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THE EFFECT OF EROSION ON THE SPATIAL DIFFERENTIATION OF THE PHYSICAL PROPERTIES OF ORTHIC LUVISOLS

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A b s t r a c t. The study on Orthic Luvisols developed from loess were conducted on a field belonging to an experimental farm in the Lublin Upland (Poland). The objective of the study was to determine the spatial differentiation in the granulometric composition, humus content, and the physical properties of the soil as a result of erosion. Detailed mapping showed a mosaic-type variability in non-eroded soils, in soils of various classes of erosion, and in depositional soils on watershed areas and on slopes. Slight and moderate classes of soil erosion resulted in a deterioration in the soil properties under study. Further erosion was accompanied by a gradual improvement in the properties of the soils, attaining levels similar to those of non-eroded soils. The depositional soils also had favourable physical properties. The location of the soils over various forms of the terrain studied had a less pronounced effect on the differentiation in their properties than was in the case of class erosion.

INTRODUCTION

Water erosion results in a strong differentiation in the soil cover, in the form of a restriction or extention of the natural soil profiles. The resultant soils of various erosion classes and depositional soils differ from non-eroded soils not only in their morphological features but also in their granulometric and mineral composition, as well as in their humus and plant nutrient contents [3,6,11,18]. Numerous authors have made the following observations: a deterioration in the physical properties of eroded soils, and especially a decrease in the content of waterstable soil aggregates [8], an increase in soil density with a decrease in porosity [6,9], a lowering of the field water capacity [6], a decrease in the retention of useful water [3,18], and a deterioration in the retention of useful water [3,18], and a deterioration in the pore distribution [11,12]. The result of the aforementioned observations was a decreased crop yield on the eroded soils [1,3,8,12,18]. However, studies by some authors [7,14,16] showed that not all eroded soils were characterized by properties worse than those of non-eroded soils. Also depositional soils had fovourable characteristics [8,9].

In the most studies the influence of soil water erosion on soil properties was based on spot experiments on selected soil profiles [3,6,8,9,11,12,14,16]. In the Polish agricultural literature the variability of properties of loess soils was investigated in nivelation-soil cros sections [10,13,15,19]. The only few authors [1,4,5] have undertook the attempt of determination of spatial differentiation in soil properties of eroded areas (i.e., studies which could be used in the design of suitable agromelioration measures and antierosion measures). Therefore, the objective of this study is to determine the spatial differentiation of erosion classes, physical properties, granulometric composition, and humus content of Orthic Luvisols developed from loess.

MATERIALS AND METHODS

The field studies on Orthic Luvisols developed from loess were conducted in the beginning of May 1986, at the Elizówka experimental farm in the Lublin Upland (Fig. 1). The field involved in the studies was under a spring barley culture (*Hordeum vulgare L.*) in the tillering phase. Detailed mapping was performed for non-eroded soils, eroded soils, and depositional soils, using a hypsometric map on a scale of 1:1 000. The method applied was that of a reticule map spaced at every 25 m. The total number of test points was 323, and the surface area of zone mapped was 20.2 ha (one test point per 625 m^2). The mapping process was based on an original classification of erosion classes of the Orthic Luvisols, in which the primary classification criterion was the construction of the remaining soil profile after erosion. This classification allowed the authors to distinguish the following:

- non-eroded soils of the construction profile: Ap-E-Bt1-Bt2-BC-C1-Ck2, where the cultivated horizon was developed from the natural Ah and E horizons;
- slightly eroded soils of the construction profile: Ap-Bt1-Bt2-BC-C1-Ck2, where the cultivated horizon was developed from the remainder of E horizon and of the Bt1 horizon;
- moderately eroded soils of the construction profile: Ap-Bt2-BC-C1-Ck2, where the cultivated horizon was developed from the Bt1 horizon and partially from the Bt2 horizon;
- strongly eroded soils of the construction profile: Ap-BC-C1-Ck2 or Ap-C1-Ck2, where the Ap horizon was developed mainly from the BC horizon;
- completely eroded soils (very strongly eroded soils) of the construction profile: Apk-Ck, where the cultivated horizon was developed from carbonate loess;
- depositional soils of the construction profile: Ap-Ch-2Ah-2E or Ap-Ch1-Ch2, where the cultivated horizon was developed from contemporary water-land deposits.

Concurrently with the mapping, samples were taken from all the test points for laboratory analysis. The samples were taken from the cultivated horizons of the soils. For the determination of the water-air properties, samples of undisturbed structure were taken into metal cylinders having a capacity of 100 cm^3. Analysis of the granulometric composition was determined using the Prószyński areometric method [2] and the humus content using the Tiurin method [2]. The contents of waterstable aggregates was determined according to the wet sieving method using a modified Baksheyev apparatus [17]. The bulk density of the soils was calculated from the ratio of the mass of soil dried at a temperature of 105 °C to its volume. The water capacity was determined in low pressure chambers: within the soil water potential range from 0 to -49 kPa, on porous ceramic plates, and within the soil water potential range from -196 to -1 550 kPa, using celophane as a membrane. The useful water retention (%, w/w) along with total porosity and the distribution of pores (%, v/v), were calculated on the basis of appropriate water capacities. The air permeability was determined by means of an LPiR-1 apparatus in which measurements were conducted at a constant pressure of 0.98 kPa and the values measured were read in terms of $m^2Pa^{-1} \times 10^{-8}$.

