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Water retention of the loess-derived Luvisols with lamellic illuvial horizon in the Trzebnica Hills (SW Poland)

Abstract: The aim of work was to characterize the water retention in the silt-textured Luvisols with lamellic illuvial horizon (argic) that occur in the loess covered northern part of the Silesian Lowland. Soil pits were localized on the Trzebnica Hills near the villages: Machnice (profile 1), Skarszyn (profile 2) and Zaprężyn (profile 3 and 4). Profiles Machnice 1 and Skarszyn 2 were situated in the upper parts of the hills covered with beech stands with an admixture of oak, linden and maple. Profiles Zaprężyn 3 and 4 were situated in the central and lower parts of the arable slope. During the field work conducted in April 2011, 29 soil samples were collected for texture, bulk density and water properties analysis. The soils under study were characterized by texture of silt loam with lower clay content in humus horizons (“loamy silt” according to Polish classification), and higher clay content (“clayey silt”) in the illuvial and subsoil horizons. The texture of all examined profiles was dominated by the „loess” fractions. Variable abundance of the massive lamellae causes variations in water properties of the illuvial (sub-)horizons. It was found that lamellic illuvial horizons in the loess-derived Luvisols have higher field water capacity than the homogenous illuvial horizons, apart of the clay content. There was no apparent effect of the horizon kind (homogeneous versus lamellic) on the soil bulk density. These properties mainly depended on the total clay content in a particular horizon (sub-horizon).

Key words: Luvisols, water properties, lamellae illuvial horizon, homogenous illuvial horizon

INTRODUCTION

Luvisols cover over 5 mln km² of the Earth surface in humid temperate climate zone. These soils are mainly located in central Europe, western Russia, eastern China, North America and in the Mediterranean area (Bockheim and Gennadiyev 2000). According to various estimates in Poland, Luvisols cover at least 40% of land surface and occur in all geographic regions except for mountainous areas (Bednarek and Prusinkiewicz 1997). Luvisols derived from silty materials are known e.g. from the Lublin Upland, the Zachodniowołyńska Upland, the Roztocze Gorajskie, the Małopolska Upland, the Silesian Lowlands, the Sudetes Foreland and the Carpathian Foothills (Klimek 2005; Turcki and Słowińska-Jurkiewicz 1994; Zaleski et al. 2003; Zaleski 2012), as well as from the Błotno-Sochaczewska plain (Chojnicki 1993). Genesis of Luvisols is related to lessivage process that involves a substantial vertical transfer of fine colloidal clay particles from surface to subsurface horizons (Driessen et al. 2001; Jaworska and Dąbkowska-Naskręt 1999). The process results in a differentiation of the soil profile on eluvial and illuvial horizons. Enrichment of B-horizon in clay fraction is observed as clay films on surface of soil aggregates, coarser pores or soil channels (Konecka-Betley and Zagórski

1994). The diagnostic horizon for Luvisols is an argic illuvial horizon. Typical “homogeneous argic horizon” is characterized by the gradual increase of clay content at the interface between E and Bt horizons. The other form – “lamellic argic horizon” is a result of pedogenic concentration of the clay fraction in the clearly separated horizontal layers (lamellae) of variable thickness (Driessen et al. 2001).

Luvisols derived from loess are considered soils with exceptionally favorable hydro-physical properties (Turcki and Witkowska-Walczak 2004), conditioned mainly by texture, structure of porosity and mineral composition of the colloidal fraction. Because of the high retention capacity for the plant-available water, Luvisols have a great importance in agriculture. Because of this, the silt-textured Luvisols that are widespread in the Lower Silesia, were the subject of many previous studies (e.g. Borkowski 1966; Chodak 1980; Licznar and Drozd 1988; Kabała and Marzec 2010). However, the characterization of water properties concerned only Luvisols with typical (homogeneous) illuvial horizon. There is no information about physical and water properties of loess derived Luvisols with lamellic illuvial horizons in the available polish literature involving soil science.

The aim of the present work was to characterize the water retention in the silt-textured Luvisols with

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lamellic illuvial horizon (argic) that occur in the loess covered northern part of the Silesian Lowland.

