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Effect of biowaste compost and nitrogen fertilization on macroporosity and biopores of Molli-gleyic Fluvisol soil**

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A b s t r a c t. The aim of this study was to evaluate the follow-up effect of biowaste compost on the structure and macroporosity of soil two years after compost application. The results were compared with mineral nitrogen fertilization and untreated control. A long-term crop rotation experiment was established on a silty loam Molli-gleyic Fluvisol in eastern Austria. In the 13-year field experiment different rates of compost and nitrogen fertilizers were applied. The compost used was source-separated organic household waste compost at rates of 7, 13 and 18 t ha^{-1} year^{-1} on average. Nitrogen fertilization was applied to supply 27, 47 and 64 kg N ha^{-1} year^{-1} on average. Undisturbed soil samples were collected in March 2005 and July 2005 from the 10-20 cm soil layer, and characteristics of macropores were determined with special focus on biopores content.

Results showed that the long-term application of compost and nitrogen fertilizer in the investigated soil did not cause any significant influence on macropore volume. The only effect of compost and nitrogen fertilization was observed in biopores content. Nitrogen fertilization increased participation of biopores of 1000-2000 μm and 2000-4000 μm in diameter with respect to control and compost treatment. This effect can be ascribed to higher plant biomass production at the nitrogen fertilization treatment.

K e y w o r d s: biowaste compost, nitrogen fertilization, soil macroporosity, biopores, image analysis

INTRODUCTION

Compost production and its utilization in agriculture has become a strong trend in Europe. The main benefits of compost application are lower disposal costs, recycling of nutrient elements in soil and counteracting the decrease of organic matter in soil. The agronomic utilization of organic wastes is the way of solving two problems - waste disposal and correction of the low organic matter content of many agricultural soils (Aggelides and Londra, 2000). Numerous researches deal with chemical aspects of compost utilisation, such as fertility and pollution (Bartl *et al*., 2002; Businelli *et al*., 1996; Giusquiani *et al*., 1992; Illera *et al*., 1999). Compost improves nutrient supply to plants and thus may reduce the input of mineral fertilizer. Although, on fertile soils the nitrogen fertilizer effect is very low at the beginning, but it increases during long-term compost fertilization (Erhart *et al*., 2005).

Many researches have identified the influence of compost amendment on physical properties of soil. Authors agree that organic wastes improve the soil physical properties (Aggelides and Londra, 2000; Bazzoffi *et al*., 1998; Tester, 1990). According to Giusquiani *et al.* (1995), compost increased total porosity and enhanced the soil structure and quality of the pore system. Organic matter, including compost, has beneficial effects on soil structure and leads to enhancement of hydraulic properties (Felton, 1995), slows down crust formation, delays runoff and reduces erosion. Changes in physical properties of soil are usually ascribed to the dilution effect as a result of mixing the soil with organic material of lower density (Khaleel *et al*., 1981; Tester, 1990). Although, these effects are clearly identified just after compost application in rather compacted and heavy soil (Aggelides and Londra, 2000; Celik *et al*., 2004), sandy soil (Tester, 1990; Turner *et al*., 1994) or when high rates of compost (90 t ha^{-1} year^{-1}) were applied (Giusquiani *et al*., 1995).

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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 understand its modification induced by management practices including compost addition (Pagliai and Vignozzi, 2002; Pagliai *et al*., 1981). One of the most important factors influencing soil structure is earthworm burrowing and excreting activity. The relationships between soil fauna and soil structure have been widely investigated in cultivated soil due to different agricultural managements, such as fertilization, crop rotation and tillage systems (Lamande *et al*., 2003). It was shown that with an increase in nutrient availability, earthworms generally reach higher biomass and number (Timmerman, 2006). Many studies have shown that organic fertilizers favour earthworms more than inorganic ones (Estevez *et al*., 1996; Whalen *et al*., 1998). However, sometimes a negative effect of high mineral and organic fertilization has been reported as well. That is probably related to high salt concentrations and the occurrence of substances that might be toxic to earthworms (Curry, 1976).