The results of the determination of the soil properties have been presented in the form of individual maps. The results have also been subjected to statistical variance analysis for individual non-orthogonal classification in order to determine the significance of differences between particular erosion classes and between particular forms of relief. Slope angle of 6 % was adopted as the criterion of distinguishing the slopes from the watershed area and the valley bottom.

RESULTS AND DISCUSSION

The area under study enveloped a slightly inclined watershed area (151 test points), a slope (104 test points), and the bottom of a dry valley (68 test points) (Fig. 1). A characteristic feature of the test area was the mosaic-type differentiation of the non-eroded soils, soils of various erosion classes, and depositional soils on the watershed area and on the slope (Fig. 2). The non-eroded soils constituted only 43 test points, (i.e., a minority even on the watershed area) (Table 1). Soils of various erosion classes comprised a total of 173 test points and dominated not only on the slope but on the watershed area as well. Among these soils the most frequently noted were the slightly eroded soils - 58 test points and the most sparsly noted were the completely eroded soils being present at just 24 test points. Depositional soils covered the entire bottom of the valley, the lower part of the slope, and slight depressions in the watershed area (a total of 68 test points). The mosaic-type variability of the soil cover was the effect of the levelling off of the original micro-relief of the loess surface through water erosion and cultivation.

The soils studied contained in their cultivated horizons 0.3 to 2.0 % (w/w) of the granulometric fraction of 1-0.1 mm, 54 to 68 % (w/w) of the granulometric fraction of 0.1-0.02 mm, and 31 to 46 % (w/w) of the granulometric fraction below 0.02 mm (4 to 20 %, w/w of the clay fraction of below 0.002 mm) (Fig. 3). It was the difference in the clay content that had the strongest effect on the physical properties of the soils studied. In the non-eroded soils the mean content of the clay fraction was 9 % (w/w) (Table 2). It increased significantly in the slightly and moderately eroded soils (up to 14 %, w/w) as a result of extending the cultivation onto the illuvial horizons Bt1 and Bt2, enriched with that fraction. In soils severely and completely eroded the content of the clay decreased.

The humus content varied within very wide limits, but did not display any significant relationship to the erosion class of the soils (Table 2). The largest area was taken up by the range of values from 1.50 to 1.75 % (w/w) (Fig. 4).

A consequence of the mosaic-type variability of the erosion classes and of the clay fraction and humus contents was an analogous variability in the physical properties of the soils under study. The content of waterstable soil aggregates of diameters greater than 0.25 mm varied from 10.8 to 54.8 % (w/w), but most frequently falling within the range from 20 to 30 % (w/w) (Fig. 5). The highest content was observed in the depositional soils (an average of 32.2 %, w/w) and in non-eroded soils. As a result of erosion, the content of waterstable soil aggregates decreased considerably, especially in soils of the moderate erosion class. The decrease was observed in all of the aggregate fractions, including also the fraction of 1-10 mm in diameter, considered to be the most valuable from the agriculture viewpoint (Table 2).

The bulk density of the soils varied from 1.21 to 1.62 Mg m^{-3}, but the dominant

Table 1. Test points according to forms of relief and classes of erosion

Classes of erosion	Forms of relief			
	Watershed area	Slope	Valley bottom	Total
Non-eroded soils	35	8	-	43
Slightly eroded soils	32	26	-	58
Moderately eroded soils	18	27	-	45
Strongly eroded soils	31	15	-	46
Completely eroded soils	7	17	-	24
Depositional soils	28	11	68	107
Total	151	104	68	323

