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Original Research

Effect of Organic Amendments on Morphometric Properties of Macropores in Stagnic Gleysol Soil

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Abstract

The application of organic wastes, particularly composted municipal refuse and sewage sludge, significantly influenced soil structure and related physical properties of soil. A field experiment was conducted in 2005 on Stagnic Gleysol soil where different organic amendments were applied, such as compost, pig manure and sewage sludges. The results were compared with mineral fertilizers and untreated control. The amounts of all fertilizers were determined to supply 110 kg N ha^{-1}. The application of organic amendment, such as pig manure and sewage sludge, decreased the macroporosity of soil. These changes concerned the regular and irregular pores ranging 50-1000 μm in diameter. It was probably the result of a choking effect of particles leached from the sewage sludge and pig manure. Mineral fertilization, compost or sewage sludge did not influence the porosity of soil.

Keywords: sewage sludge, compost, pig manure, image analysis, macroporosity

Introduction

The use of organic wastes, such as compost and sewage sludges, in agriculture and for land reclamation is increasingly being identified as an important issue for both soil conservation and residual disposal. Lower disposal costs, recycling of nutrient elements in soil and counteracting the decrease of organic matter in soil are the main reasons for the agronomic utilization of compost. The application of organic wastes, particularly composted municipal refuse and sewage sludge, is a way to solve two problems: waste disposal and the correction of the low organic matter content of many agricultural soils [1]. Most sewage wastes contain valuable nutrients that could be used to improve soil fertility. Numerous research has dealt with chemical aspects of compost utilization, such as fertility and pollution [2-7].

Soil structure is one of the most important properties affecting crop production because it determines the depth that roots can penetrate, the amount of water that can be stored in the soil and the movement of air, water and soil fauna. Numerous physical parameters of soil, such as bulk density, porosity, air and water permeability, water retention, and penetration resistance are strictly connected with soil structure. Quantification of the pore space in terms of shape, size, orientation and arrangement of pores in soil allows us to define the complexity of soil structure and to understand its modification induced by management practices, including organic matter addition [8-11].

Many researchers have identified the influence of organic fertilizers amendment on physical properties of soil. Positive effects of organic fertilizer applications on soil properties have been documented for soil structure, bulk

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density, water retention and soil biological activity [12, 13]. But this effect is largely dependent on the soil texture, the rate of wastes used, the period after wastes application and waste type and processing method [14].

The aim of this study was to evaluate the effects of different types of organic fertilizers, pig manure and municipal organic wastes like compost and sewage sludges on soil structure with respect to mineral fertilization and untreated control. It was our hypothesis that organic amendments play a favourable role in soil structure. The objective of our study was to evaluate morphometric characterization of soil macropores by image analysis on soil sections when different organic fertilizers were used in field trials.

Table 1. Soil characteristics of Stagnic Gleysol from trial location in Czernichow (10-18 cm layer).

pH (KCl)		5.6
Total organic C	g kg^{-1}	15.3
N	g kg^{-1}	1.59
P	mg kg^{-1}	71.8
K	mg kg^{-1}	297.5
Bulk density	g cm^{-3}	1.52
Solid particle density	g cm^{-3}	2.58
Total porosity	cm^3 cm^{-3}	0.41
Sand	g kg^{-1}	280
Silt	g kg^{-1}	580
Clay	g kg^{-1}	140
Texture		Silty loam

Methods

Experimental Design

The field experiment was set up in Czernichów near Kraków, Poland (N 49^{o}59.625'; E 19^{o}41.910') in 2005. The experiment was laid out in randomized block design in six treatments replicated four times with a plot size of 5/6 m. The treatments considered were:

- Control (0), untreated, where crop was raised without any nutrient application
- Mineral fertilizers (M), 110 kg N ha^{-1}, 58.6 kg P ha^{-1} and 120 kg K ha^{-1} were applied
- Compost (C), obtained from composting plant of Kraków, Płaszów, at a rate of 6.46 t fresh matter ha^{-1}
- Pig manure (PM), at rate of 14.30 t fresh matter ha^{-1}
- Sewage sludge (SS1), obtained from a sewage-treatment plant of Krzeszowice, at a rate of 14.15 t fresh matter ha^{-1}
- Sewage sludge (SS2), obtained from a sewage-treatment plant of Czernichów, at a rate of 10.26 t fresh matter ha^{-1}