The aim of this study was to evaluate the follow-up effect of biowaste compost on soil macroporosity two years after last compost application in comparison with mineral nitrogen fertilization and untreated control. In this experiment the hypothesis was adopted that long term (13 years) compost application may play a favourable role in soil structure and lead to permanent changes in soil macroporosity. The objective of the study was to characterise morphometric parameters of soil macropores in a diameter range from 50 to >2000 μm with special focus on biopores investigated by image analysis on soil sections. The field trial with different rates of compost and nitrogen fertilization was established in 1993-2005 on silty loam Molli-gleyic Fluvisol in Obere Lobau, East of Austria.

MATERIAL AND METHODS

The soil type on the experimental field was Molli-gleyic Fluvisol (FAO, 1998). Table 1 reports some soil characteristics. The climate of the experimental site, situated in Lower Austria, north-east of Vienna, was rather dry. The average annual temperature was 10.5°C and the average annual rainfall amounted to 540 mm (data from the meteorological station Grossenzersdorf) (Table 2).

The investigation was carried out in the framework of a long-term field experiment of the Ludwig Boltzmann Institute for Biological Agriculture and Applied Ecology dealing with the use of biowaste compost. The experiment was set up in Obere Lobau near Vienna, Austria, in the autumn of 1992. It included three treatments with compost fertilization at rates of 7, 13 and 18 t fresh matter ha^{-1} year^{-1} on average of 13 years (C1, C2, C3), three treatments with mineral nitrogen fertilization at rates of 27, 47 and 64 kg N ha^{-1} year^{-1} on average (N1, N2, N3), and an untreated control without any fertilization (0) in six replications in a latin rectangle design. Amounts of N fertilizer (N1, N2 and N3 treatments) varied according to crop needs and soil test results, plus 17 kg P ha^{-1} and 54 kg K ha^{-1} on average. Individual plots measured 6.3/10 m. The crops, the dates and amounts of compost and nitrogen fertilizer are listed in Table 3. In this trial, biowaste compost obtained from the composting plant of the City of Vienna was used (Table 4). The compost feedstock consisted of source-separated organic waste which included organic household waste and yard trimmings at a 2:3 ratio. The compost was produced in an open windrow process with regular turning using windrow turner and front-end loader during at least 4-6 months.

The soil at the experimental site was cultivated (depth 10 cm) after harvest, and tilled (depth 28 cm) in September/October every year. For mechanical weed control, cereals were harrowed 1-2 times in April/May, potatoes were also hoed. The crop residues (straw of cereals and potatoes) were usually left on the field. The compost was applied in August/September, shortly before tillage (except 1998, when it was applied in April and incorporated a few days later with the making of ridges for potatoes). The seedbed was usually prepared a few days after tillage and the winter cereals were sown.

The laboratory analyses of soil were carried out in the Department of Machinery Exploitation, Ergonomics and Agronomy Fundamentals and Department of Soil Science and Soil Protection, Agricultural University of Cracow.

Due to more detailed characterization of pores in low water potential range, the macropore system of the investigated soil was characterised by image analysis on sections prepared from undisturbed soil samples (Jongerius and Heintzberger, 1975; Murphy, 1989). The soil samples were collected in March, at the beginning of the vegetation season, and in July, just before harvesting. The 10-20 cm soil layer was chosen for the investigation and the samples were taken in a vertical position using metal boxes (80/90/40

Table 1. Soil characteristics of Molli-gleyic Fluvisol from trial location (0-20 cm layer)

Texture	-	Silty loam
Sand	g kg^{-1}	150
Silt	g kg^{-1}	620
Clay	g kg^{-1}	230
Bulk density	g cm^{-3}	1.19
Total porosity	cm^3 cm^{-3}	0.568
$CaCO_3$	g kg^{-1}	275
Total organic C	g kg^{-1}	20.0
pH_{KCl}	-	7.2