MATERIAL AND METHODS

Soil pits were localized on the Trzebnica Hills delimiting the north-eastern border of Silesian Lowland. Trzebnica Hills are part of end-moraine hills indicating a maximum range of the Warta (Riss) glaciation. The contemporary area of hills is covered with late-Pleistocene loess material with the thickness of up to 8 meters. Loess decalcification in the Trzebnica Hills generally is not deep, and it does not exceed 2–3 meters (Jary et al. 2002; Jary 2002). Mean annual air temperature in the study area is 9.5°C, and the mean annual precipitation is 500 to 620 mm. The area is located in the border zone between positive and negative climatic water balance (Dubicki et al. 2002). Soil profiles were localized near the villages: Machnice (profile 1), Skarszyn (profile 2) and Zaprężyn (profile 3 and 4). Profiles Machnice 1 and Skarszyn 2 were situated in the upper parts of the hills covered with beech stands with an admixture of oak, linden and maple. Profiles Zaprężyn 3 and 4 were situated in the central and lower parts of the arable slope.

Soil morphology was described according to Guidelines for Soil Description (2006). Classification of soils was established using Polish Soil Taxonomy (Komisja V Genezy, Klasyfikacji i Kartografii Gleb PTG 2011) and the FAO-WRB classification (IUSS Working Group WRB 2007). In each of the distinguished soil horizons were collected the disturbed and undisturbed samples. Particle-size distribution of the ≤ 2 mm fraction, after sample dispersion with heksametaphosphate-bicarbonate, was conducted using sand separation on sieves and the hydrometer method for silt and clay fractions, according to the official standard PN-R-04032. The names of texture classes were given in line with the Polish Soil Science Society classification (Polskie Towarzystwo Gleboznawcze 2009). Undisturbed soil samples were collected in stainless steel rings (100 cm³) for the bulk density and water properties determination. Water retention was assessed for pF value ranges from pF 0 to pF 2.7 by using a sand block (0–2.0 pF) and kaolin-sand block (2.2–2.7 pF). The organic carbon was determined in disturbed samples by dry combustion method with absorption of CO₂ using Stroelein CS MAT 5500.

Due to low number of cases (only four profiles) no specific statistical analysis was done, only the Pearson correlation coefficients (at $p < 0.05$) were

calculated for the entire set of samples using Statistica 10 package.

RESULTS AND DISCUSSION

Morphology and classification of the soils studied

The soils studied belonged to the same soil type and reference group (according to FAO-WRB). They are characterized by similar texture and physico-chemical properties. The surface horizons in the profile 1 and 2 are characterized by silt loam texture (clay content $< 12\%$), other distinguished soil horizons have higher clay content ($> 12\%$) and belonged to silt loam texture class (Polskie Towarzystwo Gleboznawcze 2009). Soil profiles under beech stands have an arrangement of soil horizons: A-Et-Bt-BC-Ck typical of “natural” Luvisols (Komisja V Genezy, Klasyfikacji i Kartografii Gleb PTG 2011), with weakly developed humus horizon and well preserved eluvial horizon. Eluvial horizon gradually passes into illuvial horizon, which is homogeneous in the upper part, whereas in the lower part clearly differentiated into dense and dark lamellae (7–30 mm thick). Lamellae have sharp upper boundary and diffused bottom, and are separated by light-colored layers of loess with clearly lower clay content. According to the Polish Soil Classification (Komisja V Genezy, Klasyfikacji i Kartografii Gleb PTG 2011) both profiles represented “gleby płowe typowe” with very weakly developed redox features. According to FAO-WRB (IUSS Working Group WRB 2007), the soils belonged to the reference group of Luvisols, and after taking into account the relevant qualifiers, to Albic Cutanic Lamellic Luvisols (Siltic). Arable soils (profiles Zaprężyn 3 and 4) have deep or very deep (colluvial) humus horizon with clear features of secondary development into the cambic horizon in their lower parts. Eluvial horizons in these profiles are fragmentarily preserved or absent. Lamellic illuvial horizon in the profile Zaprężyn 3 lays under „homogeneous” transitional horizon EB, and directly below AB horizon in the profile Zaprężyn 4. According to the Polish Soil Classification (Komisja V Genezy, Klasyfikacji i Kartografii Gleb PTG, 2011), the profiles Zaprężyn 3 and 4 were classified as “gleby płowe z cechami brunatnienia” that is, according to FAO-WRB (IUSS Working Group WRB 2007), a close equivalent of Cutanic Lamellic Luvisol (Colluvic, Siltic) in a profile Zaprężyn 3 and Lamellic Luvisol (Siltic) in a profile Zaprężyn 4.

