FOLIA GEOGRAPHICA
SERIES GEOGRAPHICA-PHYSICA
Vol. XL 2009: 91–103
ISSN 0071-6715

WATER AND AIR PROPERTIES OF ERODED LOESS SOILS OF THE PROSZOWICE PLATEAU

Marcin Żyła

Institute of Geography and Spatial Management, Jagiellonian University, Kraków, Poland
marcin.zyla@uj.edu.pl

Loess-based soils are characterized by high agricultural value and have been cultivated since the Neolithic. Intensive agricultural activity has transformed these soils, especially due to intensified erosion processes. The aim of this paper is to present the basic water and air properties of the investigated soils, namely: soil solid phase density, bulk density, capillary water capacity, total porosity, and air capacity. The research presented herein includes chernozems at different stages of erosion-based transformation compared to strongly eroded initial loess soils from the Proszowice Plateau. Erosion processes in the research area have brought about a transformation of soil profile morphology and have partially influenced its water and air properties. The most important transformation in initial loess soils is the lack of subsurface transition horizons which offer the best conditions for plant growth and play a very important role in supplying water and air to plants. The research presented herein shows that during the analysis of the physical properties of surface horizons (Ap, Akp), care needs to be taken to account for the period of sampling due to seasonal agricultural activity that affects soil's physical properties. In the deeper soil horizons, this is not an important issue as agricultural activity is performed at limited depths (ca. 20–35 cm).

Key words: initial loess soils, chernozems, erosion, water and air properties

1. INTRODUCTION

The nature of loess as a parent material of soils becomes apparent in their intrinsic properties such as their water and air properties. All soils located in loess regions are classified as top grade for agricultural purposes (Borowiec 1965, 1966; Klimowicz, Uziak 2001; Licznar, 1985; Olszewski *et al.* 1965; Turski 1985). These soils have been cultivated by man since the Neolithic period (Kruk 1972; Kruk *et al.* 1996; Valde-Nowak 2004). This activity has contributed to the evolution of these soils where anthropogenic processes have affected natural processes or have caused their substantial acceleration (Skiba & Kołodziejczyk 2004). An example of an accelerated natural process is erosion in the agricultural regions of loess highlands such as the Proszowice Plateau in south-central Poland. Such processes lead to a gradual reduction in thickness of the soil profile as a result of progressive denudation of the soil cover. Years of agricultural activity lead to degradation of a natural soil structure within the layer of soil affected by mechanical agricultural activity. These soils experience slow changes in the morphology of the soil profile and its physical properties. Soils in eroded loess regions can be classified into two groups based on degrees of change: 1. initial loess soils (siltosols) eroded to the point where the plough zone includes parent material; 2. chernozems characterized by different degrees of soil degradation. These chernozems include typical (haplic) chernozems, chernozems with an *agric* horizon, chernozems with a *cambic* horizon, chernozems with an *argillic* horizon, and eroded chernozems (Żyła 2007).

The impact of agricultural activity (cultivation) on the physical properties of soils is not unidirectional. Soils are ploughed on the one hand and compacted by wheels on the other. Both processes affect the physical properties of topsoil. The water and air properties of surface soil horizons are characterized by significant differences over time and across space even within the same area. On the other hand, subsurface horizons of particular solis are beyond the reach of agricultural cultivation are characterized by much more balanced and standarized physical properties.

The purpose of this work is the analysis of the water and air properties of chernozems at different stages of erosion and soil degradation (typical chernozems, chernozems with an *agric* horizon, eroded chernozems) with a comparison to the highly eroded initial loess soils of the Proszowice Plateau.

2. MATERIALS, SCOPE, AND METHODS

The research included 19 soil profiles located within the Proszowice Plateau. Detailed water and air analysis was performed on the soils of 13 of the 19 profiles. The profiles are located in the vicinity of Boronice, Słonowice, Witów, and Wymysłów (Fig. 1).

