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SPATIAL VARIABILITY OF PHYSICAL SOIL PROPERTIES IN CONDITIONS OF ECOLOGICAL FARMING IN PROTECTED AREA

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Abstract

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In 2005–2009 the temporal and spatial dimensions in the six research sites were studied in order to assess the impact of environmental management on change of basic physical properties of the soil. Crop rotation was as follows: perennial fodder crops – perennial fodder crops – winter crops – root crops – spring crops – annual fodder crops. Soil sampling to determine bulk density, porosity and maximum capillary capacity was realised two times a year in spring and autumn at the six locations (I.–VI.) from the depth of 0.05 to 0.15 m. The results obtained were tested by statistical methods (analysis of variance, LSD-test). Soil bulk density is influenced by ecological farming in the five-year time series in comparison with 1996 and decreased its value in the interval ranging from 0.91 to 1.36 t m^{-3} in both samples. The porosity corresponded with bulk density, which in 2009 increased in all locations to the optimal levels for plant growth. The maximum capillary capacity in 1996 reached very low values (17.40 to 20.65%). In 2009 its value increased from 25.59 to 42.84%, which may be associated with sum of precipitation and ecological farming, too. The positive change of soil bulk density and porosity and increasing the maximum capillary capacity was recorded in comparison with 1996. Test of obtained results confirmed a statistically significant effect of experimental year and localities on the bulk density, porosity and maximum capillary capacity. The date of sampling significantly influenced the values of porosity and the maximum capillary capacity.

Key words: ecological farming, physical properties of soil, bulk density, porosity, maximum capillary capacity

Introduction

Ecological farming system is a modern form of land management in mountain areas and it is theoretically regarded as a transitional system from conventional agriculture to alternative one (Olah, Boltižiar, 2009; Olah et al., 2009; Boltižiar et al., 2008; Boltižiar, 2006). The main criterion in introducing ecological farming systems on land is the application of knowledge of functioning of natural ecosystems, that are characterized by a variety of plant and animal species and where solar energy is the only power source.

Authorities claim that management methods known as low-input, organic, ecological, biodynamical or biological (Petr, Dlouhý, 1992) are more durable and the system referred to as conventional agriculture is less permanent.

In order to evaluate sustainability of the agro-ecosystems certain indicators are used that are generally understood as measurable expressions of the status or characteristics of the system (Klír, 1997). Physical, chemical and biological soil parameters can be used as indicators of sustainability (Michaeli, Boltižiar, 2010). Larson and Pierce (1991) confirmed that the basic physical indicators are suitable for assessment of soil quality and sustainability of the system. Šimansky et al. (2008) hold that ecological farming systems on brown soil have a more positive effect on physical and hydro-physical soil properties than an integrated farming system.

The aim of our work was to investigate the basic physical soil properties in conditions of ecological farming system in the temporal and spatial dimensions.

Material and methods

The research project was carried out throughout the years 2005–2009 in production conditions in the investigated area Liptovská Teplička, where ecological farming system has been applied since 1996.

The area of Liptovská Teplička is situated in the Nízke Tatry National Park at an altitude ranging from 846 to 1492 m a.s.l. In terms of geomorphological division it is a part of the subassemblies of the Kráľovohorské Tatry Mts. The climate is relatively homogeneous. The whole area is situated in the mild zone with sum of average daily temperatures above 10 °C ranging from 1600 to 2000 and average precipitation of 700–1200 mm (Fig. 1).

The soil conditions are relatively homogeneous, the largest area being represented by Cambisols mostly moderate and strongly skeletal, mainly in subsoil. The second most common type of soil is Rendzic, moderate, shallow and skeletal. In addition, Histosols occur in this territory (Table 1). From the point of view of relief, the majority of the land is situated on the slopes.

In the current crop structure cereal acreage represents 33.3%, potatoes 16 to 18% and fodder crops 49.8%. Crop rotation is as follows: perennial fodder (clover mixture), perennial fodder (clover mixture), winter crops (winter wheat,

T a b l e 1. Particle grain-size composition of soil (%) of the studied area Liptovská Teplička in depth 0.05–0.15 m.