T a b l e 2. Monthly average temperature and sum of precipitation (Grossenzersdorf meteorological station)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	Monthly average temperature (°C)											
January	2.1	1.1	4.1	0.1	-3.0	-2.8	1.7	0.3	-1.4	0.2	0.8	-0.7
February	3.4	-2.1	0.5	5.4	-3.2	3.0	5.2	1.1	4.6	2.7	6.0	-2.0
March	5.5	4.0	8.4	4.3	2.0	5.2	5.1	7.0	6.2	6.8	6.9	5.7
April	10.1	10.4	10.2	10.6	9.8	7.4	11.6	11.5	13.3	9.4	9.9	9.8
May	15.2	17.3	14.9	14.7	15.8	15.8	15.5	15.8	17.3	16.8	17.6	17.9
June	18.7	18.7	18.8	17.2	18.9	18.6	19.8	18.2	20.3	17.4	20.3	22.4
July	21.3	20.6	23.2	22.8	18.5	19.3	20.7	21.2	19.1	21.0	21.9	21.7
August	24.2	19.6	21.6	19.4	19.0	20.2	20.9	19.2	21.6	21.6	20.6	23.4
September	15.6	16.1	17.4	14.3	12.5	15.2	14.7	17.6	15.2	13.7	14.6	15.3
October	8.7	10.4	8.1	11.1	11.0	7.8	10.8	10.7	12.8	13.0	9.2	7.6
November	5.3	0.9	6.7	2.5	7.1	5.1	2.3	3.4	7.7	13.8	7.5	6.5
December	0.3	2.1	2.0	-0.4	-2.7	2.4	-1.1	1.1	2.1	-2.1	-0.8	0.9
Mean	10.9	9.9	11.3	10.2	8.8	9.8	10.6	10.6	11.6	11.2	11.2	10.7
	Sum of precipitation (mm)											
January	14	29	19	22	34	15	13	9	29	15	6	38
February	13	11	5	28	26	12	2	36	24	15	29	1
March	89	13	27	42	21	59	27	23	72	47	58	11
April	22	21	71	55	95	32	18	55	19	26	65	23
May	14	14	37	48	108	63	42	72	27	20	45	76
June	90	53	43	119	84	70	45	70	15	55	77	52
July	25	107	50	53	32	175	75	82	69	82	101	56
August	2	84	35	47	80	18	40	73	64	37	121	32
September	34	31	37	128	74	33	94	74	60	105	43	32
October	46	59	52	8	36	20	76	20	39	8	99	28
November	68	40	50	35	17	61	29	45	50	29	49	28
December	28	37	27	61	15	36	21	49	32	33	53	32
Sum	445	499	453	646	622	594	482	608	500	472	746	409

mm). Samples were dried at room temperature. Then they were saturated with polyester resin (POLIMAL 109 32K). The samples were put in a vacuum chamber and the pressure was cyclically changed from -85 kPa to atmospheric pressure in order to remove any entrapped air. After hardening of the resin the samples were cut to slices and then they were 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 (Głąb, 2007a). The surfaces of samples (80/90 mm) were scanned at a resolution of 600 dpi using Epson Perfection 4870 Photo scanner. The images were saved as tiff files. The total number of images was 896 (128 from every treatment). They were analysed using the APHELION software for image analysis (ADCIS S.A. and Amerinex Applied Imaging). The final result was set of pores grouped in six diameter classes according to a method described by Głąb (2007b): 50-100, 100-200, 200-500, 500-1000, 1000-2000, and >2000 μm. The pores were also divided into three classes according to their shape expressed by the shape factor (4π area perimeter^{-2}) (Pagliai *et al.*, 1983): regular (shape factor 0.5-1.0), irregular (0.2-0.5) and elongated (0.0-0.2).

The most accepted classification of pores based on their morphology according to Brewer (1964) identified six main types of pores: packing pores, vughs, channels, planes, chambers and vesicles. Channels, chambers and mammil-

T a b l e 3. Crop sequence, dates and amounts of compost and mineral nitrogen fertilizer applications (calcium ammonium nitrate)

