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Full Length Research Paper

Water physical properties of eugley in a protected part of alluvial plains of the central Danube Basin

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This paper presents the results of the water physical properties of eugley in the area of the central current of Danube River, the part of the alluvial plain which is protected from flooding by an embankment. The aim of the research during vegetative period was to present the basic physical properties of this soil in the protected part of the alluvial plains, the depth of underground water, and distribution of the immediate moisture. It was determined that this land had a high total clay content, ranging from 60.02 to 70.26% on the average. According to granulometric composition, the textural classes ranged from loamy sand, sandy-clay loam, loam to clay loam. Specific mass values ranged from 2.65 to 2.84 g/cm3, volume mass from 0.96 to 1:54 g/cm^3, and the total porosity of this soil ranged from 43.22 to 64.31%. Air capacity of this soil ranged from 3.1 to 34.7% vol, and plant available water ranged from 7.96 to 28.80% vol. During the measurement of groundwater levels in 2006 when Danube water level was high, a high correlation coefficient was determined (r = 0.72 to 0.96) between water level and underground water oscillation, in 2007 correlation was low (r = 0.07 to 0.25).

Key words: River Danube, eugley, water-physical properties, alluvial plain.

INTRODUCTION

Studies pertaining to Danube alluvial plain contributed to its specification in terms of morphological forms. Depending on the intensity of sediment deposition in the major rivers inundations of three genetic parts were distinguished: coastal, central and pre-terrace part (Wiliams, 1949). Each part was characterized by specific relief, hydrological and vegetational conditions. According to Antić et al. (1968) the pre-terrace part was characterized by low relief form in the form of depressions, the depth of underground water of up to 1 m, and forest vegetation of *Populetu nigrae et albae, Salicetum albae, Cariceto-Salicetum,* and swamp vegetation of *Magnocaricion, Scirpo phragmitetum* and *Lemno salvinetum.* In the pre-terrace part of alluvial plains the euglej soils mostly prevailed in the lowest parts. According to the soil classification of Yugoslavia (Škorić et al., 1985) the euglej represents the soils from the hydromorphic class, which belongs to the class of gleic soils of A-G structures.

It is characterized by a dark grey humus horizon (Aa), of a thickness less than 50 cm, which has mostly loamy to clay textural composition, and a gleic layer (G) at a certain depth. Humus of these soils was formed by decomposition of hydrophilic vegetation under anerobic conditions, and is reffered to as 'hydromul' or hydromorphic humus (Miljković, 1996).

Considering the depth of gleic horizon the euglej soils were divided into ά-glej (0 to 40 cm), β-glej (40 to 80 cm) and γ-glej (80 to 120 cm), Antić et al. (1969), while the mentioned author has singled out two more ά/β-glej and β/γ-glej. Production properties of these soils depend on the depth of the gleic horizon, and the way of moisturizing. According to the way of moisturizing the eugleic soils can be divided into: hypogleic (exclusively underground water moisturizing), where gleic process takes place in the lower part of the profile; epigleic (surface water moisturizing), where gleic process takes place in the upper part of the profile; and amphigleic, where soil is exposed to the influence of both the underground and the surface waters, so the soil is exposed to the gleic process from both sides (Miljković, 1996).

In the protected part of the alluvial plains hydrological

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Table 1. Sites of pedological profiles.

No. of profiles	Soil type	Name of major cities	Name of locality	Geographycal		Height above sea level (m.a.s.)	Distance from the shore (m)
				Length	Width		
4/06	Eugley	Novi Sad	Kać 1	45°17′49.4″ N	19°53′16.1″ E	73.50	3.716
9/06	Eugley	Novi Sad	Kać 2	45°17′30.2″ N	19°53′18″ E	73.75	3.106
11/06	Eugley	Čelarevo	Čelarevo	45°15′41.9″ N	19°32′33.4″ E	77.30	1.320
15/06	Eugley	Kovilj	Kovilj	45°13′10.2″ N	19°58′10.5″ E	72.50	2.071
18/06	Eugley	Novi Sad	Kać 3	45°18′8.2″ N	19°50′53.5″ E	73.00	4.161

conditions and the evolution of soils have been significantly altered. After the 1932 and construction of protective embankments along the central Danube stream, the land in this part of the alluvial plains has been protected from flooding waters. Changes in moisture regime in the last seven decades has had a considerable influence on the characteristics of this soil. The greatest impact on pedogenetic processes and properties of eugleic soil processed in this area was exerted by a groundwater regime, and according to the way of moisturizing this soil was classified as hipogleic.