Diameter of the particles (mm)	Studied locality					
	I.	II.	III.	IV.	V.	VI.
	Cambisols	Histosols	Cambisols	Cambisols	Cambisols	Cambisols
> 0.25	31.3	24.9	14.5	11.5	32.5	16.0
0.25–0.05	21.6	13.9	15.5	18.9	13.9	14.9
0.05–0.01	27.8	27.7	32.4	24.3	22.2	31.3
0.01–0.001	15.5	27.4	29.3	3.3	24.0	2.6
< 0.001	3.8	6.1	8.3	11.0	7.4	8.2
I. Category	19.3	33.5	37.6	45.3	31.4	37.8
Soil	**loamy sand**	**loam**	**loam**	**clayey loam**	**loam**	**loam**

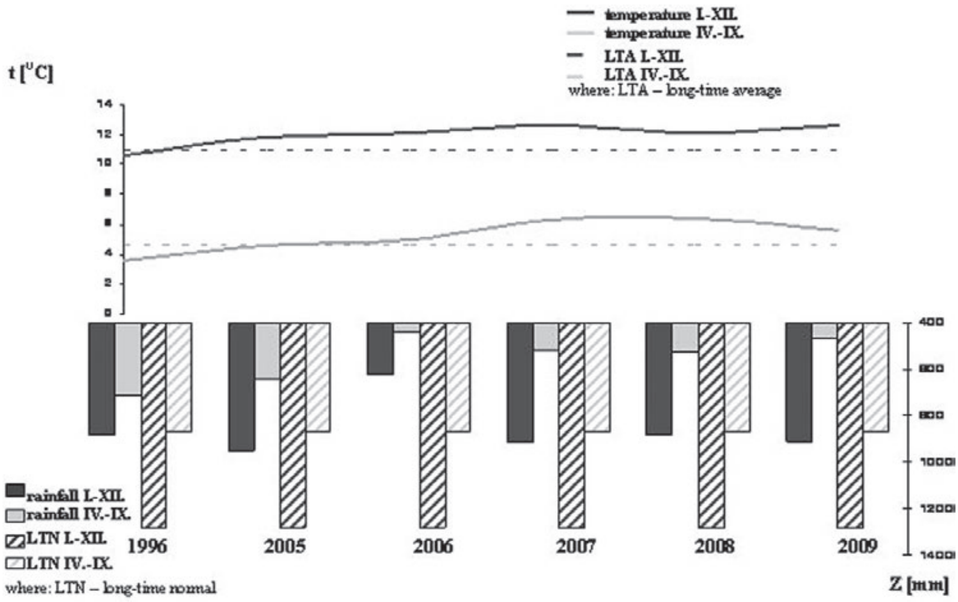

Fig. 1. The course of average air temperatures (°C) and sum of precipitation (mm) during observed period.

winter rye, triticale and winter barley), root crops (potatoes), spring crops (spring barley, oats), annual mixture (oats pea, peas, ryegrass). Arable land is fertilized with manure dosage of about 30 t ha^{-1} once in two years. The permitted phosphorous and potassium mineral fertilizers were not added in recent five years). The permanent grassland and arable land were fertilized with the Natural Harmony fertilizer in the spring season in dosage of 3 000 $l.ha^{-1}$ (minimum nutrients content: total nitrogen as N in dry mass at least 15%, total phosphorus as P_2O_5 in dry mass less than 0.2%, total potassium as K_2O in dry mass less than 0.4%, total sulfur as S in dry mass at least 16.5%).

The soil samples for physical soil properties determination were sampled twice in year, in spring time in connected coppice, in summer time before harvest, two or three times repeatedly on six permanent research sites (Fig. 2) from the depth of 0.05 to 0.15 m. The research sites are indicated as follows: I. – Podždiar; II. – Záteplica I., III. – Záteplica II., IV. – Váh-Rovienky, V. – Predzatračany; VI. – Nový diel.

We studied and evaluated the bulk density ($t.m^{-3}$), porosity (%), maximum capillary capacity (%) in Kopecky physical cylinder with a capacity of 100 cm^3 and grain composition by pipettes method of Kačinsky (Fiala et al., 1999). The obtained data were processed statistically by means of the software STATGRAPHIC (analysis of variance) and evaluated according to Grofík, Fľak (1990).

Results and discussion

For physical and hydro-physical soil properties it is very important to classify soil type on the basis of grain composition. On the basis of clay particles content and in accordance with Novák´s classification scale (Fulajtár, 2006), soils in monitored sites are clay-sandy soils (site I), in sites II., III., V. and VI. clay soils and in IV. site clay-loam soils (Table 1).