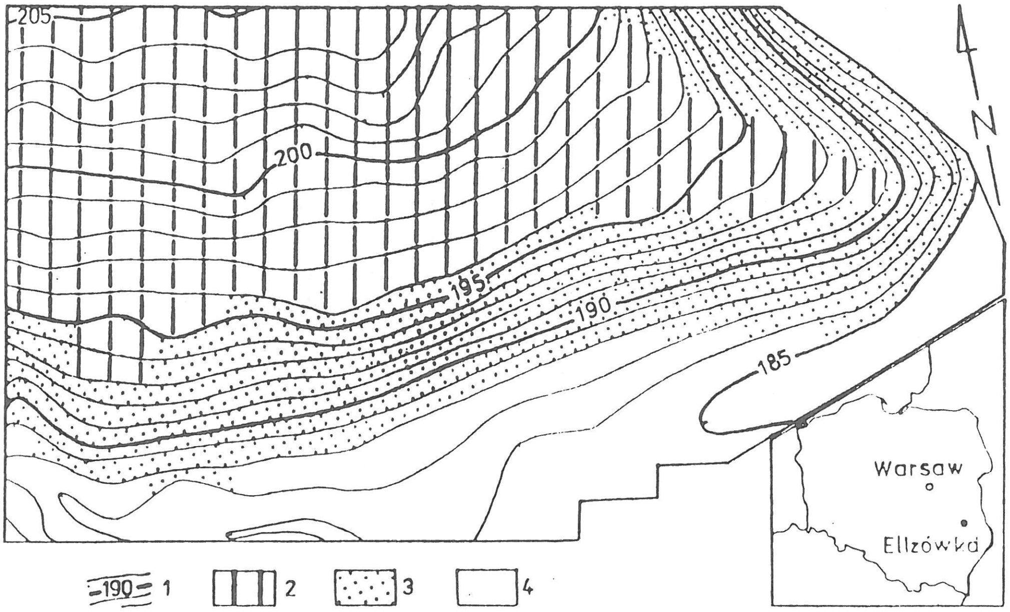

Fig. 1. Hypsometry, forms of relief and location of investigatied area: 1 - contour lines, 2 - watershed area, 3 - slope, 4 - valley bottom.

Fig. 2. Erosion classes of the soils: 1 - non-eroded soils, 2 - slightly eroded soils, 3 - moderately eroded soils, 4 - strongly eroded soils, 5 - completely eroded soils, 6 - depositional soils.

Fig. 3. Content of clay fraction (<0.002 mm).

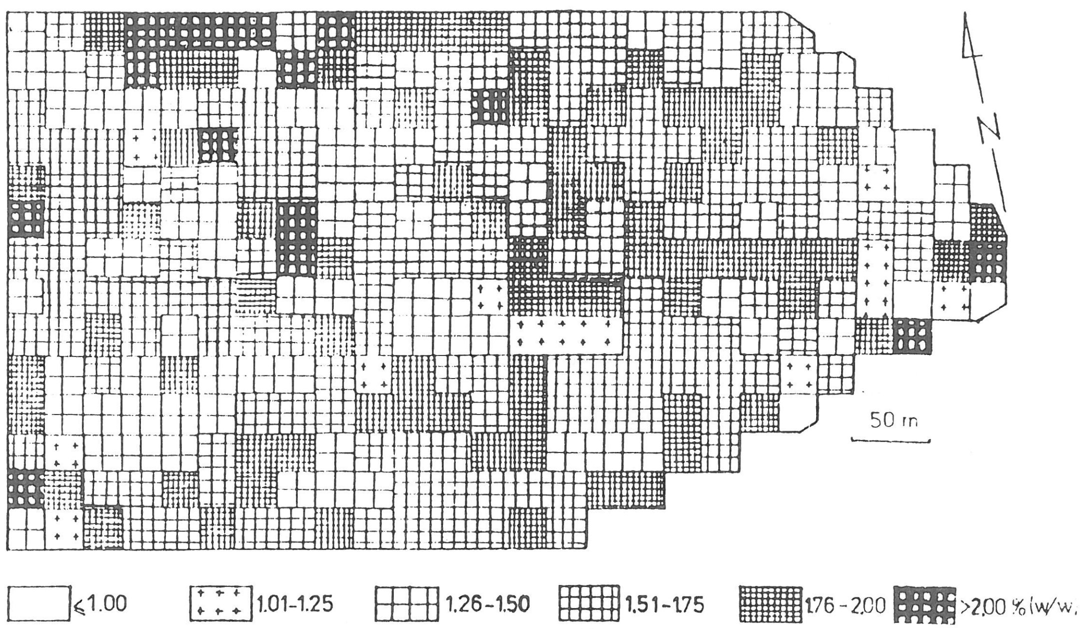

Fig. 4. Content of humus.

Table 2. Analysis of variance of soil properties for various erosion classes ($\frac{\text{average}}{\text{minimum}-\text{maximum}}$)