MATERIALS AND METHODS

Object of investigation

This study determined the area encompassing the central Danube current located in the protected part of alluvial plain, which will represent the properties of this soil in the central Danube basin by displaying eugleic soil. The survey lasted through 2006, and 2007. Pedology profiles and piezometers for measuring underground waters were located along the left Danube bank on three localities: Bačka Palanka-Čelarevo, Novi Sad-Kać and Kovilj. Morphology description was done, and samples for laboratory tests were collected. During vegetation period the underground water level was measured every 15 days. Five pedology profiles of eugleic soils representing the pre-terrace part of alluvial plains were processed in this paper (Table 1, Photo 1 and 2).

Working method

Physical properties of all soil samples were analyzed using the following methods:

(i) Determination of mechanical soil content according to International B-pipette method with preparation in Sodium-pyrophosphate; Bošnjak et al. (1997),
(ii) Determination of volume soil mass using Kopecky cylinders (100 cm^3), Bošnjak et al. (1997);
(iii) Determination of specific soil mass according to Albert-Bogs method using xylol as inert liquid, Bošnjak et al. (1997),
(iv) Total porosity (%) calculated using values of specific and volume mass of soil, Bošnjak et al. (1997),
(v) Moisture retention at a pressure of 0,33 bar using porous plate, (Richards, 1948);
(vi) Moisture retention at a pressure of 6.25 and 15 bar using pressure membranes, (Richards, 1948);
(vii) Differential porosity is determined from the difference of the total porosity and moisture retention under different pressures; Bošnjak et al. (1997),
(viii) Useful water capacity (water accessible to plants), calculated from the difference of water retained at a pressure of 0.33 and 15 bar; Bošnjak et al. (1997),
(ix) Air capacity was calculated from the difference of total porosity and water retained under pressure of 0.33 bar (%); Bošnjak et al. (1997),
(x) Capillary rise of water in soil, Bošnjak et al. (1997),
(xi) Soil water permeability that is Darcy's coefficient, Bošnjak et al. (1997).

RESULTS AND DISCUSSION

Physicomechanical properties of eugley

It was obvious when examining the granulometric composition of eugleic soils (Table 2) that the fraction of total clay and dust ranging on the average from 60.02 to 70.26%, prevailed in all prifiles, while fraction of total sand was in the range of 29.74 to 39.98% except in the profile 11/06, where average value of total clay and dust was 27.99% and average content of total sand was increased to 72.01%, which was explaned by great participation of total sand in gleic subhorizon. In all pedological eugleic profiles, the total content of clay and dust decreased with depth, while the share of the total sand increased. Živković et al. (1972), mentioned for soils of this type in Danube inundation some 55 to 60%, and in loes terrace depression cca. 60 to 65% of total clay. Živanov and Ivanišević (1986) mentioned that the content of total clay ranged from 68.4 to 70% in the humus horizon, and gleic subhorizon (Gso), while high content of total sand of 98% was found in lower gleic subhorizon (Gr). Very high clay content soil which were flooded due to high water levels in the area of alluvial plains in the part of southwest Spain was also confirmed by Moreno et al. (1995). Textural class of these soils ranged from loamy sand, sandy-clay loam, loam to clay loam. Specific masses ranged on the average from 2.65 to 2.84 g/cm^3, volume mass from 0.96 to 1.54 $g/cm^{3,}$ and the values of total porosity from 43.22 to 64.31%. By studying the humogleic soils, which also belong to gleic soil class Mukaetov et al. (2005), found similar values of specific and volume mass, and slightly lower total porosity in comparison to eugleic soils.

