ARCHIVES OF ENVIRONMENTAL PROTECTION
vol. 36 no. 3 pp. 97 - 109 2010
PL ISSN 0324-8461

THE INFLUENCE OF URBAN GREEN WASTE COMPOST ON THE PHYSICAL QUALITY OF SOIL EXPOSED TO EROSION

JAN PALUSZEK

University of Life Science in Lublin, Institute of Soil Science and Environment Management
S. Leszczyńskiego str. 7, 20-069 Lublin, Poland
e-mail: jan.paluszek@up.lublin.pl

Keywords: Eroded soil, compost, soil structure, water properties, air properties.

Abstract: A field experiment was conducted to assess both direct and after effects of composted urban green waste applied at the rates of 10 and 20 $Mg \cdot ha^{-1}$ on aggregate size distribution, aggregate water stability, water and air properties of Haplic Luvisol developed from loess exposed to surface water erosion. In the first year of the study, compost fertilization resulted in a significant reduction of an unfavorable proportion of clods > 10 mm, while air-dry aggregates with sizes of 1–5 mm and 0.25–1 mm increased within the 0–10 cm layer of the eroded soil. In the second year after compost application, there was a significant increase in the water-stable aggregate content with sizes of 0.25–10 mm in the treated soil as compared to the control plots. However, no significant differences in aggregate size distribution and aggregate water stability were stated in the third year after compost application. A direct influence of compost addition was reflected in a significant decrease in bulk density and significant increases in actual soil moisture, maximum water capacity, saturated hydraulic conductivity, total porosity, the fraction of macropores with diameters > 20 μm, and air permeability in the surface layer of the soil. At the same time, there was a significant decrease in the proportion of soil mesopores with diameters between 0.2 to 20 μm, whereas no significant differences in field water capacity and retention of water useful for plants were observed. Values of Dexter's index *S* of soil physical quality in the compost-amended soil were comparable to those found in the control plots. The dose of 20 $Mg \cdot ha^{-1}$ turned out to be more effective.

INTRODUCTION

Soil quality can be conceptualized as the capability of soil to function within natural or agriculturally managed ecosystems, to sustain plant and animal productivity, maintain water and air quality, and support human health and habitation [17]. Physical properties suggested as soil quality indicators include soil depth, thickness of humus horizon, soil color, texture, structure, and compaction, water capacity, retention of water useful to plants, infiltration, aeration, crusting, surface runoff, and susceptibility to water erosion.

Soil erosion is a major process of physical degradation of soil cover in agricultural areas with a strongly developed relief [6, 12, 18, 21, 29]. During the process, cultivated horizons located on upper convex segments of slopes become increasingly reduced, and soil material is accumulated in hollows. This results, in turn, in more or less reduced pedons within eroded soils and overbuilt pedons within colluvial soils. Destruction of soil genetic horizons is accompanied by depletion of humus substances and nutrients in soil. In contrast to non-eroded soils, Ap horizons of eroded soils developed from illuvial horizons or parent material have poorer aggregation, aggregate water stability and less favorable water-air properties [15, 25, 27, 28, 30]. Also, erosion processes tend to wash away or colmatate crop plants, and to leach mineral fertilizers and plant protection chemicals, posing a threat to the environment, particularly to surface and underground water. Affecting crops and soil fertility, erosion contributes to great losses of crop productivity and its lower quality [5, 10, 19]. In water management, erosion processes cause increased river sedimentation and colmatation of water reservoirs as well as damage to drainage facilities.

As a result of poor aggregate water stability, eroded soils are susceptible to crusting at the soil surface and further water erosion during periods of heavy runoff. Since the soils are potentially rich in plant nutrients, their water-stable aggregate structure should be restored. In order to increase soil organic matter contents and to improve soil structure and water-air properties, high doses of natural or organic fertilizers are applied together with NPK fertilization and liming [4, 9, 26]. According to some studies, organic waste compost may elevate organic carbon content in soil and enhance its physical, physico-chemical and chemical properties [1, 16, 34]. Meeting required standards, urban green waste compost is of the greatest quality [3, 7, 13]. Materials used for composting include grass, leaves, ground-up tree and bush branches, green waste from marketplaces, and garden refuse.

The purpose of the study was to assess both direct and after effects of composted urban green waste applied in moderated doses on aggregate size distribution, aggregate water stability, water and soil properties of Haplic Luvisol developed from loess.

MATERIAL AND METHODS

The study was conducted in the period of 2005–2007, in a small loess catchment typical of loess areas in Poland, located in the town of Bogucin (51°19'56"N and 22°23'18"E) on the Nałęczów Plateau (Lublin Upland). The catchment is a model research object of the Institute of Agrophysics of the Polish Academy of Sciences in Lublin, where processes of soil erosion have been studied for more than ten years [29]. The field experiment was carried out on a slope with inclination ranging from 11 to 15%, transversal to the direction of tillage. The study comprised plots with two doses of compost and control plots in 3 replications, on Haplic Luvisols affected by different erosion degrees, e.g.: the slightly eroded soil with the sequence of genetic horizons Ap-Blt-B2t-BC-Ck, moderately eroded soil with the sequence of horizons Ap-B2t-BC-Ck, and strongly eroded soil with the sequence of horizons Ap-BC-Ck (9 plots in total). The plot size (5×3 m) was limited by a distinctive mosaic pattern of the soil cover on the loess slopes, formed by patches of non-eroded soil, pedons with different degrees of erosion, and colluvial soil.

