VERSITA
DOI: 10.2478/ssa-2013-0008

SOIL SCIENCE ANNUAL
Vol. 64 No 2/2013: 41–48

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Assessment of soil structure of Luvisols developed from loess classified in various complexes of agricultural suitability

Abstract: The objective of the study was the estimation of the aggregate size distribution and water stability of aggregates in Luvisols developed from loess, classified in three agricultural suitability complexes of soils used in Poland: very good wheat (1), good wheat (2) and deficient wheat complex (3). Soils classified in the very good wheat complex had a significantly higher content of air-dry aggregates with sizes in the range of 0.25–10 mm than those classified in the good wheat and deficient wheat complexes. The aggregate size distribution of Ap horizons of soils classified in the very good wheat complex was assessed as highly favourable, and the composition of Ap horizons of soil from the good wheat and deficient wheat complexes as favourable. The aggregate size distribution of the subsoil in the depth of 25–75 cm was assessed as favourable, while in the depth of 75–100 cm as medium favourable. The soils classified in the very good wheat and good wheat complexes were characterised by significantly higher contents of stable aggregates with sizes of 0.25–10 mm and 1–10 mm compared to the soils of the deficient wheat complex. Water stability of aggregates in the Ap horizons of soils classified in the very good wheat and good wheat complexes was estimated as good, and in the Ap horizons of soils of the deficient wheat complex as medium. Whereas, the water stability of aggregates in the Et, Bt, BC and C horizons was assessed as very poor. The reason of the deterioration of aggregate-size distribution and decrease of water-stable aggregate content with sizes of 0,25–10 mm, especially in Luvisols classified in the deficient wheat complexes was accelerated soil erosion.

Keywords: Luvisols developed from loess, eroded soils, complexes of agricultural suitability, aggregate size distribution, aggregate water stability

INTRODUCTION

Soil structure is an important aspect of agricultural soil quality. Favourable soil structure is characterised by a high content of stable macroaggregates with sizes of 0.25–10 mm, and especially 1–10 mm, with a low share of clods with sizes >10 mm and microaggregates <0.25 mm (Lenart, 2002; Bronick and Lal, 2005; Guimarães et al., 2011). Under field conditions, a stable aggregate structure protects against excessive compaction of soil, ensures a favourable content of capillary pores in the soil (with equivalent diameter of 0.2–20 µm), for the retention of water available to plants, and a suitable content of macropores, with diameters >20 µm, that ensure hydraulic conductivity as well as air capacity and permeability (Rząsa and Owczarzak, 2004; Lipiec et al., 2007; Sławiński et al., 2011; Pranagal, 2011). Due to that plant roots have free access both to water and to oxygen contained in the soil air. The stability of aggregates has an effect on the growth of soil microorganisms, enhances the biological activity of soil, creates suitable conditions for the germination, emergence and growth of plants, affects the length of their roots and density in the canopy. In addition, water stable aggregate structure protects the soil against surface crusting, increases the infiltration of rainwater, reduces the rate of surface runoff and water erosion (Le Bissonnais, 1996; Owczarzak and Rząsa, 2006; Paluszek, 2010).

Cultivation treatments have a strong effect on the formation of a stable aggregate structure of soil, through organic and mineral fertilisation, crop rotation, and the stabilising effect of the roots of legumes and grasses (Lenart, 2002; Ball et al., 2005, Bronick and Lal, 2005; Suwara and Szulc, 2011). At the same time, intensive tillage, excessive crumbling of the soil mass, use of monoculture of cereal plants and insufficient fertilisation cause a deterioration of the quality of soil structure (Pagliai et al., 2004; Pranagal 2011).

The classification of the agricultural suitability of Polish soils include the types of soils, texture, morphologic features, some physical, physicochemical and chemical properties, relief, intensity of erosion and moisture conditions. Depending on the classification of soils in the particular agricultural suitability complexes, they can be characterised by various physical properties, including diverse quality of the structure (Paluszek, 2011a, 2013). The objective of the study presented here was the comparison and es-

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timation of the aggregate size distribution and the water stability of aggregates in Luvisols developed from loess, classified in various agricultural suitability complexes used in Poland. The Luvisols cover an area of 50% of Poland. As a result of intensive agricultural use, soils situated on loess slopes are prone to water and tillage erosion. According to the Polish classification slight intensity of the processes of erosion on inclined slopes determines the inclusion of soils in good wheat complex of agricultural suitability, however moderate and strong intensity of soil erosion – in deficient wheat complex.