Values of water retention (Table 3) were relatively high at all apllied pressures in regard to the following textural

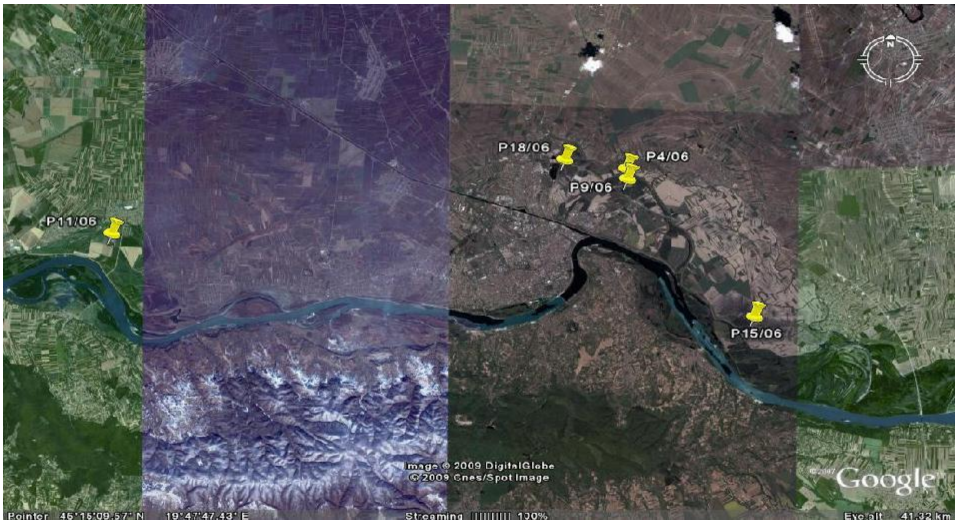

Photo 1. Area of investigation.

Photo 2. Position of the object in the Republic of Serbia.

classes: sandy clay loam, loam and clay loam, so the capacity for air in these textural classes was consequently very low. Water retention capacity for loamy sand was low, and values for air capacity were elevated. Air capacity values were generally increased with depth in every pedological profile, as well as the values of water accessible to plants, except in 18/06 profile, where these values increased in the surface humus horizon. Values of air capacity ranged from 3.1 to 34.7% vol, while plant available water ranged from 7.96 to 28.80% vol. Value of Darcy's coefficient was the lowest in the surface horizons of these soils due to increased content of clay and dust fraction, and this coefficient increased towards the depth of the profile, that is, vertical water permeability was greater with the increased share of total sand for each profile, except the 18/06 profile. Values of capillary rise were the greatest in regard to loamy sand class (27.8 cm), while in regard to loam and clay loam these values were the lowest and ranged from 8.5 to 9.7 cm (Tables 2 to 4).

When analyzing the content of different eugleic soil pores (Table 4) it can be seen that all humus horizons (Aa) contained most of the tiny fine pores (>0.2 m), somewhat lesser amount of medium size pores (10 to 0.2 m), and the least amount of coarse pores (>10 m). This distribution of pores in the humus horizon contributed to the explanation of the great content of total clay and dust found in these horizons, which belonged to the following textural classes: loam, sandy clay loam, and clay loam.

Table 2. Granulometric composition, specific and volume mass, total porosity of eugleic soils.

Number of profiles	Horizon	Depth (cm)	Coarse sand 2.0-0.2%	Fine sand 0.2-0.02%	Dust 0.02-0.002%	Clay less than 0.002%	Total sand greater than 0.02%	Total clay and dust less than od 0.02%	Textural class	Spec. massa g/cm^3	Vol-mass g/cm^3	Total porosity %
4/06	Aa	0-25	3.074	32.446	46.32	18.16	35.52	64.48	loam	2.86	1.42	50.35
	Gso	25-80	1.94	39.94	40.44	17.68	41.88	58.12	loam	2.82	1.35	52.12
	Average		2.51	36.19	43.38	17.92	38.70	61.30		2.84	1.39	51.24
9/06	Aa	0-35	3.668	28.932	48.36	19.04	32.6	67.4	loam	2.75	1.33	51.64
	Gso	35-80	0.478	46.882	36.16	16.48	47.36	52.64	loam	2.79	1.34	50.17
	Average		2.07	37.91	42.26	17.76	39.98	60.02		2.77	1.34	50.91
11/06	Aa	0-50	6.71	39.49	26.6	27.2	46.2	53.8	sandy clayey loam	2.54	1.54	39.37
	Gso	50-90	18.02	66.78	9.64	5.56	84.8	15.2	clayey sand	2.79	1.74	37.63
	Gr	90	16.12	68.92	9.8	5.16	85.04	14.96	clayey sand	2.81	1.33	52.66
	Average		13.62	58.40	15.35	12.64	72.01	27.99		2.71	1.54	43.22
15/06	Aa	0-35	0.747	37.053	39	23.2	37.8	62.2	loam	2.69	0.96	64.31
	Average		0.747	37.053	39	23.2	37.8	62.2		2.69	0.96	64.31
18/06	Aa	0-45	0.73	21.59	45.48	32.2	22.32	77.68	clayey loam	2.72	1.09	59.93
	Gr (Ab)	45	0.44	36.72	32.52	30.32	37.16	62.84	clayey loam	2.57	1.20	53.31
	Average		0.59	29.16	39	31.26	29.74	70.26		2.65	1.15	56.62