In 2005, spring wheat (*Triticum aestivum* L. variety Nawra) was sown, having replaced sugar beet (*Beta saccharifera*). Cultivation management included winter ploughing, cultivatoring and harrowing in spring. Mineral fertilization per hectare was as follows: 40 kg of N (on a one-off basis, full dose before sowing, applied in the form of nitrochalk and ammonium phosphate), 23 kg of P, and 75 kg of K (applied as 60% potassium salt). At the beginning of April 2005, before wheat sowing, compost was mixed into the soil to the depth of 10 cm. Its amounts were relatively small doses of 1 and 2 $kg \cdot m^{-2}$ (10 and 20 $Mg \cdot ha^{-1}$) because compost application was designed as a supplementary agricultural treatment rather than a rehabilitation measure. The compost used in the study was produced by P.U.H. Botom Company in Raszyn from solid green waste (grass, leaves, ground-up wood) coming from Warsaw. Dry matter content in the mature compost was 50.95%. According to the producer's information, the chemical composition of the compost was as follows: Corg – 19.4% d.m., Norg – 1.3% d.m., P_2O_5 – 1.0% d.m., K_2O – 0.5% d.m.; contents of heavy metals were significantly below their limit values. For crop protection, Chwastox Turbo 340 SL was used (2 $dm^3 \cdot ha^{-1}$).

For analyses of a direct effect of the compost, soil samples were collected from the surface layer of Ap horizons (at the depth of 0–10 cm). In order to determine aggregate size distribution and aggregate water stability, collective samples were taken on four days during 2005 (May 23, June 14, July 11, and August 8). Soil samples of undisturbed structure were collected on June 14 and August 8, 2005 in 8 replications to metal cylinders of 100 cm^3 in volume (4 cylinders to determine water capacity and air permeability, and 4 cylinders to determine saturated hydraulic conductivity). Soil Corg content and physicochemical properties were assayed in the samples taken in June.

After effects of the compost on aggregate size distribution and aggregate water stability were studied in 2006 and 2007, e.g. in the second and third year after its application. Cultivation management included repeated annual skim ploughing, winter ploughing, spring cultivatoring and harrowing. Spring barley (*Hordeum vulgare* L. variety Stratus) was grown twice, and mineral fertilization per hectare was the same as in 2005, viz. 40 kg of N, 23 kg of P, and 75 kg of K. Soil material was sampled on June 20, 2006 and June 15, 2007, at the depth of 0–20 cm.

Soil texture was determined according to the Casagrande aerometric method modified by Prószyński. Organic carbon content was measured by Tiurin's method in Simakov's modification. Soil reaction in 1 $mol \cdot dm^{-3}$ KCl was determined potentiometrically using a combined electrode. Soil hydrolytic acidity in mmol $H^+ \cdot kg^{-1}$ was analyzed by Kappen's method in 1 $mol \cdot dm^{-3}$ CH_3COONa. The sum of exchangeable basic cations was estimated after Kappen in 0.1 $mol \cdot dm^{-3}$ HCl. On the basis of these assays, cation exchange capacity and a degree of sorptive complex saturation with basic cations were calculated.

In order to determine aggregate size distribution [$kg \cdot kg^{-1}$], 500-g representative samples in two replications were processed by dry sieving technique with a nest of sieves with the mesh sizes of 10, 7, 5, 3, 1, 0.5, and 0.25 mm. The content of water-stable aggregates (WSA) [$kg \cdot kg^{-1}$] was determined in four replications through wet sieving with the use of the modified Baksheyev's apparatus made by The Institute of Agrophysics of the Polish Academy of Sciences in Lublin. The sieving results were used to calculate mean weight diameter (MWD) values of both air-dry and water-stable aggregates using the procedure of Youker and McGuinness [33]. Aggregate stability was assessed following the method described by Le Bissonnais [20].

Specific soil density [$Mg \cdot m^{-3}$] was measured pycnometrically. Bulk density [$Mg \cdot m^{-3}$] was calculated from the ratio of the mass of the soil dried at 105°C to its volume. Actual soil moisture during sampling [$kg \cdot kg^{-1}$] was measured by the gravimetric method. Water capacity in the range of soil water potential from -0.1 kPa to -1554 kPa [$kg \cdot kg^{-1}$] was determined in pressure chambers, on porous ceramic plates (manufactured by Eijkelkamp and Soil Moisture Equipment Corporation). Retention of water useful to plants (within the range of potential from -15.5 to -1554 kPa) was calculated as a difference of water capacity values corresponding to the potential. Saturated hydraulic conductivity was determined with the use of Wit's apparatus (Eijkelkamp) by calculating water filtration coefficient [$\mathrm{m \cdot d^{-1}}$]. Total porosity [$\mathrm{m^3 \cdot m^{-3}}$] was calculated on the basis of values of specific and bulk soil density. Distribution of pores with equivalent diameters of > 20 µm, 0.2–20 µm, and < 0.2 µm was calculated on the basis of water capacity values expressed in $\mathrm{m^3 \cdot m^{-3}}$. Air permeability at field water saturation of -15.5 kPa ($\times 10^{-8}\ \mathrm{m^2 \cdot Pa^{-1} \cdot s^{-1}}$) was measured using LPiR-2 apparatus for the measurement of air permeability in the moulding masses (manufactured by Polish Foundry Research Institute in Cracow).

Analysis of variance (ANOVA) involving two-way classification in the completely randomised design was applied to the data pertaining to direct effects of the compost in 2005, while the after-effects in 2006 and 2007 were analyzed using ANOVA with one-way classification. The significance of differences was verified by Tukey's test.

Dexter's index of soil physical quality S [11] was calculated on the basis of water retention curves using the computer program RETC. The index S is defined by the author as the slope value of the soil water retention curve at its inflection point and should be calculated using the van Genuchten modified equation [32]:

$$S = -n\,(\theta_{\mathrm{sat}} - \theta_{\mathrm{res}})\,[1 + 1/m]^{-(1+m)}$$

where:

θ_{sat} – the volumetric water content at saturation [$\mathrm{kg \cdot kg^{-1}}$],
θ_{res} – the residual water content [$\mathrm{kg \cdot kg^{-1}}$],
n – the dimensionless parameter controlling the shape of the curve,
m – the dimensionless parameter with Mualem restriction [23]: $1 - 1/n$.