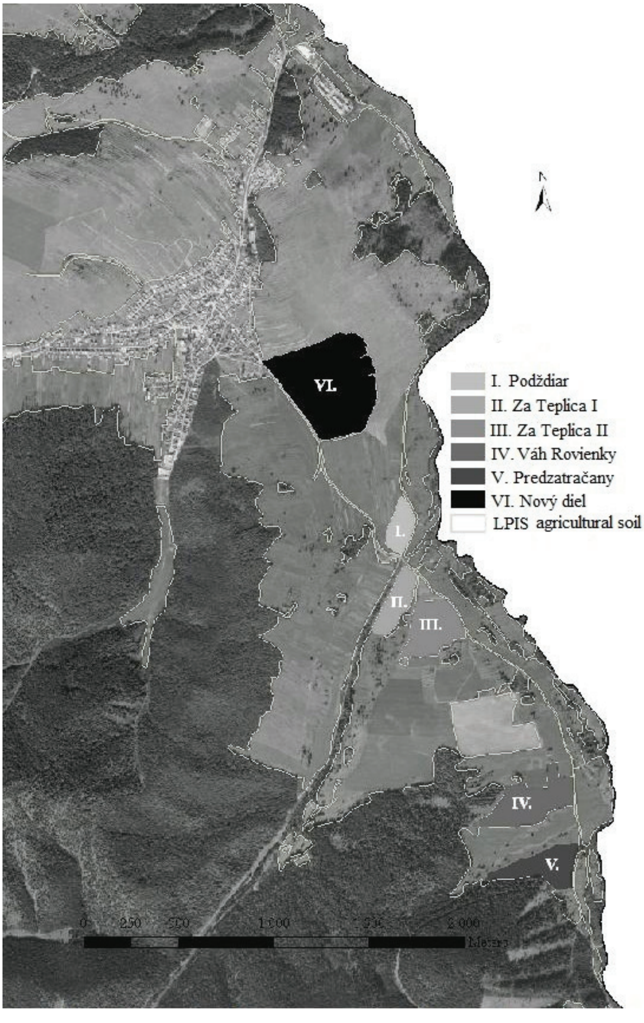

Fig. 2. Experimental localities of spatial variability of soil physical properties on the studied area Liptovská Teplička.

Bulk density as an integral value of the soil grain, humus content and anthropogenic impacts on soil should not exceed the limits given for individual types of soil (Table 2).

T a b l e 2. Critical values of bulk density soil ($t.m^{-3}$) and porosity for different of soil texture (Líška et al., 2008).

Soil texture	Sandy	Loamy sand	Sandy loam	Loam	Clayey loam and clay	Clay
Bulk density	≥ 1.70	≥ 1.60	≥ 1.55	≥ 1.45	≥ 1.40	≥ 1.35
Porosity	≤ 38	≤ 40	≤ 42	≤ 45	≤ 47	≤ 48

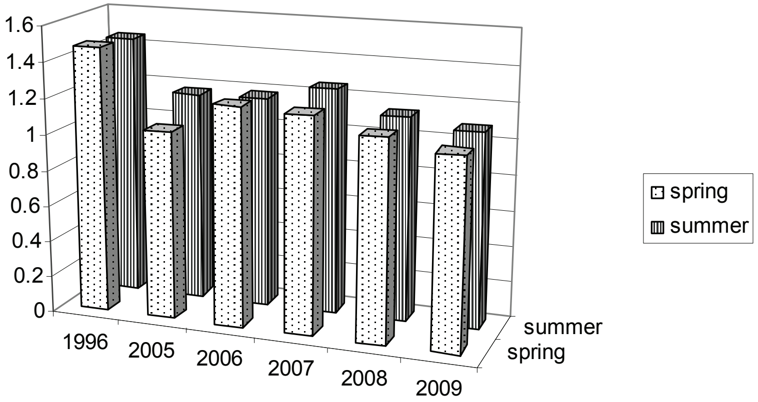

Fig. 3. Average values of bulk density (t.ha^{-1}) on the localities of the studied area Liptovská Teplička in observed period 1996 and 2005–2009.

