	14.1	19.2	10.2	12.9	1<4
	S	10.48	3.34	3.68	6.95	0.35	1.84	2>5
	CV	57.3	18.8	26.1	36.2	3.4	14.3	
Micropores·P^{-1}	X	40.6	40.4	41.7	44.6	52.7	51.5	2<5
	S	11.2	3.01	4.62	8.54	0.64	4.31	4>5
	CV	27.6	7.5	11.1	19.1	1.2	8.4	

Explanation: X – mean, S – standard deviation, CV - coefficient of variation

Table 4

Water retention in 0-30 cm (root layer) and 30-80 cm layers in studied pedons [mm]

Soils	Layer thicknes	Water out flow	Content of water				Total water capacity
			Potentially available water	Easily available water	Hardy available water	Unavailable water	
Delta landscape (Jegłownik site)							
Mn	0-30 30-80	23.7 113.5	71.2 181.9	27.0 87.8	44.1 114.1	98.7 133.8	193.6 449.2
Mtsz	0-30 30-80	50.5 88.5	74.4 218.5	36.0 92.9	38.4 145.6	97.0 136.8	221.9 443.8
Riverine landscape (Smolajny site)							
Mn	0-30 30-80	43.4 62.2	82.8 262.2	33.2 115.6	49.6 147.0	86.3 130.8.	212.4 455.2
Mtsz	0-30 30-80	93.4 57.7	84.4 263.6	34.3 115.3	40.1 148.3	86.9 135.3	264.7 456.6
Ice-dammed lakes (Reszel II site)							
Mn	0-30 30-80	30.0 120.7	94.1 177.3	35.9 58.9	57.2 118.4	81.6 122.1	205.9 420.1
Mn	0-30 30-80	35.4 56.8	88.6 202.6	51.7 84.3	36.9 118.3	87.1 156.6	211.1 416.0
Mtsz	0-30 30-80	33.8 130.0	69.6 169.6	22.4 56.3	47.2 113.3	113.9 132.1	217.3 431.7
Mtz	0-30 30-80	53.5 141.0	58.8 179.5	29.6 69.0	29.2 110.5	115.2 139.0	227.5 459.5
Morainic landscape (Lutry I site)							
Mn	0-30 30-80	29.2 136.3	64.2 165.1	16.8 43.2	47.4 121.9	77.2 138.0	170.6 439.4
Mtsz	0-30 30-80	39.3 79.0	97.1 195.5	35.2 65.5	61.9 130.0	98.4 155.0	234.8 429.5
Morainic landscape (Lutry II site)							
Mn	0-30 30-59	49.6 56.7	81.6 82.8	30.9 34.7	50.7 48.1	93.8 101.8	225.0 241.3
Mtsz	0-30 30-74	53.6 118.2	78.8 170.7	35.7 51.6	43.1 119.1	96.0 105.1	228.4 394.0
Mtsz	0-30 30-57	60.0 69.6	80.5 94.1	45.8 46.6	34.7 46.5	96.9 38.4	237.4 202.1
Mtz	0-30 30-68	63.5 84.8	97 163.0	44.7 68.3	52.3 94.7	101.7 95.2	262.2 343.0
Morainic landscape (Prusinowo site)							
Mn	0-30 30-80	33.7 124.7	57.7 182.9	25.1 55.9	32.6 127.0	86.1 130.6	168.6 438.2
Mn	0-30 30-80	29.6 94.8	58.5 185.4	14.8 62.6	43.7 122.8	80.5 123.8	168.6 404.0
Mtsz	0-30 30-80	47.4 100.1	89.4 193.3	34.5 66.3	54.9 127.0	87.3 127.3	224.1 420.7
Mtz	0-30 30-80	64.6 121.7	81.4 178.9	40.2 50.9	41.2 133.0	89.2 134.6	235.2 435.2

Mn – mucky soils, Mtsz – peat muck soils strongly silted, Mtz - peat muck soils slightly silted

Table 5

Mean values of water retention in 0-30 cm layers of studied soils in morainic landscape [mm]