RESULTS

Granulometrically, the studied Haplic Luvisol developed from loess was silt loam, comprising, depending upon the erosion class, 12–15% of sand (2–0.05 mm), 68–74% of silt fraction (0.05–0.002 mm), and 14–17% of clay (< 0.002 mm). Corg contents in the soil ranged from 8.04 to 9.20 $\mathrm{g \cdot kg^{-1}}$ and tended to decrease with an increasing erosion degree. Soil reaction was slightly acid (pH 5.8–6.1). Soil hydrolytic acidity was between 18.8 and 26.2 $\mathrm{mmol(+) \cdot kg^{-1}}$, the sum of exchangeable basic cations was within the range of 87–98 $\mathrm{mmol(+) \cdot kg^{-1}}$, while cation exchange capacity ranged from 113.3 to 116.8 $\mathrm{mmol(+) \cdot kg^{-1}}$. A degree of sorptive complex saturation with basic cations reached values between 76.9 and 80.8%.

According to the results, application of composted urban green waste elevated Corg contents in the surface layer of the eroded Haplic Luvisol, which reached up to 9.04–10.12 $\mathrm{g \cdot kg^{-1}}$ in the plots with the dose of 10 $\mathrm{Mg \cdot ha^{-1}}$ and up to 9.92–11.04 $\mathrm{g \cdot kg^{-1}}$ in plots with the dose of 20 $\mathrm{Mg \cdot ha^{-1}}$. The compost had a beneficial direct effect on aggregate size distribution. Significant changes in soil aggregation were found in May 2005 (at the first sampling) and they were also observed for all subsequent sampling times (Tab. 1). The proportion of clods > 10 mm decreased significantly (by 0.105 $\mathrm{kg \cdot kg^{-1}}$ in the plots treated with 10 $\mathrm{Mg \cdot ha^{-1}}$ and by 0.151 $\mathrm{kg \cdot kg^{-1}}$ in the plots treated with 20 $\mathrm{Mg \cdot ha^{-1}}$, on average). At the same time, there were significant increases in fractions of air-dry aggregates with sizes of 1–5 mm (by 0.048–0,070 $\mathrm{kg \cdot kg^{-1}}$) and 0.25–1 mm (by 0.032–0.052 $\mathrm{kg \cdot kg^{-1}}$), as compared to the control plots. By contrast, no significant differences in 5–10 mm aggregates and microaggregates < 0.25 mm were found. The mean weight diameter of air-dry aggregates decreased significantly (on average by 3.9 mm in the plot with the compost dose of 10 $\mathrm{Mg \cdot ha^{-1}}$ and by 5.5 mm in the plot with the dose of 20 $\mathrm{Mg \cdot ha^{-1}}$).

Table 1. Air-dry soil aggregate distribution in Ap horizon (mean values in 3 plots)

Month, year [M]	Dose of compost [Mg·ha^{-1}] [D]	Air-dry aggregate content of diameter in mm [kg·kg^{-1}]						MWD [mm]
		> 10	5–10	1–5	0.25–1	< 0.25	Σ 0.25–10	
May 2005	0	0.293	0.145	0.296	0.186	0.080	0.627	9.3
	10	0.166	0.172	0.347	0.218	0.098	0.737	6.5
	20	0.155	0.155	0.352	0.238	0.100	0.745	6.3
June 2005	0	0.336	0.154	0.286	0.158	0.066	0.598	10.1
	10	0.248	0.147	0.324	0.193	0.088	0.664	7.5
	20	0.217	0.164	0.348	0.193	0.079	0.705	7.0
July 2005	0	0.352	0.101	0.209	0.177	0.161	0.487	15.1
	10	0.315	0.124	0.242	0.180	0.140	0.546	11.3
	20	0.198	0.130	0.301	0.222	0.149	0.653	7.2
August 2005	0	0.462	0.125	0.235	0.110	0.068	0.470	16.4
	10	0.296	0.137	0.302	0.171	0.095	0.610	9.9
	20	0.271	0.138	0.304	0.188	0.098	0.630	8.3
Mean	0	0.361	0.131	0.256	0.158	0.094	0.545	12.7
	10	0.256	0.145	0.304	0.190	0.105	0.639	8.8
	20	0.210	0.147	0.326	0.210	0.107	0.683	7.2
LSD (α = 0.05)	doses D	0.066	n. s.	0.030	0.034	n. s.	0.059	2.0
	interaction D×M	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.
June 2006	0	0.299	0.157	0.289	0.159	0.096	0.605	9.0
	10	0.278	0.143	0.288	0.179	0.112	0.610	7.9
	20	0.223	0.159	0.326	0.181	0.111	0.666	6.5
LSD (α = 0.05)	doses D	0.074	n. s.	n. s.	n. s.	n. s.	0,060	2.2
June 2007	0	0.369	0.138	0.239	0.136	0.118	0.513	10.1
	10	0.397	0.132	0.240	0.133	0.098	0.505	10.7
	20	0.345	0.138	0.273	0.140	0.104	0.551	9.6
LSD (α = 0.05)	doses D	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.

n. s. – non significant differences

In the second year after compost application in dose of 20 Mg·ha^{-1}, the proportion of clods > 10 mm was significantly lower (by 0.076 kg·kg^{-1}), the proportion of air-dry aggregates with sizes of 0.25–10 mm was significantly higher (by 0.061 kg·kg^{-1}), and the mean weight diameter was significantly lower (by 2.5 mm), compared to the control plots. In the soil with the compost dose of 10 Mg·ha^{-1}, no significant differences in air-dry aggregates were found (Tab. 1). In the third year after compost application at the rate of 20 Mg·ha^{-1}, the reduction of clods > 10 mm was insignificant (by 0.024 kg·kg^{-1}) and the proportion of macroaggregates ranging from 0.25 to 10 mm was slightly higher (by 0.038 kg·kg^{-1}) in the Ap horizon of the eroded soil, compared with the control plots.