The selected soil profiles are representative of locations where topsoil erosion and denudation processes play a significant role. These locations include hilltops as well as high, middle, and convex sections of slopes. The soil profiles were described in accordance with Polish Society of Soil Science (1989) guidelines. Each sample was analyzed for: soil texture using the hydrometer method, organic carbon content using the dichromate Tyurin method, and carbonate content using Scheibler's volumetric method. Undisturbed samples in 100 cm^3 steel

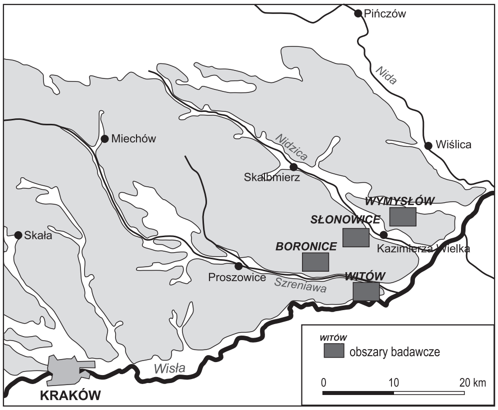

Fig. 1. Location of research area within the Miechów–Proszowice loess belt

cylinders were taken for water and air properties analysis using the Kopecky Method. Basic physical properties were determined, such as bulk density, capillary water capacity, total porosity, and air capacity. Solid phase density was determined using the pycnometric method. The results presented in Tables 1 and 2 are mean values based on 2 to 4 determinations for each soil horizon. Statistical analysis was performed using the Statistica® 8.0 package.

3. RESULTS

SOLID PHASE DENSITY

The solid phase density of soil depends primarily on its mineral composition and organic matter content. Organic matter content did not exceed 3.3% (Żyła 2007) in the soil samples that were analyzed, therefore, its impact on solid phase density was insignificant. The solid phase density of all the analyzed soils ranged from 2.55 to 2.69 Mg·m^{-3}. Such relatively close values result from similar mineral composition in the solid phase which suggests that the loess soils in question are quite homogeneous. These youngest of loess formations have their origins in the same geological period (Jersak 1973) and the same section of the Miechów-Proszowice loess belt. The main mineral constituent in the soils analyzed was quartz whose density is 2.65 Mg·m^{-3}. This value reflects the soils analyzed whose mean solid phase density is 2.64 Mg·m^{-3}.

BULK DENSITY

The bulk density (dry state – soil dried at 105°C to achieve a constant mass) of ploughed chernozem horizons is low and ranges from 1.21 Mg·m^{-3} to 1.45 Mg·m^{-3} (Tab. 1). Its highest value (1.45 Mg·m^{-3}) was determined in the surface horizons of eroded chernozems (Słonowice 3 i Słonowice 4) while its lowest values (under 1.30 Mg·m^{-3}) were noted in typical chernozems and those with an *agric* horizon (Fig. 2). In initial loess soils (Tab. 2), bulk density of Akp horizons ranged from 1.25 Mg·m^{-3} to 1.65 Mg·m^{-3} (Fig. 2).

The lowest chernozem bulk density is characteristic of A/C and C/A transition horizons featuring high levels of mesofaunal and megafaunal biological activity in the soil. This type of activity leads to numerous bioturbations. The bulk density of these horizons in typical and eroded chernozems is very similar and ranges from 1.22 to 1.36 Mg·m^{-3}. In chernozems with an *agric* horizon, the corresponding horizons are designated E/Bt and Bw. The bulk density of these two horizons is about 1.30 Mg·m^{-3} (Fig. 2).

Carbonate-containing loess occurs beneath transition horizons in chernozems and beneath surface horizons in initial loess soils. Its bulk density is clearly higher therein than in the transition horizons described above (Fig. 2). In the soils analyzed herein, its bulk density ranged from 1.45 to 1.50 Mg·m^{-3} (Tabs. 1 and 2).

Table 1. Chernozems – water and air properties.

