Int. Agrophysics, 2009, 23, 123-128

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Effect of biowaste compost and nitrogen fertilization on water properties of Mollic-gleyic Fluvisol**

T. Głąb[1]******, *T. Zaleski*[2], *E. Erhart*[3], *and W. Hartl*[3]

[1]Department of Machinery Exploitation, Ergonomics and Agronomy Fundamentals, University of Agriculture,
Balicka 116 B, 31-149 Cracow, Poland
[2]Department of Soil Science and Soil Protection, University of Agriculture, Mickiewicza 21, 31-120 Cracow, Poland
[3]BioForschungAustria, formerly Ludwig Boltzmann-Institute for Biological Agriculture and Applied Ecology, Rinnboeckstrasse 15,
1110 Vienna, Austria

Received January 13, 2009; accepted February 16, 2009

Abstract. The effect of biowaste compost and nitrogen fertilization on the soil water properties was tested in a long-term crop rotation experiment established in 1992 on a silty loam Mollic-gleyic Fluvisol in eastern Austria in the field trial different biowaste compost and mineral fertilizers were applied. Results were compared also with an untreated control. Soil samples were collected in 2005 and the water retention, saturated hydraulic conductivity and characteristics of pores were determined. Based on the water retention characteristics the pore-size distribution was established. The dominant pore fraction consisted of storage (0.5-50 µm) and transmission (50-500 µm) pores, having a total volume of more than 0.1 cm^3 cm^{-3}. Fertilization was found not to influence the amount of storage pores, and did not produce any differences in available and productive water retention. The main conclusion of this study is that long-term application of compost and nitrogen fertilizers did not have any significant influence on bulk density, water retention, pore-size distribution and the saturated hydraulic conductivity.

Keywords: biowaste compost, nitrogen fertilization, Mollic-gleyic Fluvisol, pore-size distribution, water retention, hydraulic conductivity

INTRODUCTION

Compost production and its utilization in agriculture have recently become increasingly popular in Europe. Lower disposal costs, recycling of nutrient elements in soil, and countering decreases in soil organic matter are the main reasons for the agronomic utilization of compost. The application of organic wastes solves two problems: waste disposal as such and correcting problems of low organic matter contents of many agricultural soils (Aggelides and Londra, 2000). Numerous studies have focused on the chemical aspects of compost utilization, such as fertility and pollution (Bartl *et al*., 2002). Compost was found to improve the nutrient supply to plants and thus may reduce the need for mineral fertilizers. However, the effect of nitrogen fertilization appears be very low initially for fertile soils, but may increase during long-term compost fertilization (Erhart *et al*., 2005).

Many studies have identified the influence of compost amendment on the physical properties of soils. Most studies agree that organic wastes improve the soil physical properties (Aggelides and Londra, 2000). Giusquiani *et al*. (1995) found that compost increased total porosity and enhanced soil. Organic matter, including compost, has been shown to have beneficial effects on soil structure and leads to higher hydraulic conductivities (Hargreaves *et al*., 2008), decreases crust formation, delays surface runoff and reduces erosion. Researchers have reported an increase in the water retention capacity of soils at field capacity and at the wilting point (Chang *et al*., 1983; Metzger and Yaron, 1987). These changes in the physical properties are ascribed to the mixing of soil with less dense organic material (Khaleel *et al*., 1981). These effects are most clearly identified immediately after compost application in relatively compacted, fine-textured soils (Aggelides and Londra, 2000; Celik *et al*., 2004), in coarse-textured soils (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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*Corresponding author's e-mail: rtglab@cyf-kr.edu.pl

**This project was supported by funds from the City of Vienna, Austria, Municipal Department 48.

The aim of this study was to evaluate the long-term effect of biowaste compost on soil hydraulic properties. We hypothesized that long-term application of compost would improve the soil air-water properties of Mollic-gleyic Fluvisols. The experiment was carried out in eastern Austria where precipitation during March to July totaled 270 mm (average of 1992-2003), and where water deficiency during the growing season is very common. Our main objective was to characterize the hydraulic properties of the soils and their pore-size distribution after 13 years of compost and nitrogen fertilization, and to compare results with those of an untreated control.