Property	Non eroded soils	Eroded soils: slightly	Eroded soils: moderately	Eroded soils: severely	Eroded soils: completely	Depositional soils
Content of clay fraction (<0.002 mm), % (w/w)	9 (5−15)	13 (8−19)	14 (10−20)	11 (6−17)	10 (6−14)	10 (4−18)
Content of humus, % (w/w)	1.66 (1.01−2.23)	1.60 (0.81−2.13)	1.52 (1.07−1.88)	1.67 (1.18−2.23)	1.57 (1.09−1.92)	1.66 (0.74−2.36)
Content of waterstable aggregates >0.25 mm, % (w/w)	27.5 (12.2−39.2)	22.6 (11.9−34.8)	21.1 (10.8−30.7)	23.0 (11.6−33.3)	22.6 (12.0−43.5)	32.2 (18.0−58.2)
Content of waterstable aggregates >1 mm, % (w/w)	6.2 (1.1−15.3)	4.9 (1.6−10.7)	4.5 (1.4−10.3)	5.0 (1.8−10.0)	6.4 (2.7−16.5)	8.6 (2.0−36.6)
Bulk density, Mg m^{-3}	1.46 (1.32−1.56)	1.48 (1.33−1.61)	1.48 (1.26−1.60)	1.47 (1.21−1.57)	1.46 (1.34−1.55)	1.46 (1.21−1.58)
Maximum water capacity at 0 kPa, % (w/w)	31.5 (27.1−37.9)	30.4 (24.5−38.0)	30.6 (25.1−41.0)	31.1 (26.3−40.8)	31.8 (27.1−39.2)	31.5 (25.4−42.6)
Field water capacity at -15.5 kPa, % (w/w)	25.8 (22.1−30.1)	24.5 (20.4−28.1)	24.7 (21.0−36.3)	25.4 (22.1−28.6)	25.7 (21.8−29.4)	25.5 (19.6−32.8)
Plant wilting point at -1 550 kPa, % (w/w)	6.5 (5.2−7.7)	7.2 (5.3−9.5)	7.3 (5.6−8.9)	7.0 (5.2−8.4)	6.6 (5.7−7.4)	6.8 (5.4−8.6)
Retention of water useful to plants from -15.5 to -1550 kPa, % (w/w)	19.4 (14.4−24.3)	17.3 (11.6−21.5)	17.3 (13.5−28.5)	18.4 (15.1−22.5)	19.1 (15.5−23.4)	18.7 (12.5−25.9)
Total porosity, % (v/v)	45.8 (42.0−52.7)	44.9 (39.5−52.9)	45.2 (39.7−51.7)	45.4 (40.2−52.7)	46.2 (41.7−53.5)	45.8 (39.5−54.5)
Content of macropores (>20 μm), %(v/v)	8.2 (4.6−14.7)	8.6 (4.5−13.6)	8.7 (4.6−15.4)	8.4 (4.2−15.7)	9.0 (4.6−13.9)	8.6 (3.4−19.3)
Content of mesopores (0.2-20 μm) % (v/v)	28.2 (21.5−33.8)	25.5 (18.6−31.5)	25.6 (21.7−36.0)	26.9 (21.4−32.4)	27.7 (23.2−32.3)	27.3 (18.7−35.8)

Table 2. (continued)

Content of micropores (<0.2 μm), % (v/v)	9.4 7.6–11.6	10.2 7.9–14.1	10.9 8.4–13.4	10.3 7.5–12.4	9.6 8.1–11.2	9.9 7.5–12.9
Air permeability at -15.5 kPa, x $10^{-8} m^2 Pa^{-1} s^{-1}$	11.7 2.0–52.1	10.0 2.0–59.3	13.5 2.0–89.4	14.0 2.0–105.1	7.6 2.0–26.5	15.5 2.0–128.0

9/5–15 ← 14/10–20 Statistically significant differences at P = 5 %.

range of values was from 1.41 to 1.60 Mg m^{-3}, which indicates a considerable level of compaction by the wheels of tractors and agricultural machinery (Fig. 6). Differences due to erosion were slight and insignificant.

The Orthic Luvisols developed from loess were characterized by very good water properties. Their maximum water capacity (0 kPa) was from 24.5 to 42.6 % (w/w) and depended mostly on the bulk density of the soils. The maximum water capacity decreased as a result of slight, moderate, and severe classes of erosion, but the changes were insignificant (Table 2). The field water capacity (-15.5 kPa) usually fell within the range of 20 to 30 % w/w) (Fig. 7). The highest mean values were observed in the non-eroded soils - 25.8 % (w/w). A slight erosion class resulted in a decrease in that value to 24.5 % (w/w) (Table 2).

The plant wilting point (-1 550 kPa) varied within the range of 5.2 to 9.5 % (w/w), most often attaining values of 6 to 8 % (w/w). It was closely related to the content of clay, and therefore the lowest values of the wilting points were observed in soils with no erosion - 6.5% (w/w), and the highest in soils of the moderate class of erosion - 7.3 % (w/w) (Table 2).

The retention of water useful to plants (from -15.5 to -1 550 kPa) varied between 11.6 % (w/w) and 28.5 (w/w), but most frequently attained values from 15 to 20 % (w/w) (Fig. 8). The highest values of useful water retention were observed in the non-eroded soils - an average of 19.4 % (w/w). In soils of slight and moderate classes of erosion, the useful water retention decreased significantly to 17.3 % (w/w). In soils of slight and moderate classes of erosion, the useful water retention decreased significantly to 17.3 % (w/w), and with further erosion it increased to 19.1 % (w/w) in soils completely eroded (Table 2).

Total porosity of the soils varied from 39.5 to 54.5 % (v/v). As a result of erosion the total porosity decreased, but the differences were insignificant (Table 2).

The content of macropores of diameters over 20 μm, determining the field air capacity, varied from 3.4 to 19.3 % (v/v). The predominant feature was excessively low values from 5 to 10 % (v/v) (Fig. 9). As a result of erosion, the air capacity increased somewhat, from 8.2 % (v/v) in non-eroded soils to 9.0 % (v/v) in soils completely eroded (Table 2).

The volume of mesopores of diameters of 0.2-20 μm (retaining water useful to plants) was very high in the soils under study and varied, most frequently, from 25 to 30 % (v/v). The highest mean volume of mesopores was observed in the non-eroded soils - 28.2 % (v/v). The volume of mezopores decreased as a result of erosion, this effect was most pronounced in the slightly eroded soils where the value was only 25.5 % (v/v) (Table 2).