MATERIALS AND METHODS

The field works on Luvisols developed from loess were conducted in the years 2008–2011, on 4 selected pedons, each classified in three complexes of agricultural suitability of arable soils. In total, the study comprised 12 Luvisols under winter wheat cultivation, situated in various mesoregions of the Lublin Region (Kondracki, 2011):

a) non eroded Luvisols classified into very good wheat (1) complex of agricultural suitability and II valuation class, No.: 1 – Piotrawin 51°19'39"N, 22°26'4"E, 2 – Jastków Kolonia 51°19'40"N, 22°26'28"E, 3 – Tomaszowice 51°17'9"N, 22°26'10"E, 4 – Ługów 51°19'25"N, 22°18'33"E, (Nałęczów Plateau);
b) slightly eroded Luvisols (Świtoniak, 2010) classified into good wheat (2) complex of agricultural suitability and IIIa–IIIb valuation class, No.: 5 – Gutanów 51°20'45"N, 22°17'42"E, 6 – Ludwinów 51°20'15"N, 22°16'55"E, (Nałęczów Plateau), 7 – Wólka Kraśniczyńska 50°55'19"N, 23°22'19"E, 8 – Drewniki 50°54'26"N, 23°22'53"E, (Grabowiec Plateau);
c) moderately eroded Luvisols (Świtoniak, 2010) classified into deficient wheat (3) complex of agricultural suitability and IVa–IVb valuation class, No.: 9 – Kolonia Ługów 51°19'31"N, 22°18'37"E, 10 – Kolonia Gutanów 51°21'4"N, 22°18'37"E, (Nałęczów Plateau), 11 – Poturzyn 50°33'56"N, 23°54'55"E (Sokal Plateau), 12 – Majdan Skierbieszowski 50°53'20"N, 23°23'16"E (Grabowiec Plateau).

The Luvisols selected for the study were situated on private farms, where the share of cereals in crop rotation was most often 75%. The soils were characterised by a low level of organic fertilisation, consisting mainly in ploughing-over of straw. The level of mineral fertilisation applied was varied, with a dominance of nitrogen fertilisers, while liming was applied only rarely.

Soil samples for laboratory analyses were taken in August, when wheat was in the phase of full ripeness or shortly after its harvest. These soil samples were taken in the weight of 1.5–2 kg, from four depths: 0–25 cm (from horizon Ap), 25–50 cm (horizons Et, EB, Bt1 or Bt2), 50–75 cm (horizons Bt1, Bt2 or BC) and 75–100 cm (horizons Bt2, BC or C).

The texture of the soils was determined with the areometric method of Casagrande as modified by Prószyński, separating the sand fraction on sieves with mesh sizes of 1, 0.5, 0.25 and 0.1 mm. The particle size groups were determined in accordance with the classification of the Polish Society of Soil Science of 2008 (PTG, 2009; Komisja V Genezy, Klasyfikacji i Kartografii Gleb PTG, 2011). The content of organic carbon (Corg) was assayed using the analyser Vario Max CNS Elementar, at the Central Laboratory of Chemical Analyses, IUNG, in Puławy. Soil pH in 1 mol $KCl \cdot dm^{-3}$ was measured potentiometrically using a combined electrode.

The aggregate size distribution of the soils ($kg \cdot kg^{-1}$) was determined with the method of screening in air-dry state, using a set of sieves with mesh sizes of 10, 7, 5, 3, 1, 0.5 and 0.25 mm, for soil weighed portions of 500 g, in two replications. The content of water stable soil aggregates ($kg \cdot kg^{-1}$) was determined with the method of screening in water, with the use of the modified Baksheiev apparatus made at the Institute of Agrophysics, Polish Academy of Sciences in Lublin. Weighed portions of soil with mass of 25 g were used (in 4 replications), composed of air-dry aggregates proportionally to their distribution according to size. The weighed portions of soil were placed in a set of sieves with mesh size of 7, 5, 3, 1, 0.5 and 0.25 mm. The aggregates were wetted through capillary rise, and then they were immersed in water. The time of the water screening resulting from movement of the sieves was 12 minutes. Next, the particular fractions of water stable aggregates were moved onto filter paper, dried and weighed. The results obtained for the content of the particular fractions of dry and water stable aggregates were summed up and compiled in Tables 2 and 3. On the basis of the screening, the mean weight diameters of air-dry (MWD_{dry}) and water stable (MWD_{wet}) aggregates were calculated (Kemper and Rosenau, 1986).