Soils	Value	Water outflow	Content of water				
			Potentially available water (PRU)	Easily available water (ERU)	Hardy available water (RDK)	Unavailable water pF 4.2	Total water capacity
Mucky soils	X S CV	35.5 9.6 27.0	65.5 11.1 16.9	21.9 7.5 34.2	43.6 7.9 18.1	84.4 7.3 8.6	183.2 27.9 15.2
Peat muck soil strongly silted	X S CV	49.9 7.7 15.4	91.3 13.1 14.3	40.7 7.9 19.4	50.6 11.4 22.5	94.6 4.3 4.5	235.8 11.8 5.0
Peat muck soil slightly silted	X S CV	64.1 0.8 1.2	89.2 11.0 12.3	42.5 3.2 7.5	46.7 7.8 16.7	95.4 8.8 9.2	248.7 19.1 7.7
Statistically significant differences A= 0.05		1<2.3	1<2	1<2.3		1<2.3	1<2.3

Explanation: X – mean, S – standard deviation, CV - coefficient of variation

The volume of mesopores, corresponding to potential useful retention (PRU), varied in surface horizons of the studied soils. It fluctuated between 15.6% and 30.0% in humus AO horizons, between 22.3% and 32.5% in strongly silted mucks and between 18.3% and 28.3% in slightly silted mucks (Tab. 2). High variability of this feature in a group of formations with various content of organic matter, was also noted by ŁACHACZ et al. [1998]. Mean value of PRU in the landscape of ice-dammed lake origin was the highest in AO horizons of mucky soils (26.1%) and in strongly silted mucks (29.5%) in morainic landscape. In relation to slightly silted mucks and mineral-organic deposits of mucky soils, the differences were statistically significant (Tab. 3). Similar relationships were reported for mean content of easily available water (ERU). The lowest values were recorded in AO horizons of mucky soils in morainic landscape (6.6%) whereas in Mtsz, Mtz and AO horizons of the soils in the landscape of ice-dammed lake origin the values of ERU were statistically higher (Tab. 3).

In surface soil horizons of the studied landscapes, small pores containing hardly available water (RDK), prevailed considerably among mesopores (Tabs. 2, 3). Also, a proportion of small pores (RDK) in total porosity was higher than a proportion of effective useful retention (ERU), (Tabs. 2, 3).

Water retention properties in the layer of 0-30 cm (root layer) are presented in Table 4. In 0-30-cm layer, and in the layer of 30-80 cm which retains water and affects the effectiveness of capillary rise, due to alluvial and deluvial processes considerable changes of the volume of soil pores occurred. In root layer, the amount of water available for plants in both mucky soils (57.7-94.1 mm) and peat-muck soils (69.6-97.1 mm), irrespective of the degree of silting, oscillated widely and was generally lower than the amount of unavailable water. The water outflow in root layer in mucky soils in delta and riverine landscapes was twice lower than in peat-muck soils. Total water capacity in surface horizons of mucky soils in the studied landscapes was lower than in peat-muck soils (Tab. 4). In the layer of 0-30 cm, in mucky soils in morainic landscape, mean values of total water capacity, water available and easily available for plants were statistically significantly lower than in strongly silted peat-muck soils (Tab. 5). Slightly and strongly silted peat-muck soils contained, on average, higher amounts of unavailable water and had a higher water outflow than mucky soils (Tab. 5).

Total water capacity and amount of water in the pores of various diameter, in the layer of 0-80 cm was generally affected by the thickness of peat, its type and degree of decomposition (Tab. 4).

Coefficients of linear correlation, presented in Table 7, indicate that the amount of organic matter in surface horizons of the soils in morainic landscape was significantly correlated with the volume of macro- and micropores as well as with the volume of mesopores which contain water easily available for plants (ERU). In relation to potential useful retention, correlation coefficients proved to be insignificant. The data reported in the literature [ŁACHACZ 2001, ŁACHACZ et al. 1998, BAUER, BLACK 1992, HUDSON 1994] indicate that the influence of organic matter on the amount of water available for plants is positive in the case of lower contents of organic matter. The studies carried out by ŁACHACZ et al. [1998] proved that the dependence between PRU and content of organic matter is curvilinear and may be described by square regression equation.