Basic soil properties of the soils studied

The soils under study were characterized by texture of silt loam with lower clay content in humus horizons ("loamy silt" according to Polish classification), and higher clay content ("clayey silt") in the illuvial and subsoil horizons. The texture of all examined profiles was dominated by the „loess” fractions. The percentage of coarse silt (0.05–0.02 mm) ranged between 30 and 46%, and the fine silt (0.02–0.002 mm) ranged between 15 and 27% (Table 1). The content of fine silt was higher in the surface horizons and decreased with depth, inversely to very fine sand (0.1–0.05 mm) that increased in the deeper part of soil profile. All profiles had clay-enriched illuvial horizons. However, the maximum clay content was in different sub-horizons: in lamellic sub-horizon (profiles Skarszyn 2 and Zapręzyn 3) or in transitional EB and homogenous Bt sub-horizons (profile Machnice 1). In the profile Zapręzyn 4, the highest

content of clay was found in A and AB horizons, formed probably from the plowed upper part of homogenous Bt horizon. This profile may be considered as eroded equivalent of the profile Machnice 1. The texture of particular strata in the lamellic B/C horizon (as in profile Zapręzyn 4) clearly differed each other (Table 1). Darker lamellae contained less coarse silt and very fine sand but 4% more clay than lighter inter-lamellae loess strata. The relative difference in clay content between these strata reached 30%.

Bulk density of undisturbed soil varied in a wide range of values between 1.09 and 1.61 g·cm⁻³ (Table 2). The lowest values were recorded in humus horizons (1.09–1.36 g·cm⁻³), due to negative relationship to organic carbon (Table 3), with the exception of profile Zapręzyn 4, where the high bulk density (1.47–1.53 g·cm⁻³) resulted from plowing the upper part of Bt horizon. The other specific phenomena, the „plow sole” in subsurface AB horizon (1.48 g·cm⁻³) was found in

TABLE 1. Particle-size distribution

Profile	Horizon	Depth (cm)	Particle size distribution (%)								
			>2	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	<0.002
Gleba płowa typowa/Albic Cutanic Lamellic Luvisol (Siltic)											
Machnice 1	AE	0–10	0	0,5	1	2	3,5	17	41	25	10
	Et	10–24	0	0,5	0,5	1	2	18	39	26	13
	EB	24–33	0	0	1	1	1	15	39	24	19
	Bt	33–60	0	0	1	1	1	17	39	20	21
	B/C1*	60–85	0	0	0	1	1	30	30	21	17
	B/C2*	95–145	0	0	0	1	1	26	35	20	17
	C	145–180	0	0	0	1	2	17	44	21	15
Gleba płowa typowa/Albic Cutanic Lamellic Luvisol (Siltic)											
Skarszyn 2	AE	0–6	0	0	1	1	2	19	44	26	7
	Et	6–19	0	0	1	1	2	17	45	26	8
	EB1	19–29	0	0	1	1	1	16	45	24	12
	EB2	29–42	0	0	0	1	1	18	42	20	18
	Btg	42–60	0	0	0	1	1	16	40	21	21
	Bt*	60–105	0	0	0	1	1	16	39	22	21
	B/C*	105–120	0	0	0	1	1	20	40	24	14
	Ck	120–170	0	0	1	1	1	18	41	22	16
Gleba płowa z cechami brunatnienia/Cutanic Lamellic Luvisol (Colluvic, Siltic)											
Zapręzyn 3	Ap	0–24	0	0	1	1	2	13	42	27	14
	AB	24–60	0	0	1	1	1	17	39	27	14
	EB	60–82	0	0	1	1	2	15	39	26	16
	Bt*	82–115	0	0	0	1	1	15	40	25	18
	Btg*	115–160	0	0	0	0	1	21	38	21	19
	B/C	160–200	0	0	0	0	2	23	43	17	15
Gleba płowa z cechami brunatnienia / Lamellic Luvisol (Siltic)											
Zapręzyn 4	Ap	0–16	0	0	0	1	2	16	39	22	20
	AB	16–42	0	0	0	1	1	16	39	23	20
	Bt1*	42–60	0	0	1	1	1	16	39	25	17
	Bt2*	60–82	0	0	0	0	1	16	43	23	17
	B/C*	82–140	0	0	0	1	2	19	45	18	15
	C	140–170	0	0	0	1	5	24	41	15	14
	inter-lamella	121–126	0	0	0	1	2	22	45	16	14
	lamella	126–128	0	0	0	2	3	19	40	18	18