The results were subjected to analysis of variance (ANOVA) with the use of the double classification in the completely random system, using the program Statistica 7. The significance of the differences obtained was verified with the Tukey test (least significant differences – LSD – were calculated). Also, calculation was made of the coefficients of simple correlation (r) between the content of air-dry and water stable aggregates and the content of the particular particle size fractions and Corg.

RESULTS

The studied Luvisols developed from loess, classified in the very good wheat complex, contained in their Ap horizons (0–25 cm) 12–16% of sand fraction (2–0.05 mm), 78–79% of silt fraction (0.05–0.002 mm) and 7–8% of clay (<0.002 mm). The Bt horizons (in the depth of 50–100 cm) had a higher content of clay (14–24%) and lower of silt (63–71%). Soils belonging to the good wheat complex and the deficient wheat complex contained in their Ap horizons more of the clay fraction and less silt. In addition, soil No. 7 contained, in the whole pedon, more of the sand fraction (29–30%) and less of the silt fraction than the remaining soils (Table 1). In terms of their particle size distribution, the soils studied were most often loamy silt or clayey silt.

The content of Corg. in the Ap horizons of the soils was, on average, 4.68–9.48 g·kg^{-1}, and in the sub-surface horizons it decreased to 0.72–3.36 g·kg^{-1} (Table 1). The reaction of the studied soils was most frequently strongly acidic, acidic or weakly acidic (pH 4.12–6.24), and only in horizon C, containing calcium carbonate, was an alkaline reaction noted (pH 7.34).

In the aggregate composition of the Ap horizons (0–25 cm) of the studied Luvisols, the average content of air-dry aggregates with sizes of 0.25–10 mm was 0.576 kg·kg^{-1} and it was higher than the content of clods with dimensions >10 mm (0.363 kg·kg^{-1}) and of micro-aggregates with sizes <0.25 mm (Table 2).

TABLE 1. Soil texture, Corg content and pH (range of values from 4 pedons)

Complex	Depth (cm)	Horizon	% fraction with diameter in mm			Corg (g·kg^{-1})	pH KCl
			2–0.05	0.05–0.002	<0.002		
1	0–25	Ap	13–14	78–79	7–8	6.36–9.48	4.27–6.14
	25–50	Et, EB	13–16	66–76	11–19	0.90–3.36	4.54–5.80
	50–75	Bt1	12–16	63–66	18–24	0.84–1.98	4.49–5.25
	75–100	Bt2	12–16	68–71	14–20	0.90–1.86	4.63–5.42
2	0–25	Ap	14–30	62–75	8–16	6.12–6.90	4.48–6.24
	25–50	EB, Bt1	12–30	53–71	14–27	1.44–2.52	5.00–5.39
	50–75	Bt2, BC	13–29	51–71	16–25	0.72–1.32	4.26–5.84
	75–100	Bt2, BC	14–29	51–73	13–24	0.72–0.90	4.20–6.06
3	0–25	Ap	11–14	68–71	15–19	4.68–7.50	4.12–5.79
	25–50	Bt1, Bt2	13–16	66–71	14–21	1.20–2.52	4.25–5.80
	50–75	Bt2, BC	12–17	70–71	13–17	1.32–2.16	4.36–6.10
	75–100	BC, C	11–16	69-74	11–16	0.72–2.40	4.50–7.34

TABLE 2. Air-dry soil aggregate distribution (mean values from 4 pedons)