Year	Crop	Compost							Mineral nitrogen fertilizer			
		Application date	Amounts ($t ha^{-1}$ f.m.*)			Amounts ($kg N ha^{-1}$)			Application date	Amounts ($kg N ha^{-1}$)		
			C1	C2	C3	C1	C2	C3		N1	N2	N3
1992/93	Winter rye (*Secale cereale* L. 'Danko')	9/1992	15	30	45	32	65	97	3/1993	25	50	75
1994	Potatoes (*Solanum tuberosum* L. 'Ukama')	9/1993	15	30	45	67	133	200	4/1994	40	80	120
1994/95	Winter wheat (*Triticum aestivum* L. 'Capo')	9/1994	30	45	60	54	81	108	3+5/1995	60	90	120
1996	Oats (Avena sativa L. 'Jumbo')		-	-	-	-	-	-	5/1996	30	45	60
1996/97	Spelt (*Triticum spelta* L. 'Schwabenkorn')		-	-	-		-	-		-	-	-
1998	Early potatoes (*Solanum tuberosum* L. 'Christa')	4/1998	10	20	30	80	160	240	3/1998	30	90	120
1998/99	Winter wheat (Triticum aestivum L. 'Capo')		-	-	-	-	-	-		-	-	-
1999/2000	Winter barley (*Hordeum vulgare* L. 'Montana')		-	-	-	-	-	-		-	-	-
2000/01	Winter rye (*Secale cereale* L. 'Elekt')	8/2000	10	20	30	38	76	114	3/2001	30	45	60
2001/02	Winter wheat (*Triticum aestivum* L. 'Capo')		-	-	-	-	-	-	4/2002	30	45	60
2003	Potatoes (*Solanum tuberosum* L. 'Agatha')		-	-	-	-	-	-	3/2003	30	45	60
2003/04	Winter wheat (*Triticum aestivum* L. 'Capo')	8/2003	10	20	30	85	169	254	4/2004	30	45	60
2004/05	Winter rye (*Secale cereale* L. 'Elekt')		-	-	-	-	-	-	4/2005	50	75	100
Average			7	13	18	59	114	169		27	47	64

*f.m. = fresh matter

lated vughs (subdivided from vughs) are classified as of faunal origin (Brewer, 1964). These types of pores differ in their morphometric parameters such as area, perimeter, feret diameter *etc*. which makes it possible to select them from other pores. In this study the methodology established by Ringrose-Voase and Bullock (1984) was used for biopore detection. The biopores were selected due to their convex shape and shape factor. The convex shape measures the perimeter of a convex figure around the object. The shape factor was calculated from the area and total perimeter of the object. The decision of pore classification was based on a definition described by Ringrose-Voase and Bullock (1984) and modified by VandenBygaart *et al*. (2000). The biopores were divided into three size classes: 1000-2000, 2000-4000 and >4000 μm. The minimum diameter (1000 μm) was accepted according to Lee (1985) who states that earthworms are generally >1000 μm in diameter. The isolation and measurement of the biopores >1000 μm in diameter by morphometric analysis is sufficient for estimation of the influence of earthworms on soil structure formation (VandenBygaart *et al*., 2000).

All data were analysed by analysis of variance (ANOVA) using STATISTICA 6.0 (StatSoft Inc.). The means were compared by Duncan test with a level of significance of $P<0.05$.

Table 4. Chemical and physical properties of the composts (analysed according to OENORM S2023, 1993: Untersuchungsmethoden und Gueteueberwachung von Komposten. Oesterreichisches Normungsinstitut, Wien)

Compost properties		Application year						
		1992	1993	1994	1995	1998	2000	2003
N_{tot}	g kg^{-1} d.m.[a]	9	12	15	6	21	10	18
NO_3-N	mg kg^{-1}	300	2	0.5	4	<1	<1.5	12
NH_4-N	mg kg^{-1}	55	1010	330	360	223	180	600
C/N		21	19	23	-b	9	19	12
NO_3-N/NH_4-N		5	< 1	< 1	< 1	<1	<1	0.3
EC[c]	mS cm^{-1}	3.4	0.9	1.5	2.3	1.7	0.9	1.3
pH		7.8	7.5	6.9	7.0	7.3	7.1	7.4
Organic matter	g kg^{-1} d.m.[a]	270	420	580	550	334	307	208
Water content	g kg^{-1} f.m.[d]	240	370	120	370	380	380	470

[a]data are based on 105°C dry matter weight, [b]missing value, [c] EC = electrical conductivity, [d]f.m. = fresh matter.

RESULTS AND DISCUSSION

Macropore characteristics

The soil samples were collected at two terms (March 2005 and July 2005) during the vegetation period. However, no statistically significant differences were found in soil macroporosity between terms of data collecting. The average total macroporosity (percentage of area occupied by pores larger than 50 μm in diameter) was 15.3% and varied from 14.3% (C2) to 16.4% (0) (Table 5). According to the Pagliai classification (1988), the soil can be classified as moderately porous.