Research studies show that the bulk density gets adjusted after a long-term application of ecological farming system. The measured critical values of bulk density (1.53 to 1.63 t.m$^{-3)}$ in spring 1996 have been gradually reduced and in 2009 ranged from 0.94 to 1.22 t.m^{-3} (Table 3). Thus, comparatively better results were achieved for that type and class of soil compared with the average values described in Líška et al. (2008). Similar trends in improving bulk density were also recorded in the summer sampling. In 1996, critical values of bulk density ranging from 1.51 to 1.58 t.m^{-3} were found.

In 2009, the above-given soil parameter reached a value of 0.92 to 1.23 tm^{-3} (Table 3, Fig. 3). Physical soil properties change not only under the influence of weather conditions, crop year, vegetation pass, but also under the influence of applied management system. Bulk density is most sensitive to changes of environmental conditions, which was proved in the present study. Through the given year and growing season bulk density value varied as well, depending on water availability in the soil, weather and farming methods.

From the total pore volume, which should not fall below 38% for sandy soil and below 48% for the clay-loam soil (Líška et al., 2008), the share of non-capillary pores rapidly releasing gravitational water and allowing good air exchange between soil and climate should be sufficient. The share of non-capillary pores (Pn) in comparison with capillary pores (Pk) should be higher in heavy soils. The best conditions for growth of most crops are in the total porosity of 55–65% and 20–25% of air content in soil (Rode, 1969). The positive impact of ecological farming on the land was shown in the increase of total soil porosity, which is closely related to the bulk density of the soil. Low values of total porosity were measured in 1996, during the monitored period; however, they gradually increased and in 2009 reached the optimal conditions for plant growth (Table 3, Fig. 4).

The maximum capillary capacity is a relatively unstable hydro-physical parameter and presents such an amount of water that soil that is normally able to retain in the soil

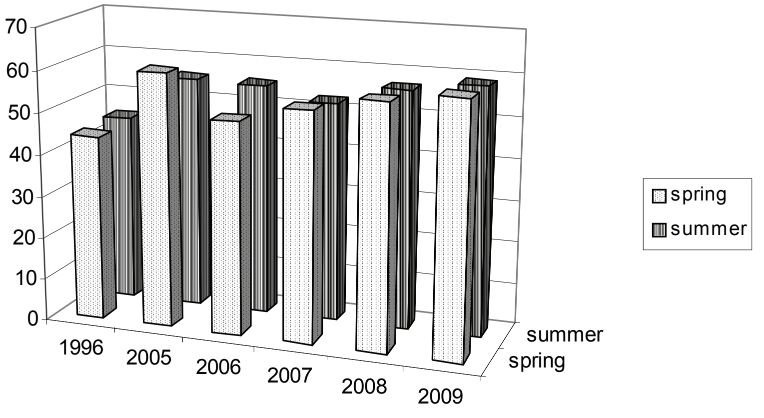

Fig. 4. Average porosity (%) on the localities of the studied area Liptovská Teplička in observed period 1996 and 2005–2009.

capillary pores after the previous saturation. The values of maximum capillary capacity during the monitored period ranged from 27.70 to 42.84% in spring, in comparison to 1996 when the low values of maximum capillary capacity (17.40 to 20.60%) were identified. Similar results were recorded in the summer when the values were in the interval 26.00 to 42.84%. The values of maximum capillary capacity in summer 1996 were significantly lower (17.90 to 20.65%). It is possible to assume that the rainfalls during this period influenced the values of this hydro-physical parameter (Table 3, Fig. 5). A statistically significant effect of the location and year on bulk density, porosity and maxi-

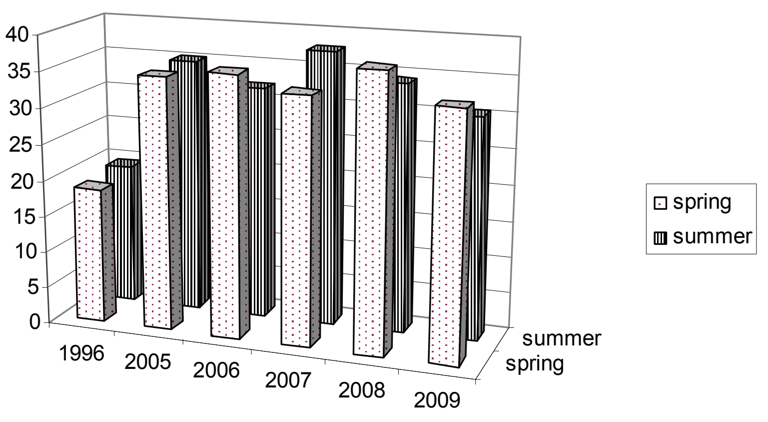

Fig. 5. Average values of maximum capillary capacity (%) on the localities of the studied area Liptovská Teplička in observed period 1996 and 2005–2009.