Complex (C)	Depth (cm) (D)	Air-dry aggregate content of diameter in mm (kg·kg^{-1})							MWDdry (mm)
		>10	5–10	1–5	0,25–1	<0,25	Σ0,25–10	Σ1–10	
1	0–25	0.281	0.170	0.296	0.173	0.080	0.639	0.466	8.4
	25–50	0.354	0.178	0.254	0.138	0.076	0.570	0.432	11.4
	50–75	0.453	0.182	0.225	0.101	0.039	0.508	0.407	13.8
	75–100	0.564	0.137	0.159	0.095	0.045	0.391	0.296	16.4
2	0–25	0.328	0.175	0.264	0.155	0.078	0.594	0.439	9.3
	25–50	0.469	0.185	0.213	0.091	0.042	0.489	0.398	13.2
	50–75	0.604	0.131	0.138	0.086	0.041	0.355	0.269	16.6
	75–100	0.568	0.148	0.160	0.088	0.036	0.396	0.308	16.5
3	0–25	0.481	0.177	0.236	0.082	0.024	0.495	0.413	13.2
	25–50	0.471	0.180	0.205	0.100	0.044	0.485	0.385	14.3
	50–75	0.444	0.148	0.205	0.109	0.094	0.462	0.353	12.4
	75–100	0.474	0.136	0.178	0.121	0.091	0.435	0.314	12.2
Mean	0–25	0.363	0.174	0.265	0.137	0.061	0.576	0.439	10.3
	25–50	0.431	0.181	0.224	0.110	0.054	0.515	0.405	13.0
	50–75	0.500	0.154	0.189	0.099	0.058	0.442	0.343	14.2
	75–100	0.535	0.140	0.166	0.102	0.057	0.408	0.306	15.0
1	mean	0.413	0.167	0.233	0.127	0.060	0.527	0.400	12.5
2		0.492	0.160	0.194	0.105	0.049	0.459	0.354	13.9
3		0.468	0.160	0.206	0.103	0.063	0.469	0.366	13.0
LSD	depths D	0.071	0.025	0.036	0.028	n. s.	0.066	0.054	2.0
($\alpha = 0.05$):	complexes C	0.056	n. s.	0.028	0.022	n. s.	0.052	0.043	n. s.
	interaction D·C	0.112	n. s.	0.056	0.043	0.047	0.104	n. s.	3.1

Explanations: LSD – Tukey's least significant difference, n. s. – non significant differences.

The Ap horizons were characterised by a significantly greater content of aggregates of 0.25–10 mm (by an average of 0.134–0.168 kg·kg^{-1}) compared to the sub-surface horizons (in the depth of 50–100 cm), including a higher content of aggregates of 1–10 mm, 1–5 mm and 0.25–1 mm. Whereas, the sub-surface horizons in the depth of 50–100 cm (especially Bt1 and Bt2 horizons) had a significantly higher content of clods with sizes >10 mm (by 0,137–0,172 kg·kg^{-1}). As a result, the MWD$_{dry}$ in the Ap horizons was 8.4–13.2 mm and it was significantly smaller than in horizons Bt (13.8–16.6 mm).

The Luvisols classified in very good wheat complex were characterised by a significantly higher content of air-dry aggregates with dimensions of 0.25–10 mm (by an average of 0.068 kg·kg^{-1}) compared to the soils of the good wheat complex, including a greater content of aggregates of 1–10 mm, 1–5 mm and 0.25–1 mm, and a smaller content of clods >10 mm (by 0.079 kg·kg^{-1}) (Table 2). The soils from the very good wheat complex had also a significantly higher content, compared to the soils from the deficient wheat complex, of aggregates with sizes of 0.25–10 mm (by an average of 0.058 kg·kg^{-1}), including aggregates of 0.25–1 mm.

During the water screening, the air-dry soil aggregates disintegrated into finer fractions, mainly microaggregates with sizes <0.25 mm and aggregates of 0.25–1 mm (Table 3). The average content of water stable aggregates with sizes of 0.25–10 mm in the Ap horizons of the soils was 0.532 kg·kg^{-1} and it was significantly higher than in the sub-surface horizons (0.161–0.273 kg·kg^{-1}). Significantly higher in the Ap horizons than in the depth of 25–100 cm was, especially, the content of stable aggregates with dimensions of 1–10 mm (by 0.223-0.248 kg·kg^{-1}), i.e. 5–10 mm, 1–5 mm and 0.25–1 mm. In horizons Et, EB, Bt BC and C, microaggregates with dimensions <0.25 mm, as products of disintegration of larger fractions, constituted as much as 0.703–0.892 kg·kg^{-1}. As a result, the WMD$_{wet}$ in the Ap horizons was, on average, 1.37 mm and it was significantly greater than in the subsoil (0.23–0.32 mm).