For a thorough characterization of soil macropores, the pore size distribution and pore shape were also considered. There were no significant differences between treatments for the porosity in all shape and size classes. The area occupied by large pores >2000 μm was 4.17% in average and it decreased to 0.47% for small pores (50-100 μm) (Table 6). The shape of pores was usually classified as elongated (Table 5). Approximately 37.9% of all macropores were elongated, whereas irregular and elongated pores were 32.9 and 29.1%, respectively. Large pores (>2000 μm) were characterized by irregular shape. Whereas, small pores (50-200 μm) were usually regular in their shape. The domination of elongated pores in upper layer of tilled soil is confirmed by results obtained by Pagliai *et al*. (2004).

The texture of the investigated soil (silty loam) can be recognized as one of the explanations for lack of differences in porosity. The influence of compost amendment is clearly identified for degraded soils or those with unfavourable texture for crop growth. Pagliai *et al*. (2004) reported that compost fertilization played a favourable role in soil porosity on clay loam compacted soil. A similar effect of influence of compost amendment on physical properties of heavy soil was confirmed by Celik *et al*. (2004) and Turner *et al*. (1994). A significant effect of organic and mineral fertilization on macroporosity was also reported for sandy soil (Marinari, 2000).

Soil samples were collected after 13 years of different compost and nitrogen treatments. However, the last compost application was in August 2003, two years before sampling. During this period, the compost had decomposed and no permanent changes in soil structure were visible. The compost amendment may affect soil porosity just after the application. Giusquani *et al*. (1995) reported that 10 and 90 t ha^{-1} application of compost every year changed soil macroporosity, but the porosity observed in autumn sampling was lesser than in spring sampling (just after when compost added). That could be explained as a result of physical stresses caused, for example, by rainfall.

Biopores

Although there were no differences in macroporosity, the influence of earthworm activity on soil porosity was statistically significant due to compost and nitrogen fertilization. We expected a higher earthworm activity at compost treatment as it was reported by Whalen *et al*. (1998) and Estevez *et al.* (1996). Whereas, the compost fertilization at 7, 13 and 18 t f.m. year^{-1} rates did not effect the biopores content, while nitrogen fertilization (N1, N2 and N3) significantly increased number and area occupied by biopores.

The most frequent fraction were small biopores of 1000-2000 μm in diameter (85% of total number of biopores) (Table 7). The classes 2000-4000 and >4000 μm were 14 and 1%, respectively. Similar proportion in biopore sizes was reported by Wuest (2001). For number of biopores there

Table 5. Effects of compost and nitrogen fertilization on soil macroporosity according to pore shape after 13 years of compost and nitrogen fertilization

Treatments	Macroporosity for shape classes (%)			Total macroporosity (%)
	regular	irregular	elongated	
0	4.67	5.42	6.30	16.39
C1	4.18	4.71	5.61	14.50
C2	4.34	4.70	5.25	14.29
C3	4.45	5.20	6.34	16.00
N1	4.52	5.05	5.83	15.41
N2	4.57	4.77	5.53	14.86
N3	4.62	5.33	5.73	15.68
Mean	4.48	5.03	5.80	15.30
Standard deviation	0.63	0.55	0.99	2.14

For all shape classes the differences between treatments were not significant at P<0.05.

Table 6. Effects of compost and nitrogen fertilization on soil macroporosity according to pore size after 13 years of compost and nitrogen fertilization

Treatments	Macroporosity for shape classes (%)					
	50-100	100-200	200-500	500-1000	1000-2000	>2000
0	0.50	1.74	3.22	3.29	3.25	4.39
C1	0.42	1.46	2.77	2.65	2.75	4.45
C2	0.48	1.51	3.14	2.98	2.64	3.54
C3	0.45	1.60	3.08	3.14	2.90	4.82
N1	0.45	1.47	3.22	3.19	3.18	3.90
N2	0.47	1.37	3.05	2.90	2.97	4.10
N3	0.53	1.93	3.30	3.07	2.86	4.00
Mean	0.47	1.58	3.11	3.03	2.94	4.17
Standard deviation	0.08	0.24	0.31	0.39	0.47	0.75

For all pore diameter classes the differences between treatments were not significant at P<0.05.

were no differences between control (0) and compost treatments (C1, C2 and C3). However, nitrogen fertilization (N1, N2 and N3) significantly increased the number of biopores in classes of 1000-2000 and 2000-4000 μm by 38 and 103%, respectively, in comparison with the untreated control. The large biopores (>4000 μm) were not affected by both compost and nitrogen fertilization. This fraction was characterized by low quantity and spatial variability.