The chemical characteristics of organic fertilizers used in the trial are presented in Table 2. The amounts of organic fertilizers were determined to supply 110 kg N ha^{-1}. Mineral and organic fertilizers were incorporated into the soil in April 2005 then conventional tillage practices (cultivation, harrowing) were applied to the trial field for preparation of seedbeds. In April 2005, seeds of wheat (*Triticum aestivum* 'Jagna') were sown at a rate of 205 kg ha^{-1}. For chemical weed control, Puma Universal (1 l ha^{-1}) and Aminopielik Gold (1 l ha^{-1}) were used.

Soil and Climate

The soil type on the experimental field was a Stagnic Gleysol. Table 3 reports some soil characteristics. The

Table 2. Physical and chemical properties of the organic fertilizers.

Property		Pig manure (PM)	Sewage sludge, Krzeszowice (SS1)	Sewage sludge, Czernichow (SS2)	Compost (C)
N_{tot}	g kg^{-1} d.m.[b]	34.0	26.2	41.6	39.0
P_{tot}	g kg^{-1} d.m.	12.8	8.2	22.3	5.9
K_{tot}	g kg^{-1} d.m.	21.8	1.9	1.2	29.9
EC[a]	mS cm^{-1}	2.89	1.69	0.47	2.62
pH (H_2O)		8.23	6.23	6.57	7.31
Organic matter	g kg^{-1} d.m.	831	414	726	531
Water content	g kg^{-1} f.m.[c]	774	703	742	563
Ash	g kg^{-1} d.m.	169	586	244	469

[a] EC = electrical conductivity

[b] data are based on 105°C dry matter weight

[c] f.m. = fresh matter

Table 3. Effects of organic and mineral fertilization on soil macroporosity according to pore shape.

Treatments	Porosity for shape classes [%]			Total macroporosity [%]
	regular	irregular	elongated	
0	6.28 a	2.78 a	0.33 a	9.39 a
C	6.60 a	2.29 a	0.23 a	9.11 a
PM	4.49 b	1.37 b	0.10 a	5.96 b
M	6.00 a	2.14 ab	0.21 a	8.35 a
SS1	4.51 b	1.61 ab	0.15 a	6.26 b
SS2	5.60 ab	2.01 ab	0.10 a	7.70 a
Mean	5.58	2.03	0.18	7.80

Means in the same column followed by the same letters are not significantly different ($P<0.05$).

climate of experimental site, situated in southern Poland near Kraków was temperate. The average annual temperature was 11°C and the average annual rainfall amounted to 579 mm (data from the meteorological station Kraków, Mydlniki).

Soil Macroporosity

The pore system of the investigated soil was characterized by image analysis on sections prepared from undisturbed soil samples [15, 16]. The soil samples were collected in April 2005, at the beginning of the vegetation season. The 10-18 cm soil layer was chosen for the investigation due to its location below harrowed level (0-5 cm) and in the middle of tilled layer where most of the roots usually are localized. The samples were taken in a vertical position using metal boxes (80/90/40 mm). Samples were dried at room temperature. Then they were saturated with polyester resin (POLIMAL 109 32K). After hardening of the resin the samples were sliced and put into a water solution of sodium hypochlorite (with 20 g dm^{-3} available Cl content) in order to brighten the solid phase of soil [17]. The surfaces of samples (80/90 mm) were scanned at a resolution of 600 dpi using Epson Perfection 4870 Photo scanner and the images (384 total) were saved as tiff files. The APHELION software (ADCIS S.A. and Amerinex Applied Imaging) was used for image analysis. The final result was a set of pores grouped in six diameter classes according to a method described by Głąb [18]:

i. >2000 µm
ii. 1000-2000 µm
iii. 500-1000 µm
iv. 200-500 µm
v. 100-200 µm
vi. 50-100 µm