In the soils of the very good wheat and good wheat complexes the content of stable aggregates with sizes of 0.25–10 mm was significantly higher than in the soils from the deficient wheat complex, specially in the Ap horizons (by 0.106–0.142 kg·kg^{-1}) (Table 3). In the soils from the very good wheat and good wheat, a significantly higher content was noted in the case of stable aggregates of 1–10 mm (on average by 0.022–0.049 kg·kg^{-1}), including especially those of 0.25–1 mm. The MWD$_{wet}$ in the Ap horizons of the

TABLE 3. Water stable soil aggregate distribution (mean values from 4 pedons)

Complex (C)	Depth (cm) (D)	Water stable aggregate contentof diameter in mm (kg·kg^{-1})					Microaggregates <0,25 mm (kg·kg^{-1})	MWD$_{wet}$ (mm)
		5–10	1–5	0.25–1	Σ0.25–10	Σ1–10		
1	0–25	0.095	0.178	0.282	0.555	0.273	0.445	1.37
	25–50	0.005	0.033	0.259	0.297	0.038	0.703	0.32
	50–75	0.002	0.021	0.205	0.228	0.023	0.772	0.25
	75–100	0.001	0.023	0.165	0.189	0.024	0.811	0.23
2	0–25	0.157	0.220	0.213	0.590	0.377	0.410	1.93
	25–50	0.002	0.048	0.244	0.294	0.050	0.706	0.33
	50–75	0.000	0.019	0.225	0.244	0.019	0.756	0.24
	75–100	0.000	0.017	0.170	0.188	0.018	0.812	0.22
3	0–25	0.040	0.120	0.290	0.449	0.160	0.551	0.81
	25–50	0.007	0.043	0.174	0.224	0.050	0.776	0.32
	50–75	0.005	0.027	0.095	0.127	0.032	0.873	0.25
	75–100	0.003	0.022	0.083	0.108	0.025	0.892	0.23
Mean	0–25	0.097	0.173	0.262	0.532	0.270	0.468	1.37
	25–50	0.005	0.042	0.226	0.273	0.047	0.727	0.32
	50–75	0.002	0.023	0.175	0.200	0.025	0.800	0.25
	75–100	0.001	0.021	0.139	0.161	0.022	0.839	0.23
1	mean	0.025	0.064	0.228	0.317	0.089	0.683	0.54
2		0.040	0.076	0.213	0.329	0.116	0.671	0.68
3		0.014	0.053	0.160	0.227	0.067	0.773	0.40
LSD	depths D	0.015	0.016	0.031	0.038	0.022	0.038	0.13
(α = 0.05)	complexes C	0.012	0.013	0.024	0.030	0.018	0.030	0.10
	interaction D×C	0.024	0.025	0.049	n. s.	0.036	n. s.	0.20

Explanations: LSD – Tukey's least significant difference, n. s. – non significant differences.

soils from the good wheat complex (1.93 mm) was significantly larger than in the Ap horizons of the soils from the good wheat (1.37 mm) and the deficient wheat complex (0.81 mm).

Statistical analysis revealed that in the studied population of soils the content of air-dry aggregates with sizes of 0.25–10 mm was closely and positively correlated with the content of silt of 0.05–0.002 mm (r = 0,45) and with the content of Corg (r = 0.52) (Table 4). A close and positive correlation with the content of silt was also noted for the content of aggregates of 1–5 mm (r = 0.47) and 0.25–1 mm (0.45), and a weak correlation – for the content of aggregates of 1–10 mm (r = 0.34). In addition, a close and positive correlation with the content of Corg was found for the content of air-dry aggregates of 1–5 mm (r = 0.57) and 1–10 mm (r = 0.49), and a weak correlation – for the content of aggregates of 0.25–1 mm (r = 0.34). Whereas, the content of clods >10 mm was closely correlated with the content of clay (r = 0.67), as was the MWD_{dry} (r = 0.66).