The volume of micropores of diameters below 0.2 μm varied from 7.5 % (v/v) to

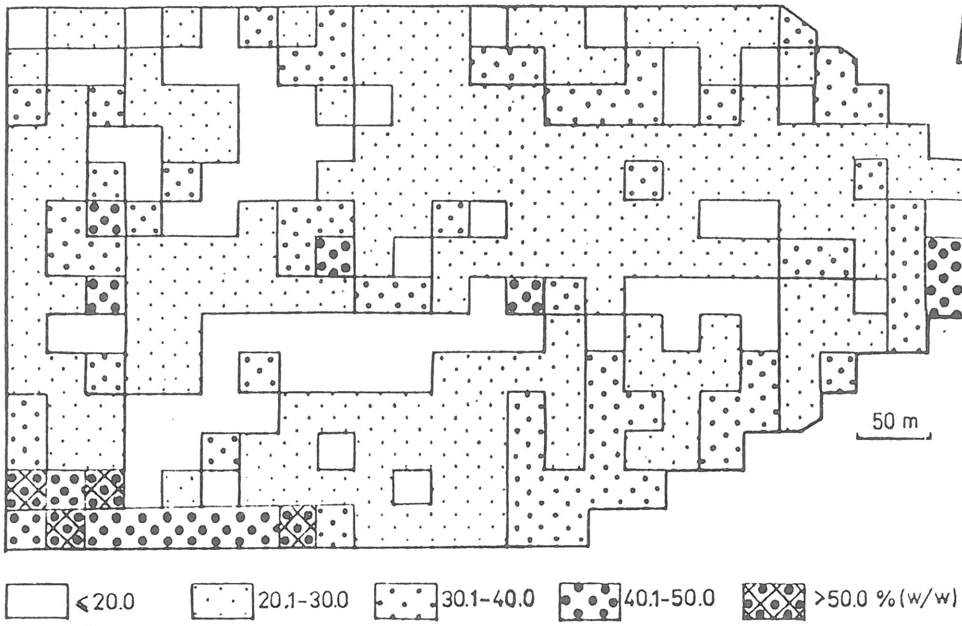

Fig. 5. Content of waterstable soil aggregates > 0.25 mm in diameter.

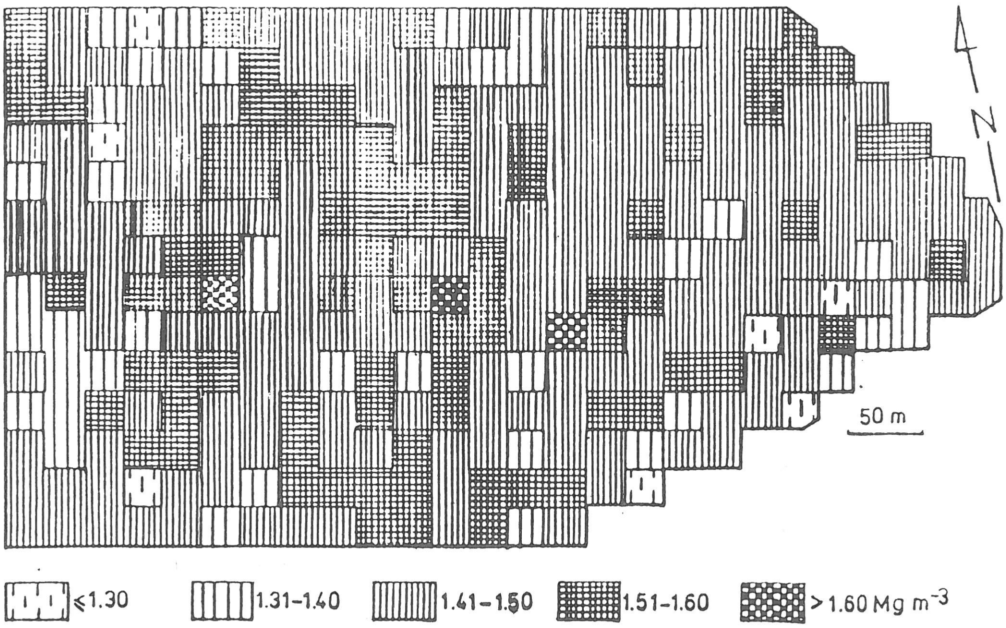

Fig. 6. Bulk density.