Horizon	Depth	Solid phase density	Bulk density	Capillary water capacity	Porosity	Air capacity
	cm	Mg·m^{-3}	Mg·m^{-3}	% vol.	% vol.	% vol.
		Słonowice 1 (typical chernozem)				
Ap	0–35	2.55	1.40	42.4	45.0	2.6
A/C	35–55	2.60	1.27	45.2	51.1	5.9
Ck/A	55–90	2.63	1.35	43.1	48.6	5.5
Ck1	90–125	2.63	1.39	43.2	47.1	3.9
		Słonowice 6 (typical chernozem)				
Ap	0–35	2.60	1.38	42.1	46.9	4.8
A/C	35–55	2.60	1.25	44.8	52.1	7.3
C/A	55–70	2.66	1.22	46.5	54.0	7.5
Ckcg1	70–100	2.66	1.42	42.9	46.5	3.6
		Witów 04 (typical chernozem)				
Ap	0–28	2.66	1.29	42.6	51.4	8.8
A	28–45	2.61	1.37	42.6	47.3	4.7
A/C1	45–60	2.64	1.32	43.8	49.9	6.1
Ck/A	82–92	2.70	1.32	45.3	50.9	5.6
Ckcg	92–160	2.62	1.48	45.7	43.3	2.3
		Boronice 4 (chernozem with an *agric* horizon)				
Ap	0–28	2.58	1.21	49.1	53.0	3.9
ABth	28–38	2.60	1.33	43.9	49.1	5.2
E/Bt	38–60	2.58	1.28	46.3	50.9	4.7
Bw	60–78	2.63	1.30	47.2	50.2	3.0
Ck	78–110	2.63	1.39	45.6	46.8	1.2
Ckg	110–130	2.63	1.46	44.7	44.5	-0.2
Ckcg	130–160	2.63	1.46	45.5	44.6	0.9
		Słonowice 3 (eroded chernozem)				
Ap	0–25	2.60	1.45	40.7	44.5	3.8
C/A	25–35	2.63	1.34	43.2	49.2	6.0
Ck1	35–75	2.63	1.43	44.3	46.1	1.9
Ck2	75–90	2.63	1.45	43.8	45.1	1.3
Ckg	90–120	2.63	1.46	45.1	44.5	-0.6
Ckcg	120–135	2.69	1.44	44.5	46.4	1.9
		Słonowice 4 (eroded chernozem)				
Ap	0–22	2.58	1.45	41.4	44.0	2.6
A/C	22–32	2.63	1.36	42.6	48.0	5.4
C/A	32–46	2.63	1.24	46.0	52.9	6.9
Ckg	46–55	2.66	1.43	43.7	46.2	2.5
Ckcg1	55–75	2.60	1.53	43.3	41.2	-2.1
Ckcg2	75–100	2.66	1.50	44.2	43.6	-0.6

Table 2. Initial loess soils – water and air properties

Horizon	Depth	Solid phase density	Bulk density	Capillary water capacity	Porosity	Air capacity
	cm	Mg·m^{-3}	Mg·m^{-3}	% vol.	% vol.	% vol.
Boronice 1						
Akp	0–23	2.66	1.46	44.0	45.1	1.1
Ck	23–50	2.69	1.44	46.8	46.3	-0.5
Ckg1	50–90	2.69	1.45	46.3	46.2	-0.1
Ckg2	90–150	2.69	1.47	45.5	45.5	0.0
Słonowice 2						
Akp	0–20	2.63	1.65	33.7	36.3	2.6
Ck	20–40	2.58	1.39	42.3	46.2	3.9
Ckg1	40–100	2.60	1.49	42.9	42.9	0.0
Ckg2	100–150	2.63	1.60	39.9	39.4	-0.5
Ckg3	150–175	2.63	1.55	43.0	41.3	-1.7
Słonowice 5						
Akp	0–25	2.63	1.40	39.5	47.1	7.6
Ck	25–55	2.63	1.47	42.4	44.2	1.8
Ckg	55–90	2.66	1.45	45.4	45.6	0.2
Słonowice 7						
Akp	0–25	2.66	1.38	40.3	48.1	7.8
Ck	25–35	2.66	1.46	40.8	45.0	4.3
Ckg	35–70	2.66	1.45	41.1	45.4	4.3
Crkc	70–150	2.66	1.51	40.1	43.2	3.1
Witów 05						
Akp	0–20	2.66	1.45	42.2	45.1	2.9
Ck	20–50	2.66	1.54	38.5	42.3	3.8
Ckg1	50–100	2.69	1.53	39.2	43.2	4.0
Ckg2	100–160	2.66	1.57	37.3	41.0	3.7
Wymysłów 1						
Akp	0–20	2.63	1.25	46.3	52.3	6.1
Ck	20–45	2.66	1.41	45.2	47.1	1.9
Ckg1	45–80	2.66	1.56	43.9	41.4	-2.5
Ckg2	80–150	2.69	1.49	44.1	44.5	0.4
Wymysłów 2						
Akp	0–25	2.66	1.35	43.4	49.4	6.1
Ck	25–55	2.69	1.56	41.6	42.1	0.5
Ckg	55–150	2.69	1.52	44.5	43.5	-1.0
2Ckg	150–165	2.69	1.52	42.3	43.5	1.2