The pores of every fraction were also divided into three classes according to their shape expressed by the shape factor (4π*area/perimeter^2) according to Pagliai et al. [19]:

i. Regular – shape factor 0.5-1.0
ii. Irregular – shape factor 0.2-0.5
iii. Elongated – shape factor 0.0-0.2

Statistics

The data were analyzed according to completely randomized block design at the experimental site with different fertilizers used in four replications. Analysis of variance (ANOVA), the differences of the means and the interaction were tested using STATISTICA 6.0 (StatSoft Inc.). Separation of means was performed by Duncan's test with a level of significance of $P<0.05$.

Results and Discussion

According to Fitzpatrick's [20] classification the structure of the investigated soil can be described as com-

Table 4. Effects of the organic and mineral fertilization on soil porosity according to pore size.

Treatments	Porosity for pore diameter [µm] classes [%]					
	50-100	100-200	200-500	500-1000	1000-2000	>2000
0	2.57 a	1.67 a	3.06 a	1.81 a	0.27 a	0.00 a
C	2.54 ab	1.65 a	2.91 a	1.64 ab	0.38 a	0.01 a
PM	1.65 c	1.08 b	1.92 b	1.06 b	0.25 a	0.01 a
M	2.30 ab	1.52 ab	2.68 ab	1.49 ab	0.35 a	0.00 a
SS1	1.82 bc	1.18 b	2.06 b	1.03 b	0.17 a	0.00 a
SS2	2.13 abc	1.33 ab	2.41 ab	1.57 ab	0.25 a	0.00 a
Mean	2.17	1.40	2.51	1.43	0.28	0.00

Means in the same column followed by the same letters are not significantly different ($P<0.05$).