In the lower subhorizons (Gso), which belonged to the loamy textural class (P4/06, P9/06) medium size pores were the most numerous, participation of tiny fine was somewhat smoller, while the share of coarse pores was very small; In Gso (P11/06) which belonged to loamy textural class the share of medium size pores was the gretaest, the share of coarse pores came nest, and the share of tiny fine pores was the smallest. Since the participation of sand in granulometric composition was the greatest, the coarse pores were the most present in Gr subhorizon (P11/06) then came the medium size pores, and the share of tiny fine pores was again the smallest.

In the 18/06 profile, where the textural class was that of clay loam, but with somewhat greater amount of fine sand, the share of coarse pores was increased in relation to medium size pores, although the tiny fine pores were the most present. In general the tiny fine pores prevailed in textural classes of humus horizons such as loam, sand, clay, loam and clay loam due to high content of total dust and clay.

In the lower layers – gleic subhorizons (Gso) the medium size pores prevailed in loam, and loamy sand due to increased sand content, but the greater percentage of coarse pores was found in loamy sand in relation to loam. In the lowest gleic subhorizons – Gr subhorizons of loamy sand the content of coarse pores prevailed, so the pore content declined towards the tiny fine pores, and in clay loam the most present were the tiny fine pores, while the content of coarse pores was

Table 3. Water retention, air capacity, water accessible to plants, Darcy's coefficient and capillary rise.

Number of profiles	Horizon	Depth cm	Total porosity %	Water retention % vol.			Air capacity (vol%)	Water accessible to plants (vol%)	Darcy's coeff. cm/sec	Capillary rise (cm)
				0.33b	6.25b	15.0b				
4/06	Aa	0-25	50.35	45.58	34.31	32.29	4.77	13.29	$2.4*10^{-5}$	13,8
	Gso	25-80	52.12	45.41	21.68	21.40	6.71	24.01	$4.4*10^{-4}$	8,5
9/06	Aa	0-35	51.64	48.55	33.17	32.01	3.09	16.54	$2.4*10^{-5}$	13,8
	Gso	35-80	50.17	47.07	19.33	18.27	3.1	28.80	$2.8*10^{-5}$	26,5
11/06	Aa	0-50	39.37	35.00	27.61	27.04	4.37	7.96	$3.6*10^{-4}$	18,8
	Gso	50-90	37.63	24.18	8.13	7.29	13.45	16.89	$8.9*10^{-4}$	27,8
	Gr	>90	52.66	17.96	6.10	5.29	34.7	12.67	$2.5*10^{-3}$	-
15/06	Aa	0-35	64.31	54.84	40.94	36.42	9.47	18.42	$1.2*10^{-3}$	12,8
18/06	Aa	0-45	59.93	46.67	31.26	30.27	13.26	16.4	$3.9*10^{-4}$	11.2
	Gr (Ab)	> 45	53.31	42.27	33.60	28.95	11.04	13.32	$3.1*10^{-4}$	9.7

Table 4. Eugleic soil pores.