In the studied mineral-organic formations and variously silted mucks, in morainic landscape, PRU and ERU proved to be statistically positively correlated with total porosity and negatively correlated with bulk density (Tab. 7), which is consistent with the studies carried out in other landscapes [PIAŚCKI et al. 1998]. Total porosity was positively, and bulk density negatively correlated with the amount of organic matter (Tab. 7). Similar relationships were noted by ZAWADZKI [1980] as well as by MARCINEK and SPYCHALSKI [1987]. However for the entire range of organic matter content, in hydrogenic soils, the dependence was curvilinear. GAWLIK and ZAWADZKI [1983] stressed that the degree of correlation

Table 6

Correlation coefficients between physical properties in surface horizons of studied soils in morainic landscape

Properties	Organic matter	Specific den sity	Bulk density	Total porosity	Water capacity at pF		
					2.0	2.7	4.2
Organic matter	1	-0.998**	-0.770**	0.722**	0.513*	0.297	0.626**
Specific density		1	0.791**	-0.743**	-0.539**	-0.328	-0.650**
Bulk density			1	-0.991**	-0.915**	-0.646**	-0.752**
Total porosity				1	0.934**	0.652**	0.748**
pF 2.0					1	0.805**	0.715**
pF 2.7						1	0.792**

Properties	Macropores	PRU	ERU	RDK	Micropores	Macropores·P^{-1}	PRU·P^{-1}	ERU·P^{-1}	RDK·P^{-1}	Micropores·P^{-1}
Organic matter	0.850**	0.317	0.475*	-0.044	0.626**	0.428	-0.101	-0.205	-0.119	0.104
Bulk density	-0.841**	-0.776**	-0.780**	-0.376	-0.752**	-0.136	-0.497*	0.196	-0.190	-0.054
Total porosity	0.833**	0.803**	0.813**	0.381	0.748**	0.122	0.510*	-0.162	0.180	-0.034
2.0	0.580**	0.912**	0.767**	0.627**	0.715**	-0.174	0.648	-0.145	0.387	0.063
2.7	0.240	0.612**	0.262	0.735**	0.792**	-0.283	0.385	-0.230	0.430	0.105
4.2	0.598	0.366	0.333	0.224	1	0.134	0.128	-0.301	0.052	0.155
Macropores	1	0.418	0.665**	-0.100	0.598**	0.546**	0.158	-0.144	-0.188	-0.022
PRU		1	0.821**	0.708**	0.366	-0.314	0.791**	-0.021	0.490*	-0.004
ERU			1	0.179	0.333	-0.008	0.634**	0.051	0.122	0.018
RDK				1	0.224	-0.530*	0.573**	-0.095	0.691**	-0.034
Macropores/P						1	-0.672**	0.361	-0.797**	-0.541*
PRU/P							1	-0.473*	0.825**	-0.494*
ERU/P								1	-0.665**	-0.834**
RDK/P									1	0.572**

* - significance at α= 0.05. ** - significance at α= 0.01

between the density of muck formations and their water retention ability depends on both the amount of organic matter, mineral fraction (ash content) and type of mineral admixtures (texture, precipitation of chemical compounds).

CONCLUSIONS

1. In young glacial, landscape of ice-dammed lake origin and morainic landscape, upper silted organic soils adjoin shallow deluvial soils and formed a sequence of mucky soils and peat-muck soils with decreasing degree of silting. In delta landscape the spatial distribution of soils was mosaic.
2. Studied soils had heterogenous, multi-modular soil profile. Surface layers were composed of mineral-organic deposits of complex origin and muck formations of various degree of silting. Underneath, below peat layers, limnic deposits occurred.
3. The soils of the investigated catenas in morainic landscape, had the highest dynamics of groundwater level which decreased beneath the peat deposits. During the periods of low groundwater level, moisture content in surface horizons fell within the range of hardly available for plants. The highest and most stable water table was reported in slightly silted peat-muck soils in the landscape of ice-dammed lake origin.
4. The processes of upper silting modified the relations between the content of organic matter and mineral fraction in the soil solid phase and led to the differentiation of the volume of soil pores which affect water conductivity and water retention abilities. Humus (AO) horizons of mucky soils had low amount of macropores. The volume of mesopores was the highest in strongly silted mucks in morainic landscape and in mineral-organic formations of mucky soils in landscape of ice-dammed lake origin. Muck horizons of the soils in this landscape had the highest volume of micropores, which accounted for more than half of soil total porosity.
5. In the studied landscapes, total water capacity in root layer (0-30 cm) was lower in mucky soils than in peat-muck soils. In morainic landscape mean content of water available and easily available for plants was significantly lower in the root layer of mucky soils than in strongly silted peat-muck soils. Slightly and strongly silted peat-muck soils had higher water outflow and contained more unavailable water.
6. In the soils of morainic landscape, statistical dependences between the amount of organic matter in surface horizons and the volume of macro- and micropores, water field capacity as well as amount of water easily available for plants (ERU) were proved.