The content of all water stable aggregate fractions correlated closely and positively with the content of Corg. (r = 0.45–0.86) (Table 4). The highest values of the coefficients of correlation were characteristic of stable aggregates with sizes of 1–5 mm (r = 0.86) and 1–10 mm (r = 0.85). Moreover, the content of water stable aggregates of 1–5 mm and 1–10 mm was weakly positively correlated with the content of silt (r = 0.30 and r = 0.31, respectively). Also the MWD_{wet} was closely and positively correlated with the content of Corg (r = 0.82) and weakly correlated with the content of silt (r = 0.29).

TABLE 4. Correlation coefficients (r) between content of granulometric fractions, Corg and aggregate size distribution and water stable aggregate content (n = 48)

Variable	Content of fractions (%)			Corg ($g \cdot kg^{-1}$)
	2–0.05 mm	0.05–0.002 mm	<0.002 mm	
Air-dry aggregates ($kg \cdot kg^{-1}$)				
>10 mm	0.14	-0.57**	0.67**	-0.48**
5–10 mm	-0.06	0.03	0.03	0.23
1–5 mm	-0.24	0.47**	-0.42**	0.57**
0.25–1 mm	0.07	0.47**	-0.74**	0.34*
<0.25 mm	-0.06	0.49**	-0.63**	0.05
Σ0.25–10 mm	-0.13	0.45**	-0.50**	0.52**
Σ1–10 mm	-0.19	0.34*	-0.28	0.49**
MWDdry	0.16	-0.59**	0.66**	-0.50**
Water stable soil aggregates ($kg \cdot kg^{-1}$)				
5–10 mm	0.16	0.28	-0.58**	0.74**
1–5 mm	0.07	0.30*	-0.50**	0.86**
0.25–1 mm	0.09	-0.12	0.08	0.45**
Σ0.25–10 mm	0.13	0.16	-0.37**	0.84**
Σ1–10 mm	0.11	0.31*	-0.56**	0.85**
MWD_{wet}	0.14	0.29*	-0.57**	0.82**

Explanations: * significance level $\alpha = 0.05$, ** significance level $\alpha = 0.01$.

DISCUSSION

The presented results demonstrate a considerable variation in the aggregate composition and the content of water stable aggregates, both among the Luvisols classified in the particular soil suitability complexes and among the horizons within the pedons. The higher content of air-dry aggregates with sizes of 0.25–10 mm in the Ap horizons compared to the sub-surface horizons Et, EB, Bt and BC was a result of higher content of Corg and lower content of clay fraction <0.002 mm. Whereas, the higher content of clay in horizons Bt and BC was conducive to stronger lumping of the soil mass.

The reason of the deterioration of soil structure in Luvisols classified in the good wheat and deficient wheat complexes was accelerated soil erosion. As a result of slight and moderate erosion classes, when cultivation reached Bt horizon enriched with clay, the content of air-dry clods with sizes >10 mm increased, and the content of air-dry soil aggregates 0.25–10 mm decreased.

The content of air-dry aggregates with sizes of 1–10 mm was considered to be the best criterion for the estimation of quality of the aggregate size distribution of the soils of Poland (Paluszek, 2011b). The following ranges of aggregate sizes were determined as the limit values: at the content of <0.150 $kg \cdot kg^{-1}$ – the aggregate size distribution was assessed as very unfavourable, in the range of 0.150–0.250 $kg \cdot kg^{-1}$ – as an unfavourable, 0.250–0.350 $kg \cdot kg^{-1}$ – medium favourable, 0.350–0.450 $kg \cdot kg^{-1}$ – favourable, and >0.450 $kg \cdot kg^{-1}$ – very favourable aggregate size distribution. According to that classification, the aggregate size distribution of the Ap horizons of the soil classified in the very good wheat complex was estimated as very favourable, and the composition of the Ap horizons of the soils from the good wheat and the deficient wheat complexes – as favourable. Also the sub-surface horizons in the depth of 25–75 cm had a favourable aggregate size distribution, while in the depth of 75–100 cm – medium favourable.