MATERIALS AND METHODS

The field trial in a latin rectangle design was set up in the Obere Lobau near Vienna, Austria, in 1992. The applied treatments were biowaste compost fertilization at three rates: 7 (C1), 13 (C2) and 18 (C3) t fresh matter ha^{-1} year^{-1} on average for 13 years, mineral nitrogen fertilization at three rates: 27 (N1), 47 (N2) and 64 (N3) kg N ha^{-1} year^{-1} on average, and an untreated control (0). Detailed information concerning the experiment, such as crop rotation, the physical and chemical properties of the compost, the dates and amounts of compost and nitrogen fertilization, are presented elsewhere (Głąb *et al.*, 2008).

Soil type at the field site was a Mollic-gleyic Fluvisol (IUSS Working Group WRB, 2007). The climate at the 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 rate 540 mm (Głąb *et al.*, 2008).

Soil samples were collected in March 2005 at the beginning of the vegetation season, and in July 2005 just before harvesting. The 10-20 cm soil layer was chosen for the investigation due to its location in the tilled layer where most of the roots usually are localized, but below the harrowed layer. The soil moisture characteristic was determined using pressure chambers with ceramic plates (Klute and Dirksen, 1986a). For the water retention characteristics we used undisturbed soil samples collected using metal cylinders of 100 cm^3 capacity in four replications from every plot (the total number of samples was 168). The soil samples were placed in the pressure chambers and equilibrated with seven different water potentials (-3.9, -15.6, -33.0, -77.9, -195.7, -491.7 and -1554.8 kPa). The time of equilibrium in the extractor was determined using a burette system for measuring the outflow volume. The soil water retention curves were expressed in terms of the following equation (Van Genuchten, 1980):

$$\theta = \frac{\theta_s}{\left[1+(\alpha h)^n\right]^{(1-1/n)}} \qquad (1)$$

where: θ is the soil water content (cm^3 cm^{-3}), h is the soil water tension (kPa), θ_s is the saturated water content (assuming equivalence with total porosity), and α and n are model parameters. Equation (1) was fitted to the measured data of each soil sample using a nonlinear least-squares procedure.

Once the parameters of Eq. (1) were estimated, we used the obtained $\theta(h)$ function to calculate available water retention (AWR) and productive water retention (PRW). AWR is defined as the difference between the moisture contents at -33 kPa and -1500 kPa water potential, while PRW is defined here as the difference between the moisture levels at -33 kPa and -490 kPa water potential. The soil water retention characteristic was also used to estimate the pore-size distribution according to the procedure described by Kutilek *et al.* (2006). The curves of pore-size distribution were derived from the derivative curves, when the water potential h (kPa) was replaced by the equivalent pore diameter (μm). The volumes of the different pore categories were determined according to the pore classification of Greenland (1977), who characterized pores as bounding space pores (<0.005 μm), residual pores (0.005-0.5 μm), storage pores (0.5-50 μm), transmission pores (50-500 μm) and fissures (>500 μm). The hydraulic conductivity K_s at saturation was determined by the Klute method (Klute and Dirksen, 1986b) using undisturbed soil samples.

The effects of compost and mineral fertilization on the soil hydraulic properties were analyzed statistically using an analysis of variance (ANOVA) for a latin rectangle design. A separation of means was carried out with the Duncan's test using a level of significance of P<0.05. The analysis of variance and the differences of the means were tested using STATISTICA 6.0 (StatSoft Inc, Tulsa, OK, USA)

RESULTS AND DISCUSSION

The mean bulk density of the investigated soil was 1.2 g cm^{-3} and the total porosity was 0.57 cm^3 cm^{-3} (Table 1). Compost amendments at rates of 7, 13 and 18 t fresh matter ha^{-1} year^{-1} on average and N mineral fertilisations at rates of 27, 47 and 64 kg N ha^{-1} year^{-1} on average did not lead to any changes in bulk density and total porosity.