T a b l e 3. Basic physical soil properties on the localities of the studied area Liptovská Teplička (depth of sampling 0.05–0.15 m).

Parameter	Locality	Sampling	1996	2005	2006	2007	2008	2009
ρ_d ($t.m^{-3}$)	I.	spring	1.39	1.06	1.27	1.32	1.09	1.22
		summer	1.52	1.30	1.33	1.26	1.17	1.11
	II.	spring	1.33	0.91	1.17	0.98	0.85	0.99
		summer	1.43	0.93	1.11	1.16	0.91	0.88
	III.	spring	1.60	1.08	1.19	1.22	1.12	0.98
		summer	1.58	1.16	1.08	-	1.19	0.92
	IV.	spring	1.40	1.16	1.22	1.16	1.13	1.05
		summer	1.28	1.08	1.13	-	1.13	1.14
	V.	spring	1.63	1.02	1.32	1.27	1.31	1.22
		summer	1.51	1.30	1.36	1.29	1.21	1.23
	VI.	spring	1.53	1.07	1.15	1.28	1.22	0.94
		summer	1.44	1.27	1.09	1.34	1.24	1.24
Po (%)	I.	spring	47.62	59.92	52.09	50.06	58.75	53.78
		summer	42.55	51.13	49.98	52.30	55.96	58.13
	II.	spring	49.81	65.55	55.72	63.06	67.79	62.82
		summer	46.11	65.96	58.00	56.28	65.60	66.75
	III.	spring	39.74	59.30	55.21	54.09	57.91	62.96
		summer	40.36	56.11	59.09	-	55.19	65.27
	IV.	spring	47.11	56.40	53.92	56.08	57.51	60.48
		summer	51.64	59.23	57.55	-	57.21	56.82
	V.	spring	38.40	61.70	50.36	52.06	50.74	54.02
		summer	43.00	50.87	48.77	51.51	54.30	53.76
	VI.	spring	42.42	59.81	56.75	51.85	53.79	64.49
		summer	45.51	52.02	58.87	49.55	53.13	53.34
Θ_{MKK} (%)	I.	spring	18.45	36.90	35.80	35.80	38.75	38.42
		summer	20.25	38.75	35.25	39.00	36.15	31.38
	II.	spring	20.60	41.10	39.75	35.65	38.05	42.84
		summer	19.80	38.65	32.90	40.00	35.25	32.89
	III.	spring	18.20	32.55	29.00	31.60	34.40	27.70
		summer	17.90	31.20	29.90	-	29.50	26.00
	IV.	spring	19.65	36.45	36.95	34.70	39.25	31.87
		summer	19.31	34.25	31.25	-	33.80	30.27
	V.	spring	18.00	32.75	38.30	35.80	38.25	36.29
		summer	20.65	37.85	35.60	38.40	39.l20	32.10
	VI.	spring	17.40	30.09	35.95	29.90	38.50	25.59
		summer	19.10	30.25	28.25	33.85	31.80	31.05

Notes: ρ_d – bulk density, Po – porosity, Θ_{MKK} – maximum capillary capacity, summer 2007 tilled.

mum capillary capacity was proved by the statistical test results obtained in the field conditions using analysis of variance (Table 4). Date of collection (spring, autumn) significantly influenced the values of capillary porosity and the maximum capacity. Sites VI., I. and

T a b l e 4. Analyses of physical parameters variance.

Parameter	Source of variation	Degree of freedom	Calculated F-value
ρ_d	year sampling locality residual total	5 1 5 273 287	30.62 $^{++}$ 3.29 $^{+}$ 14.11 $^{++}$
Po	year sampling locality residual total	5 1 5 273 287	28.89 $^{++}$ 14.68 $^{++}$ 8.51 $^{++}$
Θ_{MKK}	year sampling locality residual total	5 1 5 273 287	65.64 $^{++}$ 23.44 $^{++}$ 21.27 $^{++}$

Notes: $^{++}$ $P < 0.01$ $^{+}$ $P < 0.05$; P – effect of factor significant at the level $\alpha = 0{,}05$ or $\alpha = 0{,}01$;
ρ_d – bulk density; Po – porosity; Θ_{MKK} – maximum capillary capacity.