The decidedly higher content of water stable aggregates with sizes of 0.25–10 mm in the Ap horizons compared to the sub-surface horizons Et, EB, Bt, BC and C (in the depth of 25–100 cm) resulted from the notably higher content of Corg, including organic compounds stabilising aggregates. These include microbiological and plant polysaccharides, plant roots, mycelium hyphae and certain fungi (Bronick and Lal, 2005; Malamoud et al., 2009, Tobiašová and Miškolczi, 2012). The most persistent binding organic compounds are composed of aromatic humic substances, bound within aggregates with polyvalent cations of metals, and of strongly absorbing polymers originating from resistant fragments of roots, mycelium hyphae and bacterial cells.

The sum of water resistant aggregates with sizes of 1–10 mm characterises the best the stability of aggregates of the soils of Poland (Paluszek, 2011b). Based on that criterion, the limit values for the estimation of water stability of aggregates were adopted as follows: <0.070 kg·kg^{-1} – very poor water stability, 0.070–0.150 kg·kg^{-1} – poor water stability, 0.150–0.250 kg·kg^{-1} – medium water stability, 0.250–0.400 kg·kg^{-1} – good water stability, and >0.400 kg·kg^{-1} – very good water stability. According to that classification, the water stability of aggregates in Ap horizons of Luvisols developed from loess, classified in very good wheat and good wheat complexes, was estimated as good, and in the Ap horizons of soils from deficient wheat complex – as medium. Whereas, the water stability of aggregates in the sub-surface horizons Et, EB, Bt, BC and C was assessed as very poor. Le Bissonnais (1996) presented a classification of soil aggregate stability studying the relation between water resistance and soil surface crusting and water erosion. He determined the following ranges of values: at MWD$_{wet}$ <0.4 mm – aggregates are highly unstable, 0.4–0.8 mm – unstable aggregates, 0.8–1.3 mm – medium stable aggregates, 1.3–2.0 mm – stable aggregates, and >2.0 mm – very stable aggregates. According to that classification, aggregates from the Ap horizons of the studied soils from very good wheat and good wheat complexes can be estimated as stable, aggregates from the Ap horizons of soils from deficient wheat complex – as medium stable, and aggregates from the sub-surface horizons as highly unstable. The estimation of the stability of aggregates on the basis of MWD$_{wet}$ values is in agreement with the estimation on the basis of the content of water stable aggregates with sizes of 1–10 mm presented above.

The higher content of water stable aggregates in the Ap horizons of soils from good wheat complex than of soils from very good wheat complex may result from the varied crop rotation and soil fertilisation over the past several or more years. Under field conditions, organic and mineral fertilisation and the inclusion of legumes and grasses in the crop rotation have a highly favourable effect on the stability of soil aggregates (Lenart, 2002; Ball et al., 2005; Bronick and Lal, 2005; Pranagal, 2011). The effect of those treatments persists in the soil for several years and it can have a decisive effect on the higher water stability of aggregates of the soils classified in good wheat complex. Whereas, in the Ap horizons of the soils of deficient wheat complex, formed from the illuvial horizon as a result of moderate water and tillage erosion on slopes, next to aggregates formed naturally there are aggregates of the crumb type, formed as a result of crumbling of coherent soil mass by the working elements of the plough and other tillage implements (Dexter and Birkas, 2004). Aggregates of the crumb type, both clods with sizes of >10 mm and macro-aggregates of 0.25–10 mm, are not resistant to the effect of water and disintegrate, in their vast majority, into microaggregates of <0.25 mm. Moderate and strong erosion of soils developed from loess, under agricultural use, causes a significant decrease of water-stable soil aggregate content with sizes 0.25–10 mm (Paluszek, 2010).

The Luvisols developed from loess were characterised by better aggregate structure compared to Luvisols developed from loamy sands (Rząsa and Owczarzak, 2004). Values of aggregate size distribution and water stability aggregate content similar to those of the soils under study were found for Luvisols developed from boulder loams (Otremba, 2011; Paluszek, 2013). Whereas, compared to Chernozems developed from loess, Fluvisols (Pranagal, 2011; Šimanský, 2012; Tobiašová and Miškolczi, 2012), Histosols (Orzechowski et al., 2011) and Phaeozems developed from silt deposits (Paluszek, 2011a), the aggregate size distribution and water stability values of the soils studied were lower. Phaeozems developed from silt deposits were characterised by the highest content of water stable aggregates with sizes of 0.25–10 mm (>0.800 kg·kg^{-1}) and 1–10 mm (>0.600 kg·kg^{-1}).