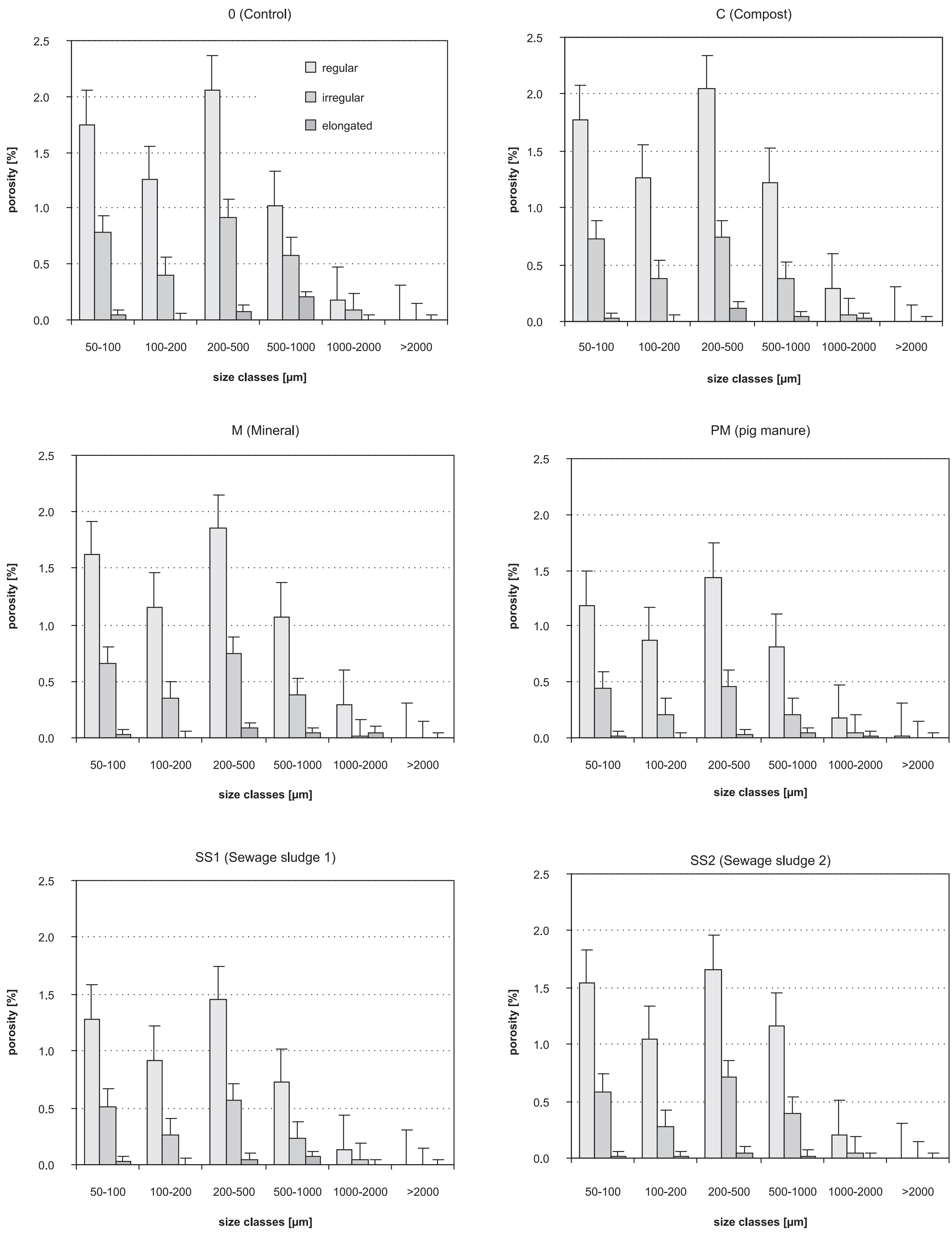

Fig. 1. Pore size distribution according to pore diameter in the 10-18 cm soil layer. Vertical lines on bars represent standard errors.

posite structure. This structure was observed in all treatments and it consisted of three types of structure: angular blocky, granular and massive. The pronounced dominant structure was massive with large area of continuous solid phase where continuous pore space was absent but occasional discrete pores with various shapes were present. Angular blocky aggregates were different in size, from very fine (<5 mm in diameter) to coarse (about 50 mm). This composite structure is characteristic for the upper layer of arable lands with traditional tillage [20].

The average total macroporosity (percentage of area occupied by pores larger than 50 μm in diameter) was 7.80% and varied from 5.96% (PM) to 9.39% (0) (Table 3). According to Pagliai's classification [21], the soil can be classified as compacted.

For a thorough characterization of soil macropores, the pore size distribution and pore shape were also considered. The most frequent size class was 200-500 μm (2.51%). The macropores were usually below 2000 μm in their size, area occupied by pores >2000 μm was below 0.01% in average. The shape of pores was usually classified as regular (Table 3). Approximately 71.8% of all macropores were regular, whereas irregular and elongated pores were 25.9% and 2.3%, respectively. There were no interactions between size and shape of pores. For all size classes the proportion between elongated, irregular and regular pores were similar. The data of pore size and shape are shown in Fig. 1.

The application of organic amendments significantly influenced the macroporosity of investigated soil. However, these differences were clearly identified when pig manure (PM) and sewage sludges from Czernichów (SS2) were applied. The total macroporosity of 7.80% for the control (0) decreased to 5.96% and 6.26% in PM and SS2, respectively. These changes concerned regular and irregular pores, whereas any mineral or organic fertilizers did not affect elongated pores. Both PM and SS2 treatments decreased the percentage of pores ranged 50-1000 μm in diameter with respect to control (0). Mineral fertilization (M), compost (C) or sewage sludges from Krzeszowice (SS1) did not significantly influence the size or shape of macropores. The significant influence of PM and SS2 treatments on soil porosity can be explained by their higher applicated rates (above 14 t fresh matter ha^{-1}) with respect to other treatments. This tendency is confirmed by results obtained by authors (not published) in the investigation in water retention properties of Stagnic Gleysol. It was noticed that application of pig manure and sewage sludges decreased macroporosity but increased volume of mezopores what resulted in favourable changes in water retention characteristics of investigated soil.