Number of profiles	Horizon	Depth (cm)	Soil pores (% vol.)		
			Coarse (>10 µm)	Medium size (10-0.2 µm)	Fine (<0.2 µm)
4/06	Aa	0-25	4.77	11.27	34.31
	Gso	25-80	6.71	23.73	21.68
9/06	Aa	0-35	3.09	15.38	33.17
	Gso	35-80	3.1	27.74	19.33
11/06	Aa	0-50	4.37	7.39	27.61
	Gso	50-90	13.45	16.05	8.13
	Gr	90	34.7	11.86	6.1
15/06	Aa	0-35	9.47	13.9	40.94
18/06	Aa	0-45	13.26	15.41	31.26
	Gr (Ab)	45	11.04	8.67	33.6

increased, and that of medium size pores was the smallest.

Dynamics of underground water in eugleic soils

Water level of Danube in 2006 (Figure 1) remained the highest since 1964. It was mostly characterized by decrease from April to October, with the main maximum reached by the mid April, and the secondary maximum reached by the mid June and August. Movement of underground water (Figure 2) in 2006 followed the movement of Danube water level. The highest level of underground water during observation period was noticed in Kovilj and Kać, while the lowest level was noticed in Čelarevo, then Kać 1 and 2.

The movement of underground water level (Table 5) was noticed in these soils from 20 cm above the soil surface to the depth of 137 cm, and the average values ranged from 18 to 80 cm beneath the soil surface. The smallest amplitude of variation was noticed in the region of Kać 3, only 55 cm and Kovilj 57 cm, while the greatest

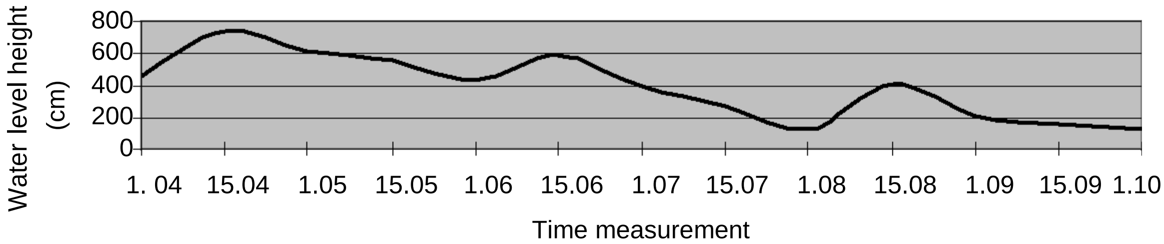

Figure 1. Danube water level in 2006.

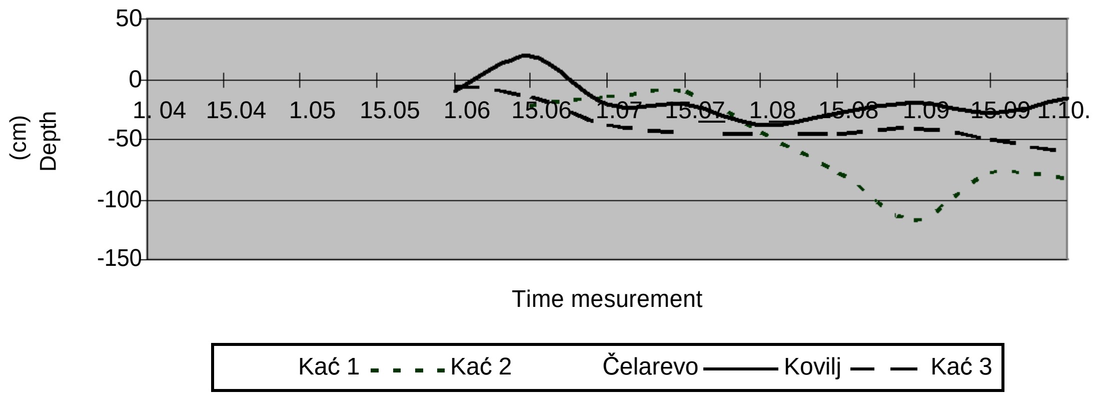

Figure 2. Dyamics of underground water in 2006.

Table 5. Relative and absolute underground water level in 2006 year.