Explanation: * lamellic Bt horizon.

the profile Zapręzyn 3. This value was higher than in directly overlying and underlying horizons. Bulk density of illuvial horizons ranged between 1.42 and 1.61 g·cm⁻³, mostly above 1.50 g·cm⁻³. It was found that the bulk density distribution throughout the illuvial horizon does not depend on the horizon kind (lamellic or homogeneous), but on the clay content in subsequent sub-horizons. The highest bulk density in the profiles Skarszyn 2 and Zapręzyn 3 was observed in the lamellic sub-horizons. In the profile Machnice 1, the highest bulk density were observed in the homogeneous sub-horizon, due to the highest clay content. The bulk density of lamellae and inter-lamellae strata has not been measured separately. Probably the bulk density of the lamellae will be higher than 1.65 g cm⁻³, if an

ranged between 42.2 and 55.9% (by soil volume) (Table 2), and both the highest and the lowest moistures at pF=0 were measured in the humus horizons. The soil water capacity in the surface horizons was not related to the land use, as differences in water content were found between pairs of profiles under the same vegetation (soils 1–2 and 3–4). The soil moisture (at pF=0) in the lamellic illuvial sub-horizons ranged between 45.5 and 51.4%; increasing or decreasing with depth depending of soil profile. Diversity of the maximum capacity (at pF=0) in the lamellic illuvial sub-horizons is much less than in the humus and eluvial horizons. No clear relation was observed in the maximum water capacity between lamellic and homogeneous illuvial sub-horizons. Although in the profiles

TABLE 2. Water properties of studied soils with regard to bulk density and organic carbon content

Soil profile	Horizon	Depth (cm)	Bulk density (g cm ⁻³)	Organic carbon (g kg ⁻¹)	pF (% v/v)					
					0	1.0	2.0	2.2	2.5	2.7
Machnice 1	Et	10–24	1.33	9.7	53.8	50.2	41.2	35.5	35.0	33.0
	EB	24–33	1.37	6.2	52.5	50.7	40.4	33.2	26.7	24.9
	Bt	33–60	1.55	3.2	48.4	46.5	36.8	34.1	27.7	24.6
	B/C1*	60–85	1.53	1.7	46.2	44.6	41.1	39.2	34.8	31.6
	B/C2*	85–145	1.52	1.2	47.0	44.9	40.4	38.1	35.1	30.6
C	145–180	1.50	1.1	47.2	45.7	39.7	36.2	27.8	25.2	
Skarszyn 2	Et	6–19	1.36	10.5	45.5	44.2	39.9	35.7	30.3	25.4
	EB1	19–29	1.39	6.7	45.7	44.0	38.7	35.3	32.7	25.8
	EB2	29–42	1.54	6.5	47.3	45.7	40.9	38.5	34.0	30.6
	Btg	42–60	1.58	3.1	42.9	41.6	38.9	38.1	34.4	32.0
	Bt*	60–105	1.60	3.8	46.0	44.2	41.2	40.0	37.2	33.8
	B/C*	105–120	1.48	2.9	48.3	47.3	41.4	39.0	34.3	28.7
	Ck	120–170	1.54	2.1	51.4	47.6	42.9	39.8	35.3	30.8
Zapręzyn 3	Ap	0–24	1.09	15.0	55.9	52.8	36.9	31.9	30.7	26.3
	AB	24–60	1.48	10.2	44.6	43.2	39.8	36.1	35.2	32.7
	EB	60–82	1.30	9.3	51.5	49.5	37.8	35.2	30.1	26.8
	Bt*	82–115	1.52	2.7	51.4	48.9	41.0	39.1	35.3	26.5
	Btg*	115–160	1.61	0.7	45.4	43.8	41.0	39.1	34.9	32.5
	B/C*	160–200	1.48	0.5	49.6	45.9	42.2	39.2	37.3	36.2
Zapręzyn 4	Ap	0–16	1.47	11.2	46.1	44.5	38.8	36.6	34.3	32.6
	AB	16–42	1.53	8.8	42.2	40.7	37.9	36.2	34.0	31.3
	Bt1*	42–60	1.46	3.8	47.3	44.9	40.3	38.3	32.7	30.0
	Bt2*	60–82	1.42	1.3	48.7	47.1	40.4	38.2	33.6	27.2
	BtC*	82–140	1.53	0.7	51.4	49.1	44.3	41.9	35.9	30.1
	C	140–170	1.37	0.5	54.5	50.0	43.9	40.9	34.9	30.3