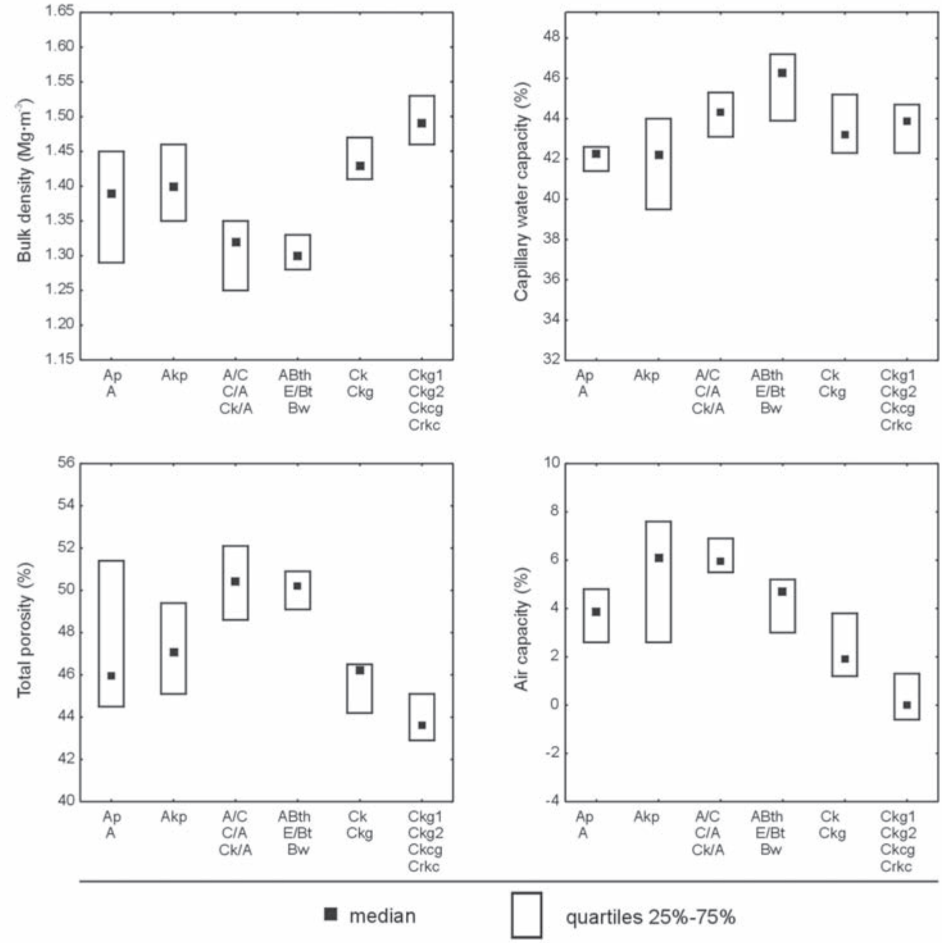

Fig. 2. Median value as well as upper and lower quartiles for analyzed water and air properties of soils based on genetic horizons

CAPILLARY WATER CAPACITY

Capillary water capacity is given as a percentage of the volume of the soil sample occupied by water held within the sample by capillary forces after gravitational water has drained away. This indicator is very important in terms of the water supply for plant roots. Capillary water capacity indicates how much water is available to plants and can remain in the soil for longer periods of time without rain. The capacity values obtained are presented in Tables 1, 2 and Figure 2.

The lowest capillary water capacity values in typical and eroded chernozems were noted in their ploughed horizons (39.4–42.6%). Capillary water capacity in the ploughed horizons of initial loess soils is quite variable. In some soils, capacity values in surface horizons are the highest within a given profile while the opposite is true in others. Soil profiles in Słonowice 2 and Wymysłów 1 are examples of extreme cases with capacity values at 33.7% vol. and 46.3% vol., respectively. These two profiles are also examples of other extreme values: highest (1.65 Mg·m^{-3}) and lowest (1.25 Mg·m^{-3}) bulk densities, respectively. This variability is a consequence of variable soil sampling periods – samples were collected both before and after ploughing. Seasonal activities such as ploughing or harrowing have a substantial impact on the physical properties of surface horizons. This problem does not affect deeper horizons so much as they are beyond the reach of most farm equipment (usually 20–35 cm). This is confirmed by the substantially smaller quartile range (25–75%) within the A/C and C/A horizons (Fig. 2). Capillary water capacity is clearly higher within deeper horizons of chernozem profiles (Tab. 1). In this case, capillary water capacity values range from 42.6% vol. to 46.5% vol. with a mean value at around 44% vol.

TOTAL POROSITY

Total porosity in the soils analyzed is a characteristic which differentiates soil profiles as well as genetic horizons within particular profiles. Ploughed-humus horizons of eroded chernozems (Słonowice 3 and Słonowice 4 profiles) stand out among chernozems in terms of their low porosity (about 44% vol.). In chernozems with an *agric* horizon (Boronice 4) and those which are classified as typical (Witów 4), total porosity in ploughed horizons exceeds 50%.