The $\theta(h)$ curves (Fig. 1) were determined using the Van Genuchten parameters which are shown in Table 2. The retention curves were next used to calculate the pore size distribution (Fig. 2). The maximum value of the porosity was obtained for pores of approximately 5 μm in diameter.

The average contents of the various pore fractions were 0.098 cm^3 cm^{-3} for bounding space pores, 0.091, 0.175, and 0.122 cm^3 cm^{-3} for residual, storage, and transmission pores, respectively, and 0.080 cm^3 cm^{-3} for the fissures. The two dominant fractions hence were the storage and transmission pores. All investigated pore fractions (bounding space, the residual, storage, and transmission pores, and the fissures) were found not to be affected by mineral or compost fertilization. The storage pores (0.5-50 μm), which contain water for plants and for microorganisms, are most strictly related with the water retention properties of the investigated soils. The

T a b l e 1. Effect of the compost and nitrogen fertilization on bulk density, pore-size distribution and the saturated hydraulic conductivity after 13 years of compost and mineral fertilization

Treatment	Bulk density (g cm^{-3})	K_s (cm day^{-1})	Pores (cm^3 cm^{-3})					Total porosity (cm^3 cm^{-3})
			Bounding space	Residual	Storage	Transmission	Fissures	
0 (control)	1.220	33.2	0.099	0.092	0.175	0.118	0.067	0.551
C1	1.194	41.4	0.101	0.091	0.173	0.121	0.083	0.569
C2	1.200	36.1	0.097	0.094	0.184	0.123	0.066	0.564
C3	1.169	37.2	0.098	0.093	0.178	0.122	0.073	0.574
N1	1.181	33.6	0.102	0.091	0.170	0.120	0.090	0.573
N2	1.164	31.6	0.093	0.088	0.171	0.125	0.099	0.578
N3	1.200	38.5	0.095	0.091	0.177	0.125	0.083	0.570
Mean	1.190	35.8	0.098	0.091	0.175	0.122	0.080	0.568
SD	0.081	21.8	0.012	0.010	0.029	0.023	0.015	0.031

Differences in bulk density, pore-size distribution and K_s between the treatments were not significant at $P<0.05$.

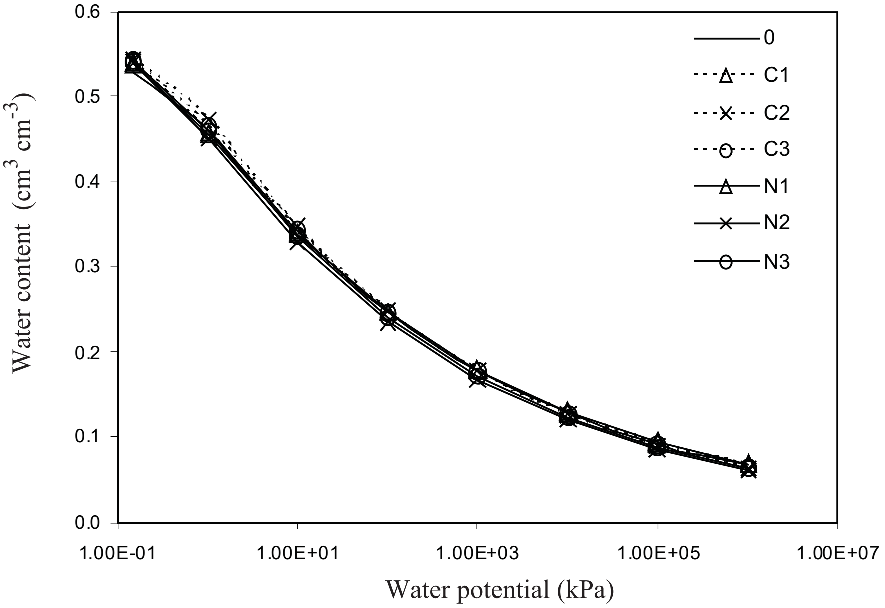

Fig. 1. Soil water retention curves based on the van Genuchten equation for field experiment data with mineral (N) and compost fertilization (C).

transmission pores facilitate the movement of water and are needed by feeding roots to grow into. The lowest pore fraction (0.080 cm^3 cm^{-3}) was associated with the larger pores >500 μm in diameter (the fissures). Fissures have a useful effect on root penetration and water movement, especially in fine textured soils (Greenland, 1977).