Explanation: * lamellic Bt horizon.

average bulk density of the entire lamellic horizons reached 1.60 g cm⁻³. Gradual decrease of the bulk density was expected in the bottom part of the illuvial horizons due to decreasing number of lamellae and clay content. This rule was true in the profiles Machnice 1 and Zapręzyn 4. However, the accumulation of the secondary carbonates, as in the profile Skarszyn 2, affected the structure of loess and caused the bulk density raise in the bottom part of Bt horizon comparable with the effect of clay accumulation. The recorded bulk density values are in the wide range of values reported

in the previous studies on Luvisols derived from silt materials (Chodak 1980; Klimek 2005; Licznar and Drozd 1988; Turski and Witkowska-Walczak 2004; Zaleski 2012).

Water properties of the soils studied

The water properties differed greatly within the profiles of Luvisols under study, but not as much as in the Luvisols with the sharp lithological discontinuity (Komisarek and Szalata 2008). The soil moisture corresponding to the maximum water capacity (pF=0)

2 and 4 the highest water capacity was in the homogeneous sub-horizons and decreased with depth, in the profiles 1 and 3, inversely, the water capacity was higher in the lamellic sub-horizons or differed from the homogeneous sub-horizons (Figure).

Water capacity at $pF=2.2$ in all the analyzed genetic horizons varied minimally in eluvial horizons of forest soils – 33.2–35.7%, in homogeneous illuvial horizons – 34.1–38.1%, and in lamellic illuvial horizons – 38.1–40.0% (in one case to 41.9%) (Table 2). In all profiles the field capacity in the lamellic sub-horizons was higher than in the homogeneous sub-horizons apart of the clay content (Figure). Worth noting is a rule that the field capacity of the homogeneous illuvial sub-horizons was always higher than this in the humus and eluvial horizons. Field water capacity increased in the deepest horizons (parent material). Due to the higher values of bulk density in this horizons (Table 3).

The water capacity at $pF=2.7$ was, in general, similar or varying in the same range in the illuvial sub-horizons of various kind. Only in the forest Luvisols, the water capacity at $pF=2.7$ was in the homogeneous

TABLE 3. Coefficients of Pearson correlation for the entire data set (coefficients significant at $p<0.05$ are marked with *)

	Corg	pF 0	pF 2.2	pF 2.7	silt	clay
d_v	-0.63*	-0.62*	0.62*	0.41*	-0.45*	0.47*
Corg		0.06	-0.73*	-0.15	0.52*	-0.18
pF 0			-0.11	-0.24	0.08	-0.29
pF 2.2				0.52*	-0.42*	0.01
pF 2.7					-0.44*	0.15
silt						-0.51*

Explanation: d_v – bulk density, Corg – organic carbon, pF0, pF2.2, pF2.7 – water capacity at given pF value.

illuvial sub-horizons lower than in lamellic sub-horizons (Figure).