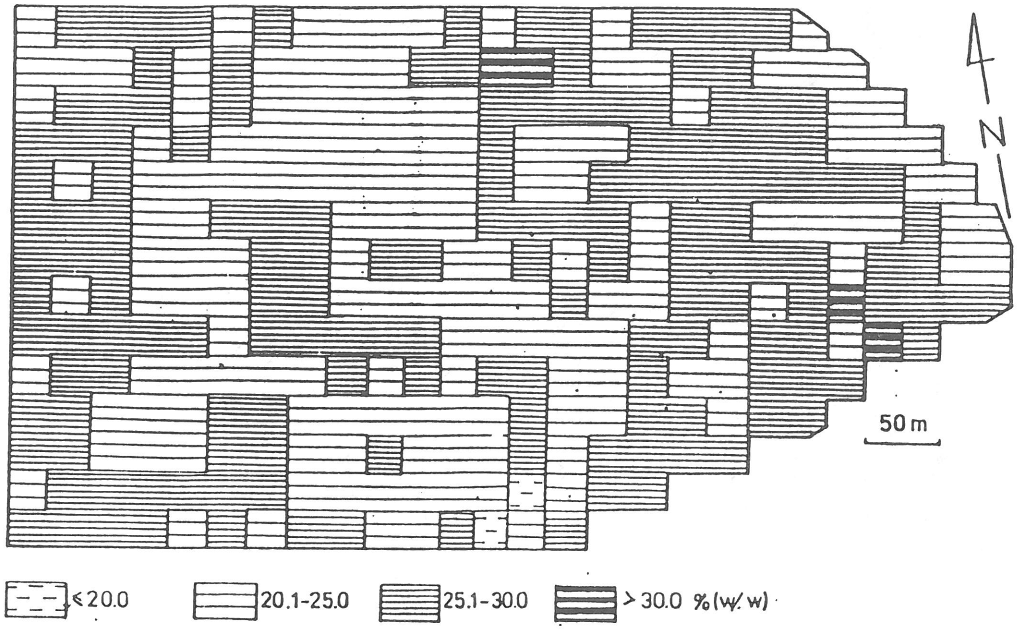

Fig. 7. Field water capacity at -15.5 kPa.

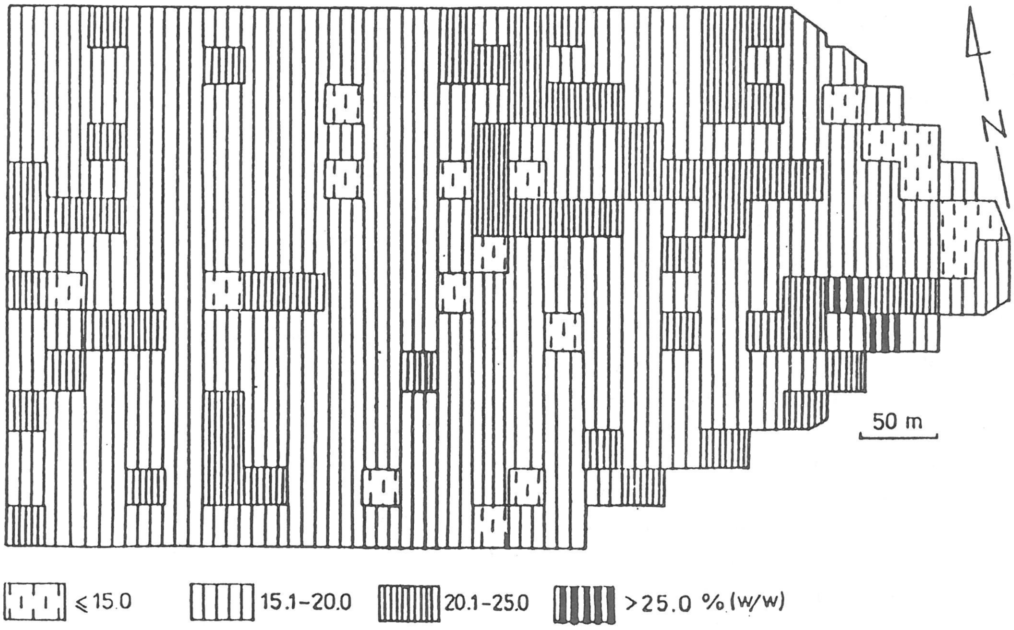

Fig. 8. Retention of water useful to plants.