We expected that organic fertilizers would play a favourable role in characteristics of the pore system that is widely reported in literature. However, the results did not show any improvement in soil porosity. On the contrary the sewage sludge from Czernichów (SS2) and pig manure (PM) decreased participation of macropores. Baran et al. [22] reported a similar effect when sewage sludge application decreased the volume of macropores. It was explained as a choking effect of particles leached from the sewage sludge.

The positive influence of compost amendment is clearly identified for degraded soils or those with unfavourable texture for crop growth. Pagliai et al. [11] reported that compost fertilization played a favourable role in soil porosity on clay loam, compacted soil. Celik et al. [23] and Turner et al. [24] confirmed a similar effect of influence of compost amendment on physical properties of heavy soil. The significant effect of organic and mineral fertilization on macroporosity was also reported for sandy soil [12, 25].

The favourable effect of compost fertilization is also clearly identified when high rates of compost are applied. Tester [26] stated that compost amendment significantly changed physical properties of soil at 240 t ha^{-1} compost rate. Mbagwu [27] noted that organic wastes incorporated into the soil at the rate of 10% increased the total porosity by 23%. Sort and Alcaniz [28] reported the application of sewage sludge at a rate of 400 t ha^{-1} induced an increase of soil macroporosity (>50 mm). The rates of organic fertilizers, especially compost, used in this study were probably too low to significantly increase the macroporosity.

It is also reported that benefits from the use of a waste product depend on an individual assessment of particular waste characteristics [29]. The effect of organic amendments application on crop yields and environment is largely dependent on factors like waste type, processing method, distribution and incubation time [30]. This can explain different effects of sewage sludge application with different origins (sewage-treatment plants of Krzeszowice and Czernichów).

Conclusions

The application of organic amendment such as pig manure and sewage sludge from Czenichów decrease the macroporosity of Stagnic Gleysol soil. These changes concern the regular and irregular pores ranged 50-1000 μm in diameter. The decrease in soil macroporosity is connected with rates of organic fertilisers applied. Mineral fertilization, municipal compost or sewage sludge do not influence the soil structure. In conclusion, the quantitative significance of organic wastes in different agro-ecological condition should be further explored with regard of factors like rates, chemical compositions and processing method, etc.

References

1. AGGELIDES S.M., LONDRA P.A. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. Bioresource Technology, **71**, (3), 253, **2000**.
2. BARTL B., HARTL W., HORAK O. Long-term application of biowaste compost versus mineral fertilization: Effects on