In the first year of the study, composted urban green waste proved to have a considerably weaker effect on aggregate stability in the surface layer of the eroded soil than on size aggregate distribution (Tab. 2). There were no significant differences in water-stable aggregates with sizes of 0.25–10 mm, which shows that soil-aggregate stabilization influenced by this fertilizer is a very slow process. A higher number of stable aggregates with sizes of 5–10 mm in the plots with the dose of 20 Mg·ha^{-1} (by 0.008 kg·kg^{-1}) and higher MWD values (by 0.08 mm) were the only changes observed in that period.

Table 2. Water-stable soil aggregate content in Ap horizon (mean values in 3 plots)

Month, year [M]	Dose of compost [Mg·ha^{-1}] [D]	Water-stable aggregate content of diameter in mm [kg·kg^{-1}]				MWD [mm]
		5–10	1–5	0.25–1	Σ 0.25–10	
May 2005	0	0.004	0.037	0.265	0.306	0.33
	10	0.009	0.040	0.288	0.337	0.37
	20	0.010	0.042	0.285	0.337	0.38
June 2005	0	0.008	0.044	0.273	0.325	0.37
	10	0.011	0.045	0.269	0.325	0.40
	20	0.015	0.054	0.298	0.367	0.46
July 2005	0	0.018	0.066	0.364	0.448	0.53
	10	0.022	0.071	0.346	0.439	0.57
	20	0.030	0.060	0.349	0.439	0.60
August 2005	0	0.032	0.071	0.312	0.415	0.64
	10	0.048	0.066	0.274	0.388	0.75
	20	0.042	0.072	0.298	0.412	0.70
Mean	0	0.016	0.054	0.303	0.373	0.47
	10	0.022	0.056	0.294	0.372	0.53
	20	0.024	0.057	0.308	0.389	0.55
LSD	doses D	0.007	n. s.	n. s.	n. s.	0.07
(α = 0.05)	interaction D×M	n. s.	n. s.	n. s.	n. s.	n. s.
June 2006	0	0.004	0.043	0.219	0.266	0.32
	10	0.012	0.040	0.260	0.312	0.39
	20	0.010	0.059	0.283	0.352	0.43
LSD (α = 0.05)	doses D	0.008	0.012	0.032	0.034	0.08
June 2007	0	0.006	0.041	0.242	0.289	0.35
	10	0.011	0.037	0.249	0.297	0.38
	20	0.013	0.047	0.258	0.318	0.41
LSD (α = 0.05)	doses D	n. s.	n. s.	n. s.	n. s.	n. s.

n. s. – non significant differences

In 2006, the after effect of the compost on aggregate stability was greater than its direct influence in 2005 (Tab. 2). The content of stable aggregates with sizes of 0.25–10 mm increased significantly (on average, by 0.046 kg·kg^{-1} in the plots with the dose of 10 Mg·ha^{-1} and by 0.086 kg·kg^{-1} in the plots with the dose of 20 Mg·ha^{-1}), compared to the control plots. Among all the examined water-stable fractions, greater numbers of the following aggregates were detected: those with sizes of 5–10 mm (by 0.008 kg·kg^{-1} in the plots with the dose of 10 Mg·ha^{-1}), with sizes of 1–5 mm (by 0.016 kg·kg^{-1}) and of 0.25–1 mm (by 0.064 kg·kg^{-1}) in the plots with the dose of 20 Mg·ha^{-1}. Also the MWD of water stable aggregates in the soil treated with compost at the rate of 20 Mg·ha^{-1} proved to be significantly greater (by 0.11 mm).

In the third year after compost application, little impact of the treatment on water stable aggregates was observed (Tab. 2). Differences in the sum of stable aggregates with sizes of 0.25–10 mm and in the content of particular water-stable fractions in the soil amended with compost were insignificant in comparison to the control plots.

Specific soil density in the Ap horizon of the eroded Haplic Luvisol was 2.65 Mg·m^{-3}. The compost dose of 20 Mg·ha^{-1} resulted in its decrease to 2.64 Mg·m^{-3}. After compost treatment, bulk density in the layer of 0–10 cm decreased significantly (on average, by 0.06 Mg·m^{-3} in the plots with the dose of 10 Mg·ha^{-1} and by 0.12 Mg·m^{-3} in the plots with the dose of 20 Mg·ha^{-1}) in comparison with bulk density in the control plots (Tab. 3). Lower compaction of the soil fertilized with compost considerably influenced some water and air properties of the soil.