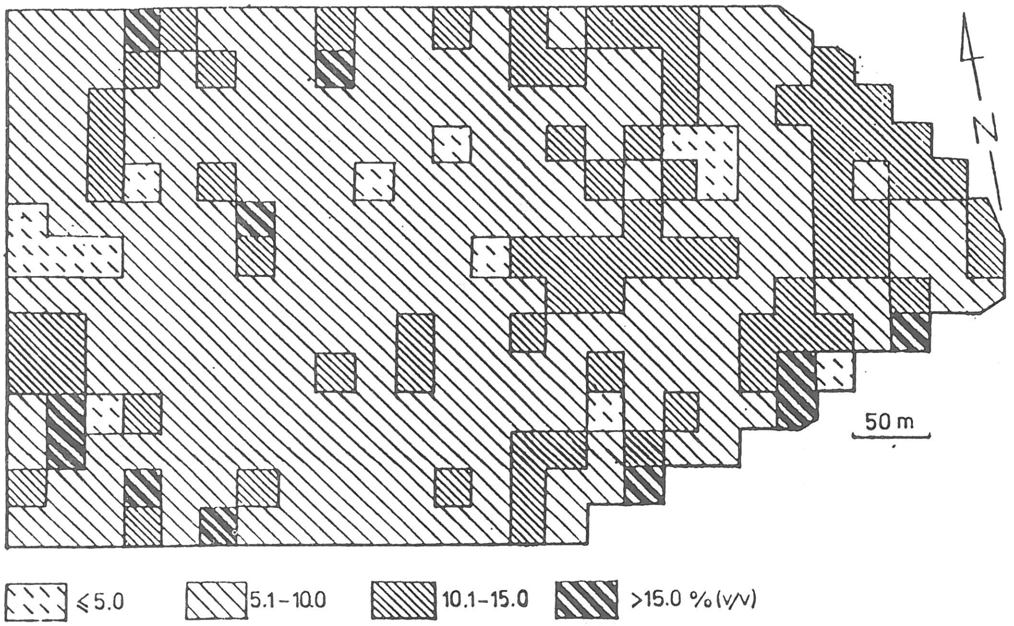

Fig. 9. Content of macropores (>20 μm).

14.1 % (v/v). As a result of erosion the content of micropores increased significantly, from 9.4 % (v/v) to 10.9 (v/v), in soils of the moderate erosion class (Table 2).

The air permeability at -15.5 kPa varied from 2.0 x 10^{-8} $m^2Pa^{-1}s^{-1}$ to 128.0 x 10^{-8} $m^2Pa^{-1}s^{-1}$ (Fig. 10). In a vast majority of test points, however, it was very low (below 10 x 10^{-8} $m^2Pa^{-1}s^{-1}$), insufficient for proper gas exchange. The highest mean values were observed in the depositional soils -15.5 x 10^{-8} $m^2Pa^{-1}s^{-1}$. As a result of moderate and severe classes of erosion the air permeability increased, while slight and complete classes of erosion resulted in a decrease in the air permeability (Table 2).

The presented maps of certain properties of Ap horizons of the Orthic Luvisols indicate considerable differentiation if we take into consideration that the soils had developed from such a homogeneous mother rock as loess. Statistical analysis confirmed the significance of many of the differences between soils of various classes of erosion. The differences concerned the content of clay fraction (below 0.002 mm), the content of waterstable aggregates of diameters over 0.25 mm and over 1 mm, wilting point, useful water retention, volumes of mezopores and micropores, and, to a lesser extent, the field moisture capacity. As a result of slight and moderate erosion classes, when cultivation reached Bt1 and Bt2 horizons enriched with clay, a certain deterioration was observed in the content of waterstable aggregates, bulk density, water capacities and water retention values, and the total porosity, as well as in the volume of mesopores and micropores.

The results obtained supported the results of the studies by Frye *et al.* [6] conducted on Typic Paleudalfs, and those by Bruce *et al.* [3] on Typic Hapludults. With further erosion the properties improved gradually. Completely eroded soils, whose Ap horizons had developed from carbonate loess, had favourable water properties and total porosity, similar to those of non-eroded soils.

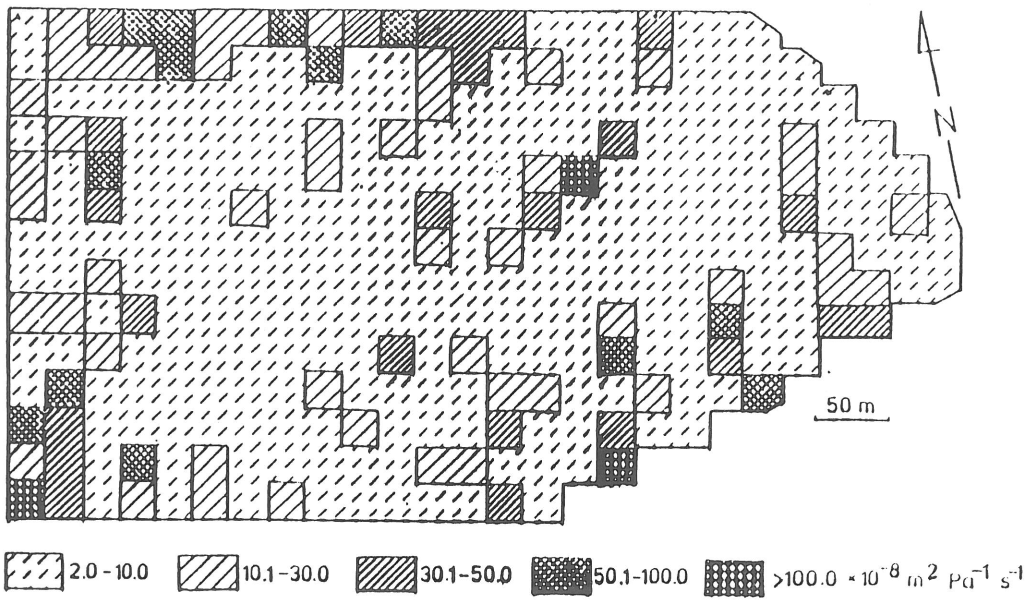

Fig. 10. Air permeability at -15.5 kPa.

Under the effect of erosion a slight improvement was observed in the air properties (air capacity and permeability) which originally had not been too favourable. Therefore, erosion need not always lead to a deterioration in the physical properties of soils, which the authors had already noted during their earlier studies [16], similarly to Savvinova [14], who studied eroded soils under high culture.