REFERENCES

AD-HOC-AG BODEN. 2005. *Bodenkundliche Kartieranleitung*. Hannover, ss. 438.

BAUER A., BLACK A. L. 1992. *Organic carbon effects on available water capacity in three soil textural groups.* Soil Sci. Soc. Am. J., 56(1): 248-254.

BIENIEK B. 1997. *Właściwości i rozwój gleb deluwialnych Pojezierza Mazurskiego*. Acta Acad. Agricult. Tech. Olst., Agricultura, Supplementum B, 64, ss. 80.

GAWLIK J., ZAWADZKI S. 1983. *Próba określenia stopnia zmurszenia torfów na podstawie gęstości murszu*. Wiad. IMUZ 15(1): 47-58.

GOTKIEWICZ J., OKRUSZKO H., SMOŁUCHA J. 1996. *Powstawanie i przeobrażanie się gleb hydrogenicznych w krajobrazie młodoglacjalnym Pojezierza Mazurskiego i Równiny Sępopolskiej*. Zesz. Probl. Post. Nauk Roln. 431: 181-201.

GOTKIEWICZ J., SMOŁUCHA J. 1996. *Charakterystyka krajobrazów młodoglacjalnych Pojezierza Mazurskiego i Równiny Sępopolskiej*. Zesz. Probl. Post. Nauk Roln. 431: 119-136.

HILLBRICHT-ILKOWSKA A. 2005. *Ochrona jezior i krajobrazu pojeziernego – problemy, procesy, perspektywy*. Kosmos 54(2-3): 285-302.

HUDSON B. D. 1994. *Soil organic matter and available water capacity*. J. Soil Water Cons., 49(2): 189-194.

KONDRACKI J. 1988. *Geografia fizyczna Polski*. PWN, Warszawa, ss. 464.

KONDRACKI J. 1972. *Polska północno-wschodnia*. PWN, Warszawa, ss. 272.

LISICKI S. 1995. *Objaśnienia do szczegółowej mapy geologicznej Polski*. PIG, Warszawa, ss. 42.

KUNTZE H. 1987. *Processe der Bodenentwicklung auf Sandmischkulturen*. Telma 17: 41-49.

ŁACHACZ A. 2001. *Geneza i właściwości płytki gleb organogenicznych na sandrze mazursko-kurpiowskim*. Rozprawy i monografie 49, UWM Olsztyn. ss. 120.

MACLAY C. D. A., ALLBROOK R. F., THOMPSON K. 1992. *Effect on development and cultivation on physical properties of peat soils in New Zealand*. Geoderma, 54: 23-37.

MARCINEK J., SPYCHALSKI M. 1987. *Wpływ zawartości materii organicznej na fizyczne właściwości gleb hydrogenicznych*. Rocz. AR, Poznań, 182: 19-33.

OKRUSZKO H. 1976a. *Wpływ melioracji wodnych na gleby organiczne w warunkach Polski.* Zesz. Probl. Post. Nauk. Rol., 177: 159-204.

OKRUSZKO H. 1976b. Zasady rozpoznawania i podziału gleb hydrogenicznych z punktu widzenia potrzeb melioracji. Bibl. Wiad. IMUZ, 52: 7-54.

OKRUSZKO H. 1976c. Domieszki mułowe i namułowe w glebach torfowych. Prace Kom. Nauk. PTG V/32: 3-13.

ORZECHOWSKI M., SMÓLCZYŃSKI S., SOWIŃSKI P. 2001. *Właściwości gleb obniżeń śródmorenowych Pojezierza Mazurskiego*. Zesz. Probl. Post. Nauk Roln. 476: 229-235.

ORZECHOWSKI M., SMÓLCZYŃSKI S. 2002. *Modyfikacja gleb pobagiennych Pojezierza Mazurskiego przez procesy deluwialne.* Zesz. Probl. Post. Nauk Roln. 487: 205-212.

PIAŚCIK H. 1996. *Warunki geologiczne i geomorfologiczne Pojezierza Mazurskiego i Równiny Sępopolskiej*. Zesz. Probl. Post. Nauk Roln. 431: 31-45.

PIAŚCIK H., SMÓLCZYŃSKI S., ORZECHOWSKI M. 1998. *Physical, water and retaining properties of hydrogenic solis of the Vistula Delta.* Polish Journal of Soil Science, Vol. XXXI/2 : 9-14.