The lack of differences obtained in the volume of storage pores resulted in very similar AWR and PWR values for the various treatments. We found that soil density and total porosity were not statistically different at the two sampling times (March and July, 2005). This also pertains to other measured soil property such as the saturated hydraulic conductivity. These findings are contrary to several studies showing the favourable effect of compost fertilization on the soil physical properties, especially when higher rates of compost are applied. For example, Mbagwu (1989) found that organic wastes incorporated into the soil at a rate of 10% increased the total porosity by 23%.

Table 2. Van Genuchten soil hydraulic parameters (θ_s, α and n) derived from field experiment with application of biowaste compost and mineral nitrogen fertilization

Treatments	θ_s	α	n	R^2*
0 (control)	0.551	2.86	1.142	0.862
C1	0.569	3.97	1.140	0.869
C2	0.564	2.60	1.147	0.897
C3	0.574	3.13	1.144	0.868
N1	0.573	4.54	1.137	0.850
N2	0.578	4.97	1.144	0.881
N3	0.570	3.66	1.146	0.885

*Coefficient of determination between measured and fitted $\theta(h)$ data for estimation of α and n.

Table 3. Effect of the compost and nitrogen fertilization on available (AWR) and productive (PWR) water retention after 13 years of compost and mineral fertilization

Fertilization	AWR (cm^3 cm^{-3})	PWR (cm^3 cm^{-3})
0 (control)	0.121	0.092
C1	0.129	0.090
C2	0.126	0.096
C3	0.123	0.093
N1	0.118	0.089
N2	0.118	0.089
N3	0.122	0.092
Mean	0.121	0.092
SD	0.031	0.032

Differences in available and productive retention between the treatments were not significant at P<0.05.

The mean values of PWR and AWR for all treatments were 0.121 and 0.092 cm^3 cm^{-3}, respectively (Table 3). Both PWR and AWR were unaffected by compost and mineral fertilization compared with untreated soil. In a previous study (Głąb and Szewczyk, 2004) we observed similar effects similar results for grasslands exhibiting good structural quality and relatively high porosities. The influence of fertilization, whether mineral or organic, was found not to be significant in that study. Some studies even reported unfavourable effects of fertilization on water retention (Zaleski and Kopeć, 2003).

The positive effects of compost amendment on air-water soil hydraulic properties have been clearly identified in several studies, for example immediately after compost application to relatively compacted fine-textured soils (Celik *et al.*, 2004), course-textured soils (Turner *et al.*, 1994) or when high rates of compost were applied (Aggelides and Londra, 2000; Giusquiani *et al.*, 1995). According to Aggelides and Londra (2000) compost amendment significant changes the water retention curves when the applied compost rates were more than 78 t ha^{-1}.

The fertilization treatments did not lead to statistically significant differences in the hydraulic conductivity among the various treatments (Table 1). The mean value of K_s of all treated plots was 35.8 cm day^{-1}. The hydraulic conductivity is related to soil porosity, in particular the transmission pores (Pagliai and Vignozzi, 2002). The lack of differences in transmission pores resulted in K_s values that were statistically not different among the various treatments. The mean total porosity of the investigated soils was 0.568 cm^3 cm^{-3}, of which 22% were transmission pores. Treating such high-porosity soils with compost at rates of 7, 13 or 18 t ha^{-1} did not change their K_s values. Soils with a high macroporosity are known to generally have higher saturated hydraulic conductivity values. According to Marinari *et al.* (2000) organic compost application considerably increased volume