Table 3. Bulk density and water properties in Ap horizon (mean values in 3 plots)

Month, Year [M]	Dose of compost [Mg·ha^{-1}] [D]	Bulk density [Mg·m^{-3}]	Actual moisture [kg·kg^{-1}]	Water capacity [kg·kg^{-1}] at			Retention of water useful for plants [kg·kg^{-1}]	Saturated hydraulic conductivity [m·d^{-1}]
				-0.1 kPa	-15.5 kPa	-1554 kPa		
June 2005	0	1.31	0.184	0.389	0.262	0.069	0.193	2.00
	10	1.27	0.173	0.415	0.261	0.073	0.188	3.21
	20	1.19	0.182	0.465	0.268	0.074	0.194	6.37
August 2005	0	1.31	0.134	0.388	0.273	0.069	0.204	1.40
	10	1.24	0.144	0.433	0.265	0.072	0.193	4.29
	20	1.19	0.148	0.469	0.281	0.073	0.208	6.54
Mean	0	1.31	0.159	0.389	0.267	0.069	0.198	1.70
	10	1.25	0.158	0.424	0.263	0.072	0.191	3.75
	20	1.19	0.165	0.467	0.274	0.073	0.201	6.45
LSD ($\alpha = 0.05$)	doses D	0.05	n. s.	0.032	0.011	0.003	0.010	1.31
	interaction D×M	n. s.	0.009	n. s.	n. s.	n. s.	n. s.	n. s.

n. s. – non-significant differences

Actual soil moisture during sampling showed significant differences among the plots only while combined with the sampling dates (Tab. 3). A significant increase (by 0.035–0.078 kg·kg^{-1}) in maximum water capacity of the soil (at the soil water potential of -0.1 kPa) attributable to compost application was detected, compared to the control plots, while no differences in field water capacity (at the potential of -15.5 kPa) in the compost-treated fields were found. Both compost doses contributed to significant increases in permanent wilting point moisture contents (at the potential of -1554 kPa), by 0.003 kg·kg^{-1} and by 0.004 kg·kg^{-1}, respectively. As a result, compost fertilization had no considerable effect on retention of water useful to plants (within the range of the potential from -15.5 kPa to -1554 kPa). In comparison with the control plots, saturated hydraulic conductivity in the surface layer of the soil treated with compost increased significantly (by 2.05–4.75 m·d^{-1} on average).

Total porosity in the soil with the compost was significantly higher (by 0.020 m^3·m^{-3} and by 0.046 m^3·m^{-3}, respectively to increasing dose of compost) than in the control plots (Tab. 4). Compost application led to significant increases (by 0.040 m^3·m^{-3} and by 0.070 m^3·m^{-3}) in macropores with equivalent diameters > 20 μm which determining air capacity of the soil at field water saturation. By contrast, the proportion of mesopores with diameters ranging from 0.2 to 20 μm, which retain water useful for plants, decreased significantly (by 0.022–0.020 $m^3 \cdot m^{-3}$). At the same time, there were no significant differences in the number of micropores with diameters < 0.2 μm (which retain water unavailable for plants). Air permeability at field water saturation (-15.5 kPa) increased significantly (by 86.9×10^{-8} $m^2 \cdot Pa^{-1} \cdot s^{-1}$ in the plots with the dose of 10 $Mg \cdot ha^{-1}$ and by 94.0×10^{-8} $m^2 \cdot Pa^{-1} \cdot s^{-1}$ in the plots with the dose of 20 $Mg \cdot ha^{-1}$).

Table 4. Porosity and air permeability in Ap horizon (mean values in 3 plots)

Month, Year [M]	Dose of compost [$Mg \cdot ha^{-1}$] [D]	Total porosity [$m^3 \cdot m^{-3}$]	Pore-size content [$m^3 \cdot m^{-3}$] > 20 μm	0.2–20 μm	< 0.2 μm	Air permeability at -15.5 kPa [$\times 10^{-8}$ $m^2 \cdot Pa^{-1} \cdot s^{-1}$]
June 2005	0	0.506	0.165	0.252	0.089	23.8
	10	0.521	0.191	0.236	0.094	23.3
	20	0.551	0.234	0.231	0.086	52.8
August 2005	0	0.505	0.148	0.267	0.090	18.9
	10	0.531	0.202	0.238	0.091	193.1
	20	0.552	0.221	0.246	0.085	177.7
Mean	0	0.506	0.157	0.259	0.090	21.3
	10	0.526	0.197	0.237	0.092	108.2
	20	0.552	0.227	0.239	0.086	115.3
LSD ($\alpha = 0.05$):	doses D	0.019	0.028	0.011	0.005	55.5
	interaction D×M	n. s.	n. s.	n. s.	n. s.	n. s.

n. s. – non-significant differences

Dexter's index of soil physical quality *S* for the soil from the control plots, calculated on the basis of water retention curves, reached the values in the range of 0.064 to 0.078. In the soil treated with compost, the index absolute values were slightly lower, ranging from 0.061 to 0.065 in the plots with the dose of 10 $Mg \cdot ha^{-1}$ and from 0.060 to 0.069 in the plots with the dose of 20 $Mg \cdot ha^{-1}$.

DISCUSSION

Application of composted urban green waste at the rates of 10 and 20 $Mg \cdot ha^{-1}$ increased organic carbon content in the 0–10 cm layer of eroded Haplic Luvisol, which is in agreement with the results obtained by other authors [1, 7, 16]. The beneficial direct effect of the compost, connected with, on the one hand, significant decreases in the proportion of clods with sizes > 10 mm and significant increases in air-dry aggregates ranging from 0.25 to 10 mm on the other, can be explained by reduced cohesion of soil mass due to compost application which prevented excessive cloddiness of the soil during the growing season. This positive effect of the compost on the soil was also present in the second year after the treatment in spite of partial dispersion of the compost during ploughing and other management practices.

Despite increased soil organic matter contents, compost addition only slightly increased water-stable aggregates with sizes of 0.25–10 mm in the first year. After submerging in water, air-dry clods > 10 mm and macroaggregates with sizes of 0.25–10 mm broke down mostly into microaggregates < 0.25 mm. This indicates that the formation of water-stable bounds between microaggregates and soil particles stimulated by this fertilizer is a very slow process.

The after effect of compost application on aggregate stability was greater in the second year than its direct effect in 2005. A significant increase in the proportion of stable aggregates with sizes of 0.25–10 mm, as compared to the control plots, is indicative of partial and slow transformation of compost organic matter into high polymers of the polysaccharide type possessing a linear structure and demonstrating a greater ability to stabilize aggregates. In the third year of the study, strong dispersion of the compost in the soil mass occurred due to management practices, and progressing mineralization of organic matter reduced an influence of the fertilizer on aggregate size distribution and water stability.