Year	Relative underground water level (cm)				Absolute underground water level (m.a.s.)			
2006	max	sn	min	max	a.max	asn	a.min	amplitude
Kać 1	-30	-80	-110	80	73,2	72.7	72.,4	0.80
Kać 2	-10	-75	-137	127	73,65	73	72.38	1.27
Čelarevo	-10	-77	-111	101	77,2	76.53	76.19	1.01
Kovilj	+20	-18	-37	57	72,7	72.32	72.13	0.57
Kać 3	+5	-38	-60	55	72,95	72.62	72.4	0.55

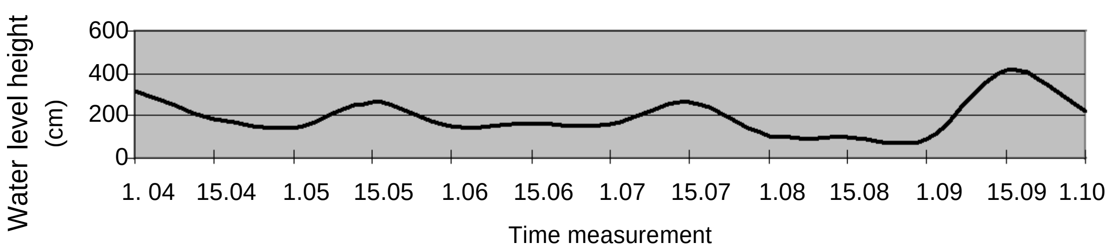

Figure 3. Danube water level in 2007.

fluctuation was noticed in Kać 2, 127 cm. During 2007, (Figure 3) the water level was significantly lower than in the previous year 2006, and it was uniform from April to November, after that the maximum was reached by the

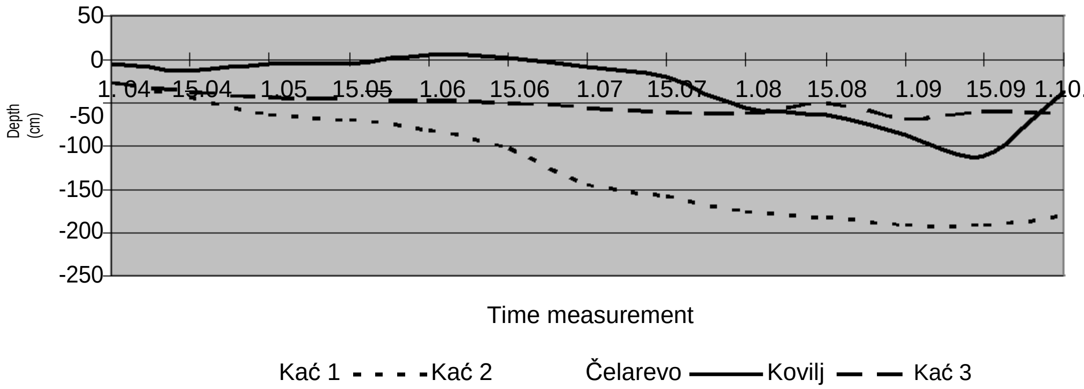

Figure 4. Dyamics of underground water in 2007.

Table 6. Relative and absolute underground water level in 2007 year.

Year	Relative level of underground water (cm)				Absolute level of underground water (m.a.s.)			
2007	max	sn	min	amplitude	a.max	asn	a.min	amplitude
Kać 1	-68	-122	-164	96	72.82	72.28	71.86	0.96
Kać 2	-25	-124	-191	166	73.5	72.51	71.84	1.66
Čelarevo	-35	-125	-160	125	76.95	76.05	75.7	1.25
Kovilj	+1	-31	-110	111	72.49	72.19	71.4	1.09
Kać 3	-25	-51	-68	43	72.75	72.49	72.32	0.43

Table 7. Correlation between Danube water level and level of underground waters.

Profile no.	Location	Distance from the Danube bed (m)	Coefficient r 2006	Coefficient r 2007
4/06	Kać 1	3.716	0.92	0.07
9/06	Kać 2	3.106	0.96	0.14
11/06	Čelarevo	1.320	0.87	0.25
15/06	Kovilj	2.071	0.72	0.12
18/06	Kać 3	4.161	0.78	0.21

mid September.