The field water capacity ($pF=2.2$) of the humus and eluvial horizons are very similar to these reported in other papers on Luvisols derived from silt materials, as in the range 37–39% reported by Licznar and Drozd (1988), Klimek (2005), and Zaleski (2012). In the Bt horizons, recorded values were higher than given in available literature on Luvisols. However, in these

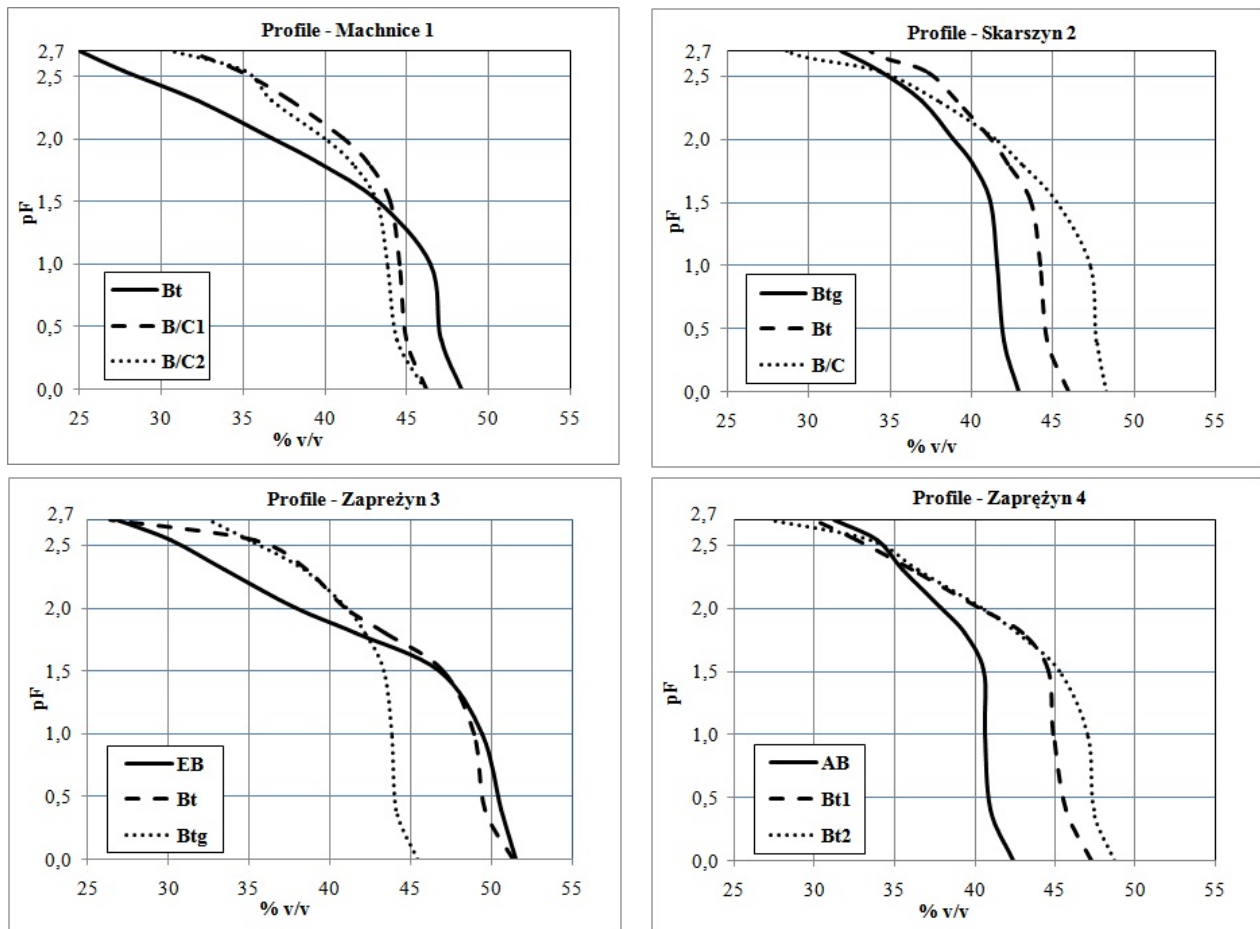


FIGURE. Water desorption curves (pF curves) for illuvial sub-horizons: (solid line) – homogenous illuvial horizons, (dashed line) – upper lamellic illuvial horizon, (dotter line) – bottom illuvial horizon (transitional to the parent material)