The differences in the soil texture and organic matter content have the strongest effect on aggregate-size distribution and content of water-stable aggregates 0.25–10 mm. Most favourable aggregation was found in soils characterized by silt and silt loam texture. However, the highest content of water-stable aggregates 0.25–10 was observed in soils containing above 3% organic mater in Ap horizon.

CONCLUSIONS

1. The aggregate size distribution of the Ap horizons of Luvisols developed from loess was characterised by a significantly higher content of air-dry aggregates with sizes of 0.25–10 mm, including aggregates of 1–5 mm, compared to horizons Et, Bt, BC and C (in the depth of 25–100 cm), and a lower content of clods >10 mm and smaller MWD_{dry}.
2. Luvisols from the very good wheat complex, compared to the soils from the good wheat complex, had a significantly higher content of air-dry aggregates with sizes of 0.25–10 mm, including aggregates of 1–10 mm, 1–5 mm and 0.25–1 mm, and a lower content of clods of sizes >10 mm. The soils from the very good wheat complex had also a significantly higher content, compared to the soils from the deficient wheat complex, of aggregates of sizes of 0.25–10 mm, including aggregates of 0.25–1 mm.
3. The aggregate size distribution of Ap horizons of soils classified in the very good wheat complex was estimated to be highly favourable, and that of Ap horizons of the soils from good wheat and deficient wheat complexes as favourable. The aggregate size distribution in the depth of 25–75 cm was estimated as favourable, and in the depth l of 75–100 cm – as medium favourable.
4. The content of water stable aggregates with sizes of 0.25–10 mm, including stable aggregates with sizes of 1–10 mm, 5–10 mm and 1–5 mm, and the MWD_{wet}, were significantly higher in the Ap horizons of the soils than in the subsoil.
5. The soils of the very good wheat and good wheat complexes, especially in the Ap horizons, were characterised by significantly higher contents of stable aggregates with dimensions of 0.25–10 mm than the soils from the deficient wheat complex, including a significantly higher content of stable aggregates with sizes of 1–10 mm and 0.25–1 mm.
6. The water stability of aggregates in Ap horizons of soils classified in very good wheat and good wheat complexes was estimated as good, and in the Ap horizons of the soils from deficient wheat complex as medium. Whereas, the water stability of aggregates from the Et, Bt, BC and C horizons was estimated as very poor.

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Received: May 29, 2013
Accepted: August 19, 2013

Streszczenie: Celem pracy była ocena składu agregatowego i wodoodporności agregatów w glebach płowych wytworzonych z lessu, zaliczanych do trzech kompleksów przydatności rolniczej: pszennego bardzo dobrego (1), pszennego dobrego (2) i pszennego wadliwego (3). Gleby należące do kompleksu pszennego bardzo dobrego zawierały istotnie więcej powietrznie suchych agregatów o wymiarach 0,25–10 mm od gleb kompleksu pszennego dobrego i pszennego wadliwego. Skład agregatowy poziomów Ap gleb kompleksu pszennego bardzo dobrego oceniono jako bardzo korzystny, a skład poziomów Ap gleb kompleksu pszennego dobrego i pszennego wadliwego jako korzystny. Skład agregatowy poziomów podpowierzchniowych w warstwie 25–75 cm oceniono jako korzystny, natomiast w warstwie 75–100 cm jako średnio korzystny. Gleby kompleksu pszennego bardzo dobrego charakteryzowały się istotnie większą zawartością trwałych agregatów o wymiarach 0,25–10 mm i 1–10 mm niż gleby kompleksu pszennego wadliwego. Wodoodporność agregatów w poziomach Ap gleb zaliczanych do kompleksu pszennego bardzo dobrego i dobrego, oceniono jako dobrą, a w poziomach Ap gleb kompleksu pszennego wadliwego jako średnią. Natomiast wodoodporność agregatów w poziomach Et, Bt, BC i C oceniono jako bardzo słabą. Przyczyną pogorszenia składu agregatowego i zmniejszenia zawartości wodoodpornych agregatów o wymiarach 0,25–10 mm, zwłaszcza w glebach płowych zaliczanych do kompleksu pszennego wadliwego, była przyspieszona erozja gleb.