V. located in a homogeneous group had the greatest potential impact on soil bulk density. Sites II., IV. and III. created another common homogenous group (Table 5).

The bulk density was statistically most significant in 1996 and for the sites VI., I. and V. which were located in one homogeneous group. Difference between the median values of the bulk density was not significant. In all pairs of the monitored years, the differences were statistically significant, except for the years 2007–2009 and 2008–2009. Regarding the sites, the only ones without significant differences between the median of 95% probability level were III.–IV. and V.–VI.

Regarding the porosity a significant impact on its values had the years 2008, 2005 and 2009 located in one homogeneous group, spring sampling before summer sampling and II. research site, all the other sites were located in one homogeneous group. Statistically significant differences were not found only between pairs of years 2007–1996 and 2008–2009. The difference between samples was significant. Statistical test sites showed that statistically significant differences in median values were only between sites II.–V. and II.–VI.

The maximum capillary capacity was significantly influenced by all tested factors, with the biggest influence on the value in the years 2006, 2005 and 2008 that are located in one homogeneous group (Table 5). LSD-test confirmed the significant effect observed in the spring collection on hydro-physical soil characteristics, which is related to the supply of water in the soil (Mati et al., 2008). Sites V., I. and II. located in one homogeneous group had a significant influence on the maximum capillary capacity and site III. had the lowest impact. From determining the significance of differences between the medians using the Fischer's LSD least significant difference procedures it follows that a statistically significant difference in the maximum capillary capacity was not observed only in the pair of years 2006–2009. The difference between samplings was statistically significant.

T a b l e 5. Multiplied test of soil parameters comparing ($LSD_{0.05}$).

Soil parameter	Monitored factor		Average	Homogeneous group					
ρ_d (t.m^{-3})	year	2007	1023.31	x					
		2009	1076.73	x	x				
		2005	1111.71		x				
		2008	1130.83		x	x			
		2006	1201.65			x			
		1996	1470.00				x		
	sampling	summer	1147.78	x					
		spring	1190.29	x					
	locality	II	1054.15	x					
		IV	1073.40	x					
		III	1093.33	x					
		VI	1234.21		x				
		I	1253.31		x				
		V	1305.83		x				
Po (%)	year	2007	44.74	x					
		1996	44.77	x					
		2006	54.69		x				
		2008	57.32		x	x			
		2005	58.08		x	x			
		2009	59.39			x			
	sampling	summer	51.22	x					
		spring	55.11		x				
	locality	III	50.44	x					
		V	50.79	x					
		IV	51.41	x					
		I	52.69	x					
		VI	53.46	x					
		II	60.20		x				
Θ_{MKK} (%)	year	1996	19.11	x					
		2007	29.56		x				
		2009	32.20			x			
		2006	34.14			x	x		
		2005	35.07				x		
		2008	36.07				x		
	sampling	summer	29.49	x					
		spring	32.56		x				
	locality	III	25.66	x					
		IV	28.98		x				
		VI	29.37		x				
		V	33.60			x			
		I	33.74			x			
		II	34.79			x			

Notes: ρ_d – bulk density; Po – porosity; Θ_{MKK} – maximum capillary capacity.

Significant differences between the research sites were not found only between the pairs II.–V. and IV.–VI.

Conclusion

On the basis of the research results reported in the production conditions of the years 2005–2009, the following conclusions can be made:

1. In soils with ecological farming systems, in the structures that are dominated by perennial fodder crops, as well as sufficiently high doses of organic fertilizer, positive changes of soil physical properties are observed.
2. The measured critical values of soil bulk density, porosity and maximum capillary capacity during the period were gradually adjusted and stabilized, reaching the levels comparable with the average values for the soil type.
3. In comparison with the year 1996, the positive change in the bulk density and porosity and the increase of the maximum capillary capacity was observed.
4. Test obtained results confirmed a statistically significant effect of experimental sites on the bulk density, porosity and maximum capillary capacity. The date of sampling significantly influenced the value of porosity and the maximum capillary capacity.

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