The changes in percentage of biopores in total macroporosity were similar to those in biopore quantity. The nitrogen fertilization increased the area occupied by 1000-2000 and 2000-4000 μm biopores by 32 and 74%, respectively (Table 8). The participation of 1000-2000 μm fraction in total area of biopores was 59%. For 2000-4000 and >4000 μm fractions this percentage was 35 and 7%, respectively.

Inorganic fertilizers may indirectly benefit earthworms population by increasing plant production. Plant yields, as crop residues and roots, affect the soil fauna by supplying them with dead organic matter as their food (Brusaard, 1998). Edwards and Lofty (1982) showed there was a strong positive correlation between the amount of inorganic N applied and the size of the earthworm population. At the field experiment investigated here, pronouncedly higher yields of cereals were observed when nitrogen fertilization was applied, particularly at the N3 treatment, than in the compost and control treatments (Erhart *et al.,* 2005). Sometimes a negative effect of mineral fertilization on earthworm population was observed as a result of acidifying fertilizers (Ma *et al.,* 1990). However, at this experiment no changes in pH and electrical conductivity were noticed (Bartl *et al.,* 2002).

Table 7. Number of biopores (m^{-2}) in 10-20 cm soil layer after 13 years of compost and nitrogen fertilization

Treatments	Number of biopores for diameter classes (μm)			Total
	1000-2000	2000-4000	>4000	
0	5340 a	667 a	36 a	6043 a
C1	5718 a	839 a	43 a	6570 a
C2	5456 a	762 a	32 a	6250 a
C3	5543 a	808 a	26 a	6376 a
N1	7530 b	1171 b	100 a	8802 b
N2	7325 b	1480 c	82 a	8887 b
N3	7201 b	1417 bc	74 a	8691 b
Mean	6302	1020	56	7378
Standard deviation	1071	163	14	1254

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

Table 8. Percentage of biopores in total macroporosity in 10-20 cm soil layer after 13 years of compost and nitrogen fertilization

Treatments	Percentage of biopores for diameter classes (μm)			Total
	1000-2000	2000-4000	>4000	
0	4.65 a	2.30 a	0.49 a	7.44 a
C1	4.69 a	2.52 a	0.43 a	7.64 a
C2	4.90 a	2.77 a	0.39 a	8.06 a
C3	4.51 a	2.43 a	0.23 a	7.17 a
N1	5.93 b	3.76 b	0.85 a	10.54 b
N2	6.36 b	4.00 bc	1.04 a	11.40 b
N3	6.09 b	4.25 c	0.82 a	11.16 b
Mean	5.31	3.15	0.61	9.06
Standard deviation	0.90	0.41	0.17	1.27

Explanationas as in Table 7.

In this experiment the compost fertilization was applied in August 2003, two years before soil sampling. The results show that there were no accumulated effects of organic amendment on soil pore characteristics. This supports the thesis that the effect of organic waste application on biological properties (microbial and earthworm activity) of soil is temporary and appears mainly in the first few weeks after amendment. According to Debosz *et al.* (2002), after 11 months no effects are observed. This statement is also confirmed by Giusquani *et al.* (1995).

CONCLUSIONS

1. Results show that the long-term application of compost and nitrogen fertilization on silty loam Molli-gleyic Fluvisol soil does not cause any significant influence on physical properties of soil.

2. After 13 years of crop rotation with compost application there were no stable changes in soil structure in comparison with soil without compost amendment.

3. The main reasons for lack of differences between compost and nitrogen fertilization are: the low rate of compost used, the period of time after compost application and the silty loam texture with high porosity. Nitrogen fertilization significantly increased the participation of biopores.

5. The mean contribution of biopores in macroporosity of investigated soil was 9%. This value was too small to significantly affect the total macroporosity of soil. Although there was significant influence of nitrogen fertilization on biopores, no other changes were found in the characteristics of macropores volume and their shape and size. The changes in the proportion of biopores can be ascribed to higher plant biomass production at the nitrogen fertilization treatment.

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