When referring to the classes proposed by Le Bissonnais [20], based on the mean weight diameter after wet sieving, the aggregates in the layer of 0–10 cm of the control plots were assessed mainly as very unstable (MWD < 0.4 mm), and only in July and August 2005 as unstable (0.4–0.8 mm). At the same time, the aggregates from the soil amended with the compost at the rates of 10 and 20 $g \cdot kg^{-1}$ were classified largely as unstable (MWD 0.4–0.8 mm). Low MWD values were mainly determined by small numbers of stable aggregates with sizes of 5–10 mm and 1–5 mm. The applied doses of composted urban green waste turned out to be too small to enhance aggregate stability in the eroded soil more significantly and for a longer period of time.

A beneficial effect of composts on formation of stable soil aggregates was found by numerous authors [1, 3, 7, 34]. Bresson *et al.* [7] showed that incorporated municipal solid waste *compost* in the dose of 15 $g \cdot kg^{-1}$ of dry matter improved aggregate ability in the silty loam under simulated rainfall. As a result, surface crust development in the arable layer was slowed down, surface runoff was delayed, and water erosion was reduced. The results obtained by Whalen *et al.* [34] indicate a significantly greater aggregate stability in a silt-loam soil amended with composted cattle manure in the doses of 0, 15, 30, and 45 $Mg \cdot ha^{-1}$, proportionally to the application rates of the compost. Aggelides and Londra [1] reported improved aggregate size distribution and increased aggregate stability in loamy and clayey soils treated with compost produced from town waste and sewage sludge, at the rates of 75, 150 and 300 $Mg \cdot ha^{-1}$. In the laboratory study, Annabi *et al.* [3] analyzed effects of immature and mature composts made from municipal solid waste, sewage sludge, green waste and biowaste on the mechanisms of aggregate stabilization in a silt loam soil. All the composts applied improved aggregate stability preventing the soil from surface crusting, with a less persistent effect of the mature composts. Stabilization of the aggregates caused by their increased hydrophobicity was connected with increases in microbial activity, biomass of exocellular polysaccharides of microbial origin, and the abundance of soil fungi. Improvement in aggregate stability resulted from the diffusion of the organic substances into the aggregates.

According to the literature, only a part of organic matter is responsible for soil aggregate stability. Among organic compounds involved in soil stabilization, transient binding agents include microbial and plant-originating polysaccharides which are rapidly decomposed by microorganisms. Plant roots, fungal hyphae and some fungi may act as temporary binding agents [2]. Resistant aromatic humic substances associated with polyvalent metal cations and strongly sorbed polymers are cited among persistent binding agents. They are strongly bound inside aggregates and are derived from the resistant fragments of roots, hyphae and bacteria cells. The highest resistance of soil aggregates to the destructive action of water occurs during the summer months.

The results obtained in this study show that compost organic matter reduced gravity settling of the soil mass and effectively prevented the soil, loosened after wheat sowing, from compacting. As a result, bulk density in the 0–10 layer remained significantly lower till August as against that stated in the control plots. The decrease in bulk density of the compost-treated soil had a decisive influence on significant increases in maximum water capacity and total porosity, particularly in the higher content of macropores with MWD > 20 μm. The higher proportion of macropores had, in turn, a major impact on increases in saturated hydraulic conductivity and air permeability at field water saturation.

At the same time, compost addition had little effect on field water capacity and retention of water useful for plants. Since organic matter is able to fix water by molecular forces and retain it in micropores < 0.2 μm as unavailable to plants, increases in organic matter content in the soil resulted in higher moisture at the permanent wilting point. This led to significant decreases in mesopores with diameters of 0.2–20 μm retaining water available to plants in the compost-treated soil.

In their study into effects of compost produced from town wastes and sewage sludge at the rates of 75, 150 and 300 Mg·ha^{-1} on a loamy and a clayey soil, Aggelides and Londra [1] found decreases in bulk density by 16.7–19.7% at the highest compost dose and increases in total porosity by 11.0–32.8% in a loamy soil and by 5.4–9.9% in a clayey soil, proportionally to the application rate. Saturated hydraulic conductivity was higher by 32.5–95.2% in the loamy soil and by 55.3–168.4% in the clayey soil. The increase of retention of water useful to plants was less evident. Compost application contributed to an increase in soil hydraulic conductivity and reduction in surface runoff, which is particularly important for soils susceptible to water erosion.

Increases in moisture in a sandy alluvial soil attributable to treatment with composted urban waste at the rates of 60 and 120 Mg·ha^{-1} were reported by Jamroz and Drozd [14] and Licznar *et al.* [22]. Tester [31] investigated soil moisture at the depth of 5–30 cm after 5-year compost fertilization in the doses of 60, 120 and 240 Mg·ha^{-1}. In comparison to the control plot, soil moisture at the 5-cm depth was 1.9, 2.7 and 3.1-fold higher, and at the 30-cm depth 1.3, 1.5 and 2.2-fold higher, respectively for the applied rates. Similarly, Carter [8] found increases in field water capacity and soil retention of water useful to plants in barley and potato cultivation on a compost-amended podzolic soil developed from fine sandy loam.