the nutrient and heavy metal contents of soil and plants. J. Plant Nutr. Soil Sci., **165**, 161, **2002.**
3. BUSINELLI M., GIGLIOTTI G., GUISQUIANI P. Trace element fate in soil profile and corn plant after massive applications of urban waste compost: a six year study. Agrochimica, **40**, 145, **1996.**
4. ILLERA V., WALTER I., CUEVAS G., CALA V. Biosolid and municipal solid waste effects on physical and chemical properties of degraded soil. Agrochimica, **43**, 178, **1999.**
5. KIZILKAYA R., BAYRAKLI B. Effects of N-enriched sewage sludge on soil enzyme activities. Applied Soil Ecology **30**, 192, **2005.**
6. MORENO J.L., GARCIA C., HERNANDEZ T. Toxic effect of cadmium and nickel on soil enzymes and the influence of adding sewage sludge. Eur. J. Soil Sci. **54**, 377, **2003.**
7. BERGKVIST P., JARVIS N., BERGGREN D., CARLGREN K. Long-term effects of sewage sludge applications on soil properties, cadmium availability and distribution in arable soil. Agriculture, Ecosystems and Environment **97**, 167, **2003.**
8. PAGLIAI M., GUIDI G., LA MARCA M., GIACHETTI M., LUCAMANTE G. Effects of sewage sludges and composts on soil porosity and aggregation. J. Environ. Qual., **10**, 556, **1981**.
9. PAGLIAI M., VIGNOZZI N. The soil pore system as an Indicator of soil quality. Advances in GeoEcology 35, Sustainable Land Management – Environmental Protection, **2002.**
10. RINGROSE-VOASE A.J., BULLOCK P. The automatic recognition and measurement of soil pore types by image analysis and computer programs. J. Soil Sci., **35**, 673, **1984.**
11. PAGLIAI M., VIGNOZZI N., PELLEGRINI S. Soil structure and the effect of management practices. Soil & Till. Res., **79**, 131, **2004.**
12. MARINARI S., MASCIANDARO G., CECCANTI B., GREGO S. Influence of organic and mineral fertilizers on soil biological and physical properties. Bioresource Technology, **72**, (1), 9**, 2000.**
13. FERNANDES S.A.P., BETTIOL W, CERRI C.C. Effect of sewage sludge on microbial biomass, basal respiration, metabolic quotient and soil enzymatic activity. Applied Soil Ecology **30**, 65, **2005.**
14. SMITH S.R., VOODS V., EVANS T.D. Nitrate dynamics in biosolids-treated soils. I. Influence of biosolids type and soil type. Bioresource Technol. **66**, 139, **1998.**
15. JONGERIUS A., HEINTZBERGER G. Methods in soil micromorphology. A technique for the preparation of large thin sections. Soil Survey Papers 10, Soil Survey Institute, Wageningen-The Netherlands, **1975.**
16. MURPHY C.P. Thin section preparation of soils and sediments. AB Academic Publishers, Herts, UK, pp 149, **1989.**
17. GŁĄB T. Application of sodium hypochlorite in the technique of soil section preparation. Int. Agrophysics, **21**, (2), 153, **2007.**
18. GŁĄB T. Application of image analysis for soil macropore characterization according to pore diameter. Int. Agrophysics, **21**, (1), 61, **2007.**
19. PAGLIAI M., LA MARCA M., LUCAMATE G. Micromorphometric and micromorphological investigation of a clay loam soil in viticulture under zero and conventional tillage. J. Soil Sci., **34**, 391, **1983.**
20. FITZPATRICK E.A. Micromorfology of soils. Chapman and Hall, London-New York, **1980.**
21. PAGLIAI M. Soil porosity aspects. Int. Agrophysics, **4**, 215, **1988.**
22. BARAN S., SŁOWIŃSKA-JURKIEWICZ A., PRANAGAL J. Analiza morfologiczna struktury gleby piaszczystej meliorowanej osadem ściekowym [Morphological analysis of sandy soil structure amended with sewage sludges]. Z. Probl. Post. Nauk Roln., **437**, 61, **1996**. [In Polish]
23. CELIK I., ORTAS I., KILIC S. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. Soil & Till. Res., **78**, (1), 59, **2004.**
24. TURNER H.S., CLARK G.A., STANLEY C.D., SMAJSTRALA A.G. Physical characteristics of a sandy soil amended with municipal solid waste compost. Proceedings Soil and Crop Science Society of Florida, **53**, 24, **1994.**
25. PARATA C., CHAUSSODB R., LEVEQUEA J., ANDREUX F. Long-term effects of metal-containing farmyard manure and sewage sludge on soil organic matter in a Fluvisol. Soil Biology & Biochemistry **37**, 673, **2005.**
26. TESTER C.F. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Sci. Soc. Am. J., **54**, 827, **1990.**
27. MBAGWU J.S.C. Effects of organic amendment on some physical properties of tropical Utisol. Biol. Wastes, **28**, 1, **1989.**
28. SORT X., ALCANIZ J.M. Modifcation of soil porosity after application of sewage sludge. Soil & Till. Res., **49**, 337, **1999.**
29. DEBOSZ K., PETERSEN S. O., KURE L. K., AMBUS P. Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. Applied Soil Ecology **19**, 237, **2002.**
30. SMITH S.R., VOODS V., EVANS T.D. Nitrate dynamics in biosolids-treated soils. I. Influence of biosolids type and soil type. Bioresource Technol. **66**, 139, **1998.**