PIAŚCIK H., SMÓLCZYŃSKI S., ORZECHOWSKI M. 2000. *Rozwój mokradeł w krajobrazie delty wiślanej.* Biuletyn Naukowy UWM Olsztyn. 9: 73-82.

PIAŚCIK H., GOTKIEWICZ J. 2001. *Rola pokrywy glebowej w kształtowaniu środowiska obszarów młodoglacjalnych*. Zesz. Probl. Post. Nauk Roln. 478: 511-518.

PIAŚCIK H., LEMKOWSKA B. 2001. *Prawidłowości w rozwoju i rozmieszczeniu mokradeł w dolinie Łyny na Pojezierzu Mazurskim*. Woda – Środowisko – Obszary Wiejskie 1. specj. (3): 83-99.

PIAŚCIK H., SOWIŃSKI P ORZECHOWSKI M. SMÓLCZYŃSKI S. 2001. *Sekwencja gleb obniżeń śródmorenowych w krajobrazie młodoglacjalnym Pojezierza Mazurskiego*. Zesz. Probl. Post. Nauk Roln. 476: 491-496.

PIAŚCIK H., SOWIŃSKI P. 2002. *Wpływ denudacji antropogenicznej na rozwój gleb obniżeń śródmorenowych w krajobrazie Pojezierza Mazurskiego*. Zesz. Probl. Post. Nauk Roln. 476: 491-496.

SINKIEWICZ M. 1998. *Rozwój denudacji antropogenicznej w środkowej części Polski Północnej.*UMK, Toruń, ss. 103.

SMÓLCZYŃSKI S., ORZECHOWSKI M., PIAŚCIK H. 2000. *Geneza utworów i gleb hydrogenicznych w krajobrazie delty wiślanej*. Biuletyn Naukowy UWM Olsztyn 9: 83-91.

SMÓLCZYŃSKI S., ORZECHOWSKI M., PIAŚCIK H. 2004. *Fluwialne i antropogeniczne procesy w utworach i glebach hydrogenicznych delty wiślanej. Bliskie naturze kształtowanie dolin rzecznych.* Praca zbiorowa pod redakcją Heese T. i Puchalskiego W., Koszalin: 91-98.

SOWIŃSKI P., PIAŚCIK H. 1998. *Procesy stokowe w świetle badań geomorfologicznych.* Bibliotheca Fragmenta Agronomia, 4B: 213-219.

SOWIŃSKI P., SMÓLCZYŃSKI S., ORZECHOWSKI M. 2004. *Wpływ rolniczego użytkowania na właściwości fizyczno-wodne gleb w katenie moreny dennej.* Annales UMCS. Lublin, Sec. E, 59(3): 1057-1064.

SOWIŃSKI P., SMÓLCZYŃSKI S., ORZECHOWSKI M. 2005. *Katenalna zmienność właściwości powietrzno-wodnych i retencyjnych gleb na Pojezierzu Olsztyńskim.* Zesz. Probl. Post. Nauk Roln. 506: 425-432.

SMÓLCZYŃSKI S. 2008. *Sekwencja i właściwości gleb w katenie leśnej Babięta na Pojezierzu Mrągowskim*. Rocz. Glebozn. 59(3/4): 262-267.

SMÓLCZYŃSKI S. 2009. *Mineralizacja związków azotu w odgórnie namulonych glebach organicznych Polski północno-wschodniej*. Ecological Chemistry and Engineering. W druku.

SYSTEMATYKA GLEB POLSKI. 1989. Wyd. IV. Rocz. Glebozn. 40(3/4): 1-150.

SZUNIEWICZ J., JAROS H., NAZARUK G. 1991. *Gospodarka wodna na glebach torfowych*. Bibl. Wiad. IMUZ 77: 43-57.

IUSS WORKING GROUP WRB. 2006. *World Reference Base for Soil Resources*.

ZAWADZKI S. 1970. *Relation between the content of organic matter and physical properties of hydrogenic soils*. Pol. J. Soil Sci. 1: 3-9.

ZAWADZKI S. 1973. *Laboratoryjne oznaczanie zdolności retencyjnych utworów glebowych.* Wiad. IMUZ. 11(2): 11-31.

Acknowledgement: In the years 2007-2009, the research was financially supported by the Ministry of Science and Higher Education, research project No N N305 2776 33.

Sławomir Smólczyński
Department of Soil Science and Soil Protection
University of Warmia and Mazury in Olsztyn
Pl. Łódzki 3, 10-727 Olsztyn