papers, in general, the kind of illuvial horizon (lamellic or homogenous) was not distinguished. Water field capacity of the illuvial horizons in soils of the Carpathian Foothills ranged between 31.0 and 37.2% (Zaleski et al. 2006; Zaleski 2012). Also in the loess-derived Luvisols in the Głubczyce Plateau, the water field capacity was around 33.2–36.2% (Licznar and Drozd 1988). Only Klimek (2005) reported higher field capacity of illuvial horizons, ranging between 38 and 40%, similar to this recorded in the upper homogeneous illuvial sub-horizons of soils in the Trzebnickie Hills. All cited papers confirmed that silt-textured Luvisols have higher water content (for values above $pF=2.0$) in the subsoil (Bt+B/C) than in the upper part (A+E) of the soil profile.

Although the results come from the initial stage of study and need to be verified in a larger number of soil profiles, it is already possible to indicate some regularity. In the examined soils, a homogeneous illuvial Bt horizon gradually passes into lamellic Bt horizon. In this horizon, abundance and thickness of lamellae decrease gradually with depth. Fine-textured lamellae contain few percent more clay than inter-lamellae loess strata. Relative difference in clay content may reach 30%, which explains differences in the structure and massiveness of the strata. Lamellae have very strong angular-platy structure, while the loess inter-lamellae strata are poorly angular structure. Variable abundance of the massive lamellae causes the variations in physicochemical and water properties of the illuvial (sub-) horizons. There was no apparent effect of the kind of horizon (homogeneous versus lamellic) on the bulk density and the maximum water capacity. These properties mainly depended on the total clay content in a particular horizon (sub-horizon). However, it was found that lamellic illuvial horizons in the loess-derived Luvisols have higher field water capacity than the homogenous illuvial horizons, apart from the clay content.

CONCLUSIONS

1. Total amount of clay, but not the kind of an illuvial horizon (homogeneous versus lamellic) is main factor determining the bulk density of illuvial horizon in loess-derived Luvisols.
2. Kind of illuvial (sub-)horizon (homogeneous or lamellic) does not affect the maximum water capacity of the illuvial horizon.
3. Illuvial lamellic horizons have higher field water capacity (at $pF=2.2$) than homogeneous illuvial horizons of loess-derived Luvisols.

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Właściwości retencyjne lessowych gleb pływowych z lamelowym poziomem iluwialnym z obszaru Wzgórz Trzebnickich

Strzeszczenie: Badane profile gleb pływowych wytworzonych z lessów zlokalizowane zostały na Wzgórzach Trzebnickich, które od północnego-wschodu zamykają obszar Niziny Śląskiej. Profile Machnice 1 i Skarszyn 2 zlokalizowane zostały w grzbietowych partiach wzniesień pod drzewostanami bukowymi z domieszką dębu, lipy oraz klonu. Profile Zaprężyn 3 i 4 położone są w środkowej i dolnej części stoku na polach ornych. Łącznie w trakcie prac terenowych w kwietniu 2011 roku pobrano 29 próbek glebowych. W pobranym materiale analitycznym oznaczono skład granulometryczny, gęstość objętościową oraz właściwości wodne na podstawie krzywej pF. Celem pracy była charakterystyka właściwości retencyjnych pyłowych gleb pływowych z lamelowym poziomem iluwialnym (argic). Badania wykazały, że zmienny udział masywnych lamel powoduje zróżnicowanie analizowanych właściwości wodnych poziomu iluwialnego. Lamelowe podpoziomy iluwialne w badanych lessowych glebach pływowych mają większą pojemność wodną niż homogeniczne podpoziomy iluwialne, niezależnie od zawartości iltu. Nie stwierdzono wyraźnego wpływu rodzaju poziomu iluwialnego (homogeniczny lub lamelowy) na gęstość objętościową gleby, która w większym stopniu zależna jest od zawartości frakcji ilastej.

Słowa kluczowe: gleby płowe, właściwości wodne, lamelowy poziom iluwialny, homogeniczny poziom iluwialny