The depositional soils were characterized by physical properties, granulometric composition, and humus content similar to those of non-eroded soils. Their content of waterstable soils aggregates was even somewhat higher than that of non-eroded soils, and their air properties were somewhat better, although the differences were not significant statistically. The favourable characteristics of the depositional soils are confirmed also by the results of studies by Kashtanov *et al.* [8] and by Savvinova [14].

The considerable spread in results of the analyses of the soil properties of the same class of erosion noted by the authors indicated the presence, in some cultivated horizons, of an admixture of soil material from other horizons, displaced by water erosion and by cultivation.

Considerably fewer significant differences were revealed by the variance analysis in the properties of soils located over various forms of the relief (Table 3). This indicates a less pronounced effect of location on the properties of soils as compared to the effect of the class of erosion. The soil located on the slope had a higher content of clay and a lower humus content with relation to soils located on the watershed area and on the valley bottom. The valley bottom soils (deep depositional soils) had a distincly higher content of waterstable aggregates and a more favourable air capacity and permeability when compared to the soils of the watershed area and the slope. The other physical properties, on the other hand, did not show any relation to the location of the soils on the various forms of the relief.

Table 3. Analysis of variance of soil properties for various forms of relief ($\frac{\text{average}}{\text{minimum}-\text{maximum}}$)

Property	Watershed area	Slope	Valley bottom
Content of clay fraction (<0.002 mm), % (w/w)	10 / 4–16	13 / 6–20	10 / 4–18
Content of humus, % (w/w)	1.66 / 1.01–2.23	1.53 / 0.81–1.96	1.67 / 0.74–2.36
Content of waterstable aggregates > 0.25 mm, % (w/w)	25.4 / 10.8–47.4	22.7 / 11.6–54.8	33.3 / 19.5–58.2
Content of waterstable aggregates >1 mm, % (w/w)	5.8 / 1.1–20.0	5.3 / 1.6–31.9	9.0 / 2.0–36.6
Bulk density, Mg m^{-3}	1.47 / 1.21–1.64	1.47 / 1.21–1.62	1.46 / 1.24–1.58
Maximum water capacity at 0 kPa, % (w/w)	30.7 / 24.5–40.8	31.5 / 24.6–42.6	31.6 / 25.4–41.6
Field water capacity at -15.5 kPa, % (w/w)	25.2 / 21.0–32.3	25.1 / 20.4–36.6	25.2 / 19.6–32.8
Plant wilting point at -1 550 kPa, % (w/w)	6.8 / 5.2–8.6	7.0 / 5.2–9.5	7.0 / 5.6–8.6
Retention of water useful to plants from -15.5 to -1 550 kPa, % (w/w)	18.5 / 13.8–25.9	18.2 / 11.6–28.5	18.3 / 12.0–25.9
Total porosity, % (v/v)	45.0 / 39.5–52.7	46.1 / 39.5–53.5	45.9 / 39.5–54.5
Content of macropores (>20 μm), % (v/v)	7.9 / 3.4–15.7	9.2 / 5.1–16.0	9.1 / 4.0–19.3
Content of mesopores (<0.2-20 μm), % (v/v)	27.1 / 21.0–34.6	26.6 / 18.6–36.0	26.7 / 18.7–35.8
Content of micropores (<0.2 μm), % (v/v)	10.0 / 7.5–13.6	10.3 / 7.7–14.1	10.2 / 8.1–12.9
Air permeability at -15.5 kPa, x 10^{-8} $m^2 Pa^{-1} s^{-1}$	13.7 / 2.0–105.1	8.9 / 2.0–70.7	16.9 / 2.0–128.0

$\frac{10}{4-16}$ ← $\frac{13}{6-20}$ Stastically significant differences at P = 5 %.

CONCLUSIONS

1. Field mapping revealed a mosaic-type variability of the non-eroded, eroded to various classes, and depositional Orthic Luvisols developed from loess on the watershed area and on the slope. The spatial differentiation of the granulometric distribution, humus content, and physical properties of the cultivated horizons of the soils was also high.

2. Slight and moderate erosion caused a deterioration in the properties of the soils under study. The clay fraction content increased, the content of waterstable aggregates decreased, the bulk density of the soil increased, the water capacities and retention values deteriorated, as did the pore distribution.

3. With further erosion, the soil properties enumerated gradually improved. Soils completely eroded had favourable water properties and pore composition, similar to the properties of non-eroded soils.

4. Unfavourable air properties of Orthic Luvisols improved slightly under the effect of erosion.

5. The depositional soils were characterized by favourable physical properties, similar to those of non-eroded soils, or even somewhat better.

6. The studied physical properties of the cultivated horizons of Orthic Luvisols, consisting of various erosion classes and depositional soils, were dependent on the primary genetic horizon characteristics (E, Bt1, Bt2, BC, Ck) from which they were formed as a result of soil exposure and cultivation operations. In particular, the studied physical properties were determined by the clay fraction (below 0.002 mm).

7. The location of the soils on the various forms of the relief had a lesser effect on the physical properties of the soils than the class of their erosion.

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