Proper growth and functioning of crop plants roots require an appropriate ratio between mesopores with diameters of 0.2–20 μm retaining water useful to plants and macropores > 20 μm responsible for adequate aeration. According to Olness *et al.* [24], an optimal balance between near-surface soil water holding capacity and aeration may be achieved when field capacity (a sum of mesopores of 0.2–20 μm and micropores < 0,2 μm) is 0.66 of total porosity and air capacity is 0.34. In the Ap horizon of the eroded Haplic Luvisol, the relationship was close to the optimum: field water capacity was on average 0.69 in the control plots while ranging from 0.63 to 0.59 in the compost-treated plots, and air capacity values were 0.31 and 0.37–0.41, respectively. Given the above-presented criteria, both water and air properties of the studied soil can be regarded as highly beneficial. Likewise, absolute values of Dexter's index *S* of soil physical quality above 0.050 indicate that the study eroded Haplic Luvisol, particularly its water and air properties, is of very high quality [11]. According to the author, *S* index can be used as a valuable tool for assessment of soil physical degradation or amelioration.

CONCLUSIONS

Application of composted urban green waste at the rates of 10 and 20 Mg·ha^{-1} contributed to increases of Corg contents in the surface layer of the eroded Haplic Luvisol.

A beneficial direct effect of compost on aggregate size distribution was connected with significant decreases in the proportion of clods with sizes > 10 mm as well as significant increases in air-dry aggregates ranging from 0.25–10 mm (particularly those of sizes with 1–5 mm and 0.25–1 mm) and in mean weight diameter values, as compared to the control plots.

In the second year after compost treatment, a significantly lower proportion of clods > 10 mm and a higher content of air-dry aggregates with sizes of 0.25–10 mm were observed, while comparing with the control plots.

In the first year after application of the doses of 10 and 20 Mg·ha^{-1}, only significant increases were stated in water-stable aggregates in the range of 5–10 mm and the mean weight diameter values.

In the second year, a significant after-effect of the compost in the plots treated with both doses was revealed, connected with a significantly higher proportion of water-stable aggregates with sizes of 0.25–10 mm and their greater MWD. However, no impact of compost application was found on aggregate size distribution and aggregate water-stability in the eroded Luvisol in the third year.

Both doses contributed to a significant decrease of bulk density and significant increases of maximum water capacity, wilting point, saturated hydraulic conductivity, total porosity, the content of macropores > 20 μm in diameter and air permeability at field water saturation in the 0–10 layer of the eroded Luvisol.

Compost addition did not influence actual soil moisture during sampling, field water capacity and retention of water useful for plants. At the same time, its application resulted in a significant decrease in mesopores with diameters of 0.2–20 μm.

The values of Dexter's index *S* of soil physical quality in the compost-treated plots were high but slightly lower than those obtained for the control plots.

ACKNOWLEDGMENTS

The study funded in part from research resources of 2008–2011 as the research project N N310 3088 34.

REFERENCES

[1] Aggelides S.M., P.A. Londra: *Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil*, Biores. Technol., **71**, 253–259 (2000).

[2] Amézketa E.: *Soil aggregate stability: a review*, J. Sustain. Agricult., **14**, 2/3, 82–151 (1999).

[3] Annabi M., S. Houot, C. Francou, M. Poitrenaud, Y. Le Bissonnais: *Soil aggregate stability improvement with urban composts of different maturities*, Soil Sci. Soc. Am. J., **71**, 413–423 (2007).

[4] Arriaga F.J., B. Lowery: *Soil physical properties and crop productivity of an eroded soil amended with cattle manure*, Soil Sci., **168**, 888–899 (2003).

[5] Bakker M.M., G. Govers, A. van Doorn, F. Quetier, D. Chouvardas, M.D.A. Rounsevell: *The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern*, Geomorphology, **98**, 213–226 (2008).

[6] Boardman J., J. Poesen (ed.): *Soil Erosion in Europe*, John Wiley and Sons Ltd., Chichester, England, 2006.

[7] Bresson L.M., C. Koch, Y. Le Bissonnais, E. Barriuso, V. Lecomte: *Soil surface structure stabilization by municipal waste compost application*, Soil Sci. Soc. Am. J., **65**, 1804–1811 (2001).

[8] Carter M.R.: *Long-term influence of compost on available water capacity of a fine sandy loam in potato rotation*, Can. J. Soil Sci., **87**, 535–539 (2007).

[9] Cox D., D. Bezdicek, M. Fauci: *Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil*, Biol. Fertil. Soils, **33**, 365–372 (2001).

[10] Den Biggelaar C., R. Lal, K. Wiebe, V. Breneman: *Impact of soil erosion on crop yields in North America*, Adv. Agron., **72**, 1–53 (2001).

[11] Dexter A.R.: *Soil physical quality, Part I, Theory, effects of soil texture, density, and organic matter, and effects on root growth*, Geoderma, **120**, 201–214 (2004).

[12] Fullen M.A.: *Soil erosion and conservation in northern Europe*, Progr. Phys. Geogr., **27**, 331–358 (2003).

[13] Hargreaves J.C., M.S. Adl, P.R. Warman: *A review of the use of composted municipal solid waste in agriculture*, Agric. Ecosyst. Environ., **123**, 1–14 (2008).

[14] Jamroz E., J. Drozd: *Influence of applying compost from municipal wastes on some physical properties of the soil*, Int. Agrophysics, **13**, 167–170 (1999).

[15] Jankauskas B., G. Jankauskiene, M.A. Fullen: *Soil erosion and changes in the physical properties of Lithuanian Eutric Albeluvisols under different land use systems*, Acta Agric. Scand., sec. B, Soil Plant Sci., **58**, 66–76 (2008).

[16] Kalembasa D.: *Wermikompost – nawóz do rekultywacji gleb zdegradowanych*, Zesz. Probl. Post. Nauk Rol., **418**, 2, 591–596 (1995).

[17] Karlen D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, G.E. Schuman: *Soil quality: a concept, definition, and framework for evaluation*, Soil Sci. Soc. Am. J., **61**, 4–10 (1997).

[18] Koćmit A.. *Erozja wodna w obszarach młodoglacjalnych Pomorza i możliwości jej ograniczenia*, Bibl. Fragm. Agron., **4B/98**, 83–99 (1998).