In this year the movement of underground water (Figure 4) in contrast to the previous one followed the line of Danube water level to a lower extent. Underground waters were found at greater depth in all soils due to lower Danube water level. The greatest level of underground waters was noticed in Kovilj and Kać 3, while the lowest level was noticed in Kać 1 and 2, and Čelarevo, as in previous year. Fluctuation of underground waters (Table 6) in these localities ranged from 1 cm above the soil surface to 191 cm below it. Mean values ranged on the average from 31 to 125 cm in depth. The lowest amplitude of underground water level variation ranged from 43 cm in Kać 3 to 166 cm in Kać 2. During both years of investigation differences in degree of correlation (Table 7) between Danube water level and level of underground water movement were noticable.

During 2006 when the high water level was recorded, a high degree of correlation in regard to underground water movement ranging from 0.72 to 0.96 was determined. In 2007 when Danube water level was significantly lower than in the previous year, its influence on the movement of underground waters was also significantly lower, and the correlation coefficients ranged from 0.07 to 0.25. It can be concluded from the above mentioned that only high Danube water level had significant influence on underground waters movement, while at low water level this influence was minimal. Interaction between Danube water levels and underground waters was expressed especially at high water level. Sophocleous (2002), mentioned that interaction between water currents and underground waters, which formed one hydrological entirety was significant. As mentioned by Pucci and Pope (1995), the estimation of influence of water levels on underground waters differed and depended on hydrological region. Cho et al. (2008), pointed out to the significance of underground waters and its influence on the soil, while Bouraoui et al. (1997) claimed that the soil type and its characteristics had significant influence on the movement of underground waters.

Conclusion

In soils of euglej type, which included the protected part of alluvial plain of the central Danube basin, the fraction of total clay and dust with average values ranging from 60.02 to 70.26% prevailed, while the fraction of total sand ranged from 29.74 to 39.98%, except in 11/06 profile, where the average value of total clay and dust was 27.99%, and average content of total sand was increased to 72.01%, which can be explained by the great share of fine sand present in gleic subhorizons.

Textural classes of these soils ranged from loamy sand, sandy clay loam, loam to clay loam, average values of specific mass ranged from 2.65 to 2.84 g/cm^3, while the values of volume mass ranged from 0.96 to 1.54 g/cm^3. Total porosity ranged from 43.22 to 64.31%.

Values of water retention were high for the following textural classes: sandy clay loam, loam and clay loam, so the air capacity of these textural classes was very low. Textural class of loamy sand had low water retention value, and increased air capacity values. Air capacity values, as well as the values of plant available water capacity increased with depth.

Air capacity of these soils ranged from 3.1 to 34.7% vol, and plant available water ranged from 7.96 to 28. 80% vol. Darcy's coefficient value was the lowest in the surface horizons of these soils due to greater content of clay and dust fraction, and it increased with the profile depth, that is vertical water permeability was increased with the increased share of total sand.

The highest capillary rise was achieved in textural class of loamy sand (27.8 cm), while in textural class of loam and clay loam its values ranging from 8.5 to 9.7 cm were the lowest.

In textural classes of humus horizons such as: loam, sandy clay loam and clay loam tiny fine pores prevailed due to high content of total dust and clay. In lower layers – gleic subhorizon (Gso) medium size pores prvailed due to increased content of sand, so the content of coarse pores was increased in laomy sand in relation to loam. In the lowest gleic subhorizons – Gr subhorizons, in class of loamy sand the content of coarse pores prvailed, and it decresed towards tiny fine pores, and in class of clay loam the tiny fine pores were the most present, while the content of coarse pores was also increased, and the content of medium size pores was the lowest.

Movement of groundwater during 2006 ranged in these soils from 20 cm above the surface to 137 cm in depth, and the average values ranged from 18 to 80 cm in depth. The smallest amplitude of variation was only 55 cm, while the greatest fluctuation was 127 cm.

During 2007 the underground water fluctuation in these localities ranged from 1 cm above the soil surface to 191 cm beneath it. Mean average values ranged from 31 to 125 cm in depth. The lowest amplitude variation of underground water level ranged from 43 to 166 cm.

During 2006 there was a high Danube water level, and a high degree of correlation in regard to underground waters ranging from 0.72 to 0.96 was determined. In 2007, when Danube water level was significantly lower, the smaller influence of Danube water level on the level of underground water movement was observed, and the correlation coefficients ranged from 0.07 to 0.25.

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