In strongly eroded siltosols, ploughed-humus horizons are the most porous within their given profile (Fig. 2). Total porosity in Akp horizons usually amounts to less than 48% while in exceptional cases, it equals only 36.3% (Słonowice 2).

A/C and C/A transition horizons are the most porous horizons in the eroded and typical chernozems analyzed herein. Their corresponding horizons in chernozems with an *agric* horizon are E/Bt and Bw. Total porosity in these particular horizons ranges from 48% vol. to 54% vol. with a mean value at about 51%. These values are also higher than those determined in surface (ploughed) horizons where the soil is periodically loosened by cultivation activities (Fig. 2).

Porosity is several percentage points lower within the parent material – carbonate loess – and in the chernozems analyzed, it was equal to 45% vol. on average. In initial loess soils, the values for parent material were quite similar.

AIR CAPACITY

Air capacity or the difference between total porosity and capillary water capacity is expressed in percent of volume. With the Kopecky Method, this means volume of soil pores which are filled with air after gravitational water drains but assuming that the soil is fully saturated with capillary action water.

In the ploughed horizons of chernozems, air capacity ranges from 2.6% vol. to 4.8% vol. (in some cases 8.8% vol.). In the deeper transition horizons A/C and C/A, mean values of air capacity hover around 6.2% vol. (range: 5.4% vol. to 7.5% vol.). A marked drop in air capacity occurs at the point where horizons affected by pedogenic processes meet horizons of parent material (Fig. 2).

In initial loess soils, the highest values of air capacity occur most often in loosened ploughed horizons, ranging from a low 1.1% vol. to a high 7.8% vol. (Tab. 2). Air capacity is markedly lower in subsurface parent material horizons as it is in corresponding chernozem horizons.

Certain negative values of air capacity result from problems with the method used. Porosity is calculated after a sample has been dried at 105°C while capillary water capacity using a wet sample. While the soil is being saturated, some samples of intact loess have a tendency to expand. In effect, the soil occupies more space than the original volume of the 100 cm^3 steel cylinder. This is caused by the presence of clay minerals which expand in moist environments (Turski *et al.* 1974).

4. DISCUSSION OF RESULTS

Analysis of water and air properties include all genetic horizons present in the soils of interest. These horizons can be grouped into three classes based on physical properties: surface horizons (ploughed-humus Ap and Akp horizons), subsurface transition horizons (A/C, C/A, and E/Bt), and parent material (loess) horizons (Ck, Ckg, and Crkc) which have been little altered by pedogenetic processes.

Surface horizons in all the soils analyzed (Tabs. 1 and 2) are, on the one hand, loosened by ploughing and other cultivation activities and, on the other, compressed by the weight of wheels of farm machinery. In order to properly interpret the water and air properties of surface horizons, it is important to note the dates of soil sampling, keeping in mind the effects of soil cultivation and compression.

According to Turski *et al.* (1986), the bulk density of loess soil can change from 1.06 $Mg \cdot m^{-3}$ right after ploughing to 1.40 $Mg \cdot m^{-3}$ after a wheat harvest to 1.69 $Mg \cdot m^{-3}$ after being run over by vehicle wheels. This explains why the physical properties of surface horizons exhibit such a wide range of values. Generally, however, larger differences in bulk density values can be observed in eroded loess soils than in chernozems. This is the result of stronger degradation of natural soil structure in eroded soil regions which has a direct effect on bulk density and total porosity. A weaker general structure and lower humus content make it easier to compress highly eroded soils whose bulk density in surface horizons can reach 1.65 $Mg \cdot m^{-3}$ while in chernozems, it does not exceed 1.45 $Mg \cdot m^{-3}$. Total porosity has a strong negative correlation with bulk density in the soils analyzed (Fig. 3). The soils analyzed possess a high total porosity which can be considered a mean value for loess soils in southern Poland for which J. Borowiec (1970) reported a range of values 40.7–48.7% vol.

There exist significant differences between porosity levels of particular genetic soil horizons. Eroded chernozems are the least porous among surface horizon chernozems. Their low porosity is most likely the effect of natural coprolite-based humus horizons being dislodged by erosion and denudation processes. Eroded chernozems (Słonowice 3, Słonowice 4) surface horizons, despite having the highest humus content, are less porous than subsurface transitional horizons. This is mainly the result of general degradation of natural soil structure caused by long-term agricultural activity. The soil structure of these horizons changes gradually from a coprolite and crumb structure to a sub-angular or even an angular structure with coprolite and crumb structure present in some locations (Żyła 2007).

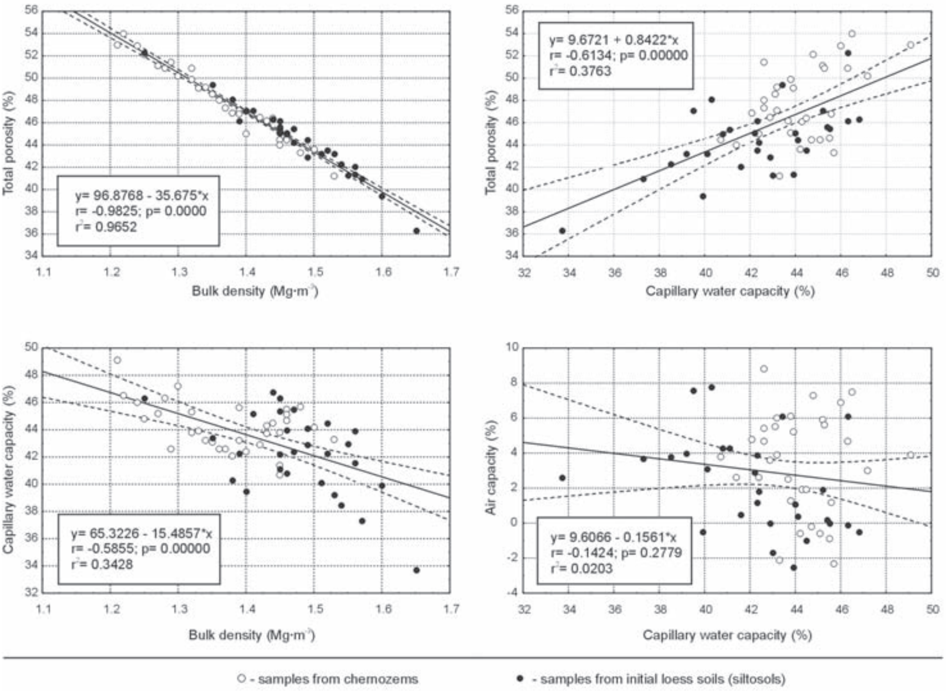

Fig. 3. Correlation between selected water and air properties in the chernozems and loess soils analyzed (significance: p= 0.95)

In eroded loess soils, ploughed-humus horizons are the most porous within their respective soil profiles. This is the effect of cultivation activity which affects surface horizons while the loess horizons located below are not altered by pedogenic processes and do not possess an aggregate soil structure.

The lowest capillary water capacity within chernozems soil profile can be observed in the ploughed horizons. This results from the presence of numerous large pores in these horizons which are too big to hold onto water via capillary action. A similar situation exists in initial loess soils where ploughing has been shown to affect capillary water capacity by loosening the soil. As a result, differences in capillary water capacity values in tilled horizons of strongly eroded soils can reach up to 13%. As porosity increases, so does capillary water capacity with the coefficient of determination reaching $R^2 = 0.37$. Capillary water capacity is also negatively correlated with bulk density with $R^2 = 0.34$ (Fig. 3).

The basic difference between eroded initial loess soils and chernozems can be observed beneath the ploughed-humus horizons. In siltosols, carbonate-containing parent material (loess) can be found right underneath ploughed horizons while in chernozems, there are A/C and C/A horizons. Such transition horizons are characterized by a well developed natural soil structure undisturbed by cultivation activities, optimal water and air properties and a lack of carbonates having been leached of them. These features differentiate them from both ploughed horizons as well as parent material horizons.

Transition horizons A/C and C/A or Ck/A (Tab. 1) are found in typical chernozems as well as partially eroded chernozems. In chernozem soil profiles with an *agric* horizon, the corresponding horizons are called E/Bt and Bw, respectively. The horizons in question have the lowest bulk density among all chernozems which does not exceed 1.36 $Mg \cdot m^{-3}$. They also have the highest porosity which usually hovers around 51% and the largest air capacity (ca. 6%). The low bulk density and high porosity of these horizons is the result of a well developed coprolite and crumb soil structure shaped by edaphon activity. Another factor that increases total porosity is carbonate leaching. Carbonates may have constituted up to 20% of loess volume before pedogenesis. Transition horizons possess the perfect set of physical properties for plant growth.

Capillary water capacity is the highest in subsurface horizons free of calcium carbonate. Within these horizons, the large number of capillary pores characteristic of loess is increased by the leaching of small crystal forms of calcium carbonate. This causes a small increase in the number of pores that can hold water via capillary action which in turn increases capillary water capacity.

No significant soil fauna activity has been observed in the weathered Bw horizons that are found right above loess layers. Hence, there is no apparent influence of large non-capillary soil pores – a product of bioturbation – on the physical properties of these horizons.

Pedogenic processes have not been observed in the horizons of parent material (loess) with the exception of some redoximorphic features. This obviously has an impact on the water and air properties of these horizons. They can be classified as horizons with a massive structure as they do not possess a clear aggregate soil structure. They possess a higher bulk density than do horizons located above them. This is particularly apparent in chernozems where transition horizons meet loess. These soil horizons are also less porous (ca. 45%) and have a smaller air capacity.

There is no clear correlation between air capacity and capillary water capacity. This can be treated as a result of mechanical agricultural activity which tends to create very large non-capillary soil pores (Fig. 3).

The water and air properties of eroded initial loess soils and chernozems are quite similar within C (Ck, Ckg, Crkc) horizons. This indicates a high degree of homogeneity of parent material within the Proszowice Plateau. Although these soil horizons have, in a relative sense, the worst water and air properties, they have very good water and air properties compared to other soil formations in Poland. The high porosity and high capillary water capacity of loess allows plants to thrive even in highly eroded places where the development of natural soil horizons is impossible given the high degree of erosion.

A comparison of soils from the loess region of the Proszowice Plateau with similar silt formations from the Carpathian Foothills (Klimek *et al.* 2000) indicates that loess soils have far better water and air properties. Loess-like formations from the Carpathian Foothills resemble loess soils in terms of texture although silt from the Foothills contains a slightly higher percentage of colloidal clay (under 0.002 mm in diameter). Their mineral content differs in terms of calcium carbonate – not present in Carpathian silt but comprising 10–20% of Plateau loess.

These differences affect the course of relevant pedogenetic processes and influence the characteristics of the soils that these formations produce. This applies to chemical properties as well as the water and air properties described herein. The absence of calcium carbonate in loess-like formations creates favorable conditions for colloidal clay dispersion and gravity-induced movement towards the bottom of the soil profile. This further leads to the creation of illuvial *argillic* horizons and even greater density in the deeper sections of soil profiles (Klimek 2000). Soils derived from loess-like deposits usually possess higher bulk density and lower porosity (Klimek 1995, 2000; Klimek *et al.* 2000). As a result, they are more compact, contain less air, and resist infiltration by water which leads to the development of redoximorphic processes – quite common for these types of soil.

The presence of calcium carbonate, a coagulant, in the loess soils of the Proszowice Plateau makes it impossible for colloidal clay to migrate through soil which prevents deeper soil horizons from becoming more compact. The translocation of clay in the investigated soils only takes place after carbonate leaching (Żyła 2007). However, once rhizoliths and micritic calcite are removed from the soil, total porosity increases and bulk density decreases.

5. CONCLUSIONS

The analyzed soils possess good water and air properties. Even highly eroded soils – initial loess soils – possess a high total porosity and capillary water capacity. These depend upon the physical properties of the parent material – loess.

The erosion processes which have caused changes to the morphology of loess soils in the Proszowice Plateau have also influenced their water and air properties. The absence of subsurface transition horizons in initial loess soils is the reason for the substantial differences in physical properties between ploughed horizons and deeper sections of soil profiles.

Subsurface transition horizons in chernozems (A/C, C/A, Ck/A) possess the best water and air properties for plant growth in terms of water supply and air supply. They are characterized by the highest porosity, the lowest bulk density, high capillary water capacity, and high air capacity.

REFERENCES

Borowiec, J., 1965, Czarnoziemy Wyżyny Lubelskiej, Część I – Warunki występowania i ogólna charakterystyka gleb (Chernozems of the Lublin Highland, Part I – Soil distribution patterns and general characteristics). *Annales UMCS*, Sectio B, 20(5):125–146.

Borowiec, J., 1966, Wpływ wylesienia i użytkowania rolniczego na morfologię i właściwości czarnoziemu w terenie urzeźbionym (The influence of deforestation and agriculture on the morphology and properties of highland chernozems). *Annales UMCS*, Sectio E, 21(4): 83–102.

Borowiec, J., 1970, Porównanie składu i właściwości lessów występujących na obszarze Polski (Comparison of composition and properties of loess soils in Poland). *Annales UMCS*, sectio B, 25(2).

Borowiec, J., 1972, Problem występowania czarnoziemów na obszarze Polski (The chernozem issue in Poland), *Annales UMCS*, Sectio B, 27(6): 159–203.

Klimek, M., 1995, Charakterystyka pokrywy glebowej eksperymentalnej zlewni Dworskiego Potoku, Pogórze Wielickie (Soil characteristics in the experimental catchment of Dworski Potok, Wieliczka Foothills). *Zesz. Nauk. UJ*, MCLXII, *Pr. Geogr.*, 100: 99–111.

Klimek, M., 2000, *Wpływ procesów glebotwórczych na stosunki wodne utworów pyłowych progu Pogórza Karpackiego (The influence of pedogenic processes on water relationships in silt formations in the Carpathian Foothills)*. Ph.D. thesis, Inst. Geogr. and Spatial Management, Jagiell. Univ.: 69 pp.

Klimek, M., Zaleski, T. & Niemyska-Łukaszuk, J., 2000, Geomorphological conditions of water-air properties in the silt soils from the edge zone of the Carpathian Foothills. *Acta Agrophysica*, 35: 93–98.

Klimowicz, Z. & Uziak, S., 2001, The influence of long-term cultivation on soil properties and patterns in an undulating terrain in Poland. *Catena*, 43: 177–189.

Kruk, J., 1972, Antropogeniczne przemiany krajobrazu wyżyn lessowych w neolicie (Anthropogenic landscape changes in loess highlands during the Neolithic). *Acta Archeol. Carpath.*, 13: 109–129.

Kruk, J., Milisauskas, S., Aleksandrowicz, S.W. & Śnieszko, Z., 1996, *Osadnictwo i zmiany środowiska naturalnego wyżyn lessowych, Studium archeologiczne i paleogeograficzne nad neolitem w dorzeczu Nidzicy (Settlement patterns and changes in the natural environment of loess highlands – An archaeological paleogeographical study of the Neolithic in the Nidzica basin)*. Inst. Archeol. i Etnol. PAN, Kraków: 139 pp.

Licznar, M., 1985, Właściwości gleb i kierunki ich ewolucji na terenach erodowanych Płaskowyżu Głubczyckiego (Soil properties and evolution trends in eroded areas of the Głubczycki Plateau), *Zesz Nauk. AR we Wrocławiu, Rozprawy*, 48: 79 pp.

Olszewski, Z., Barański, E. & Skłodowski, P., 1965, Czarnoziemy Proszowskie (Proszów Chernozems). *Roczn. Nauk Roln.*, 90-A-1: 61–106.

Skiba, S. & Kołodziejczyk, M., 2004, Geneza i taksonomia czarnoziemów polskich w świetle badań na stanowisku archeologicznym w Słonowicach (The genesis and taxonomy of Polish chernozems in light of research at the Słonowice archaeological station. [In:] *Zmiany środowiska geograficznego w dobie gospodarki rolno-hodowlanej, Studia z obszaru Polski (Changes in the geographic environment in the age of agriculture and animal science, Research from Poland)*, Muzeum Śląskie w Katowicach, Katowice: 87–97.

Turski, R., 1985, Geneza i właściwości czarnoziemów Wyżyny Zachodniowołyńskiej i Lubelskiej (Genesis and properties of chernozems in the Western Wołyń and Lublin highlands), *Roczn. Nauk Roln.*, D , 202: 6–81.

Turski, R., Domżał, H. & Słowińska-Jurkiewicz, A., 1974, Wpływ frakcji koloidalnej z uwzględnieniem próchnicy na maksymalną higroskopijność, granice konsystencji i pęcznienie gleb lessowych (The influence of colloidal clay and humus on maximum hygroscopicity, texture limits, and expansion of loess soils). *Roczn. Glebozn.*, 25, 3: 85–99.

Turski, R., Paluszek, J. & Słowińska-Jurkiewicz A., 1987, Wpływ erozji na fizyczne właściwości gleb wytworzonych z lessu (Influence of erosion on the physical properties of loess-based soils). *Roczn. Glebozn*., 38, 1: 37–49.

Valde-Nowak, P., 2004, Neolit. Lessowe centra i górskie peryferie (The Neolithic. Loess centers and mountains peripheries). [In:] *Zmiany środowiska geograficznego w dobie gospodarki rolno-hodowlanej, Studia z obszaru Polski (Changes in the geographic environment in the age of agriculture and animal science*, *Research from Poland)*. Muzeum Śląskie w Katowicach, Katowice: 383–394.

Żyła, M., 2007, *Ewolucja gleb erodowanych w obszarach lessowych, Rozprawa doktorska (Evolution of eroded soils in loess regions)*, Ph.D. Thesis, Inst. Geogr. i Gosp. Przestrz. UJ: 145 pp.