[19] Lal R.: *Soil erosion impact on agronomic productivity and environment quality*, Critical Rev. Plant Sci., **15**, 319–464 (1998).

[20] Le Bissonnais Y.: *Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology*, Europ. J. Soil Sci., **47**, 425–437 (1996).

[21] Licznar M.: *Erozja gleb w Polsce*, Zesz. Probl. Post. Nauk Rol., **418**, 1, 91–100 (1995).

[22] Licznar M., J. Weber, J. Drozd, S.E. Licznar, E. Jamroz: *Właściwości fizyczne gleby piaszczystej nawożonej kompostami z odpadów miejskich – pierwszy rok po nawożeniu*, Folia Univ. Agric. Stetin., 211, Agricult. (84), 223–228 (2000).

[23] Mualem Y.: *Hydraulic conductivity of unsaturated soils: prediction, and formulas*, [in:] Methods of soil analysis, Part 1, Physical and mineralogical methods (red. A. Klute), 2nd ed., Am. Soc. Agron. Monograph 9, 1986, 799–823.

[24] Olness A., C.E. Clapp, R. Liu, A.J. Palazzo: *Biosolids and their effects on soil properties*, [in:] Handbook of soil conditioners (red. A. Wallace, R.E. Terry), Marcel Dekker, New York 1998, 141–165.

[25] Olson K.R., R.L. Jones: *Soil organic carbon and fly-ash distribution in eroded phases of soils in Illinois and Russia*, Soil Till. Res., **81**, 143–153 (2005).

[26] Owczarzak W., Z. Kaczmarek, P. Rybczyński: *Wpływ wieloletniego nawożenia obornikiem na stan struktury warstwy ornej gleby płowej pod różnymi roślinami zbożowymi*, Zesz. Nauk. AR Szczecin, **172**, Rol. 62, 443–449 (1996).

[27] Paluszek J.: *Właściwości wodno-powietrzne erodowanych gleb płowych wytworzonych z lessu*, Acta Agrophysica, **56**, 233–245 (2001).

[28] Papiernik S.K., M.J. Lindstrom, J.A. Schumacher, A. Farenhorst, K.D. Stephens, T.E. Schumacher, D.A. Lobb: *Variation in soil properties and crop yield across an eroded prairie landscape*, J. Soil Water Conserv., **60**, 388–395 (2005).

[29] Rejman J.: *Wpływ erozji wodnej i uprawowej na przekształcenie gleb i stoków lessowych*, Acta Agrophysica, Rozpr. i Monogr., **136**, 1–91 (2006).

[30] Shukla M.K., R. Lal: *Erosional effects on soil physical properties in an on-farm study on Alfisols in West Central Ohio*, Soil Sci., **170**, 445–456 (2005).

[31] Tester C.F.: *Organic amendment effects on physical and chemical properties of a sandy soil,* Soil Sci. Soc. Am. J., **54**, 827–831 (1990).
[32] van Genuchten M.T.: *A closed-form equation for predicting the hydraulic conductivity of unsaturated soils*, Soil Sci. Soc. Am. J., **44**, 892–898 (1980).
[33] Walczak R., B. Witkowska: *Metody badania i sposoby opisywania agregacji gleby*, Probl. Agrofizyki, **19**, 1–53 (1976).
[34] Whalen J.K., Q. Hu, A. Liu: *Compost applications increase water-stable aggregates in conventional and no-tillage systems*, Soil Sci. Soc. Am J., **67**, 1842–1847 (2003).

Received: September 22, 2009; accepted: March 18, 2010.

WPŁYW KOMPOSTU Z ODPADÓW ZIELENI MIEJSKIEJ NA JAKOŚĆ STANU FIZYCZNEGO GLEBY ULEGAJĄCEJ EROZJI

W doświadczeniu poletkowym badano bezpośredni i następczy wpływ nawożenia kompostem z odpadów zieleni miejskiej w dawkach 10 i 20 $Mg \cdot ha^{-1}$ na skład agregatowy, wodoodporność agregatów, właściwości wodne i powietrzne gleby płowej typowej wytworzonej z lessu, ulegającej powierzchniowej erozji wodnej. W pierwszym roku badań stwierdzono, że nawożenie kompostem istotnie zmniejszyło niekorzystną zawartość brył o wymiarach > 10 mm, a zwiększyło zawartość powietrznie suchych agregatów 1–5 mm i 0,25–1 mm w warstwie 0–10 cm gleby zerodowanej. W drugim roku po zastosowaniu kompostu w glebie istotnie zwiększyła się zawartość wodoodpornych agregatów o wymiarach 0,25–10 mm w porównaniu z glebą poletek kontrolnych. W trzecim roku po zastosowaniu kompostu nie stwierdzono istotnych różnic w składzie agregatowym i wodoodporności agregatów glebowych. W bezpośrednim działaniu dodatek kompostu istotnie zmniejszył gęstość gleby, istotnie zwiększył wilgotność aktualną, pełną pojemność wodną, przewodnictwo wodne nasycone, porowatość ogólną, zawartość makroporów o średnicy > 20 μm i przepuszczalność powietrzną w powierzchniowej warstwie gleby. Pod wpływem nawożenia kompostem nie zmieniła się istotnie polowa pojemność wodna i retencja wody użytecznej dla roślin, natomiast zawartość mezoporów glebowych o średnicy 0,2–20 μm istotnie zmniejszyła się. Wartości wskaźnika jakości stanu fizycznego gleby S według Dextera w glebie nawożonej kompostem były zbliżone do wartości wskaźnika w obiektach kontrolnych. Bardziej skuteczne było nawożenie kompostem w dawce 20 $Mg \cdot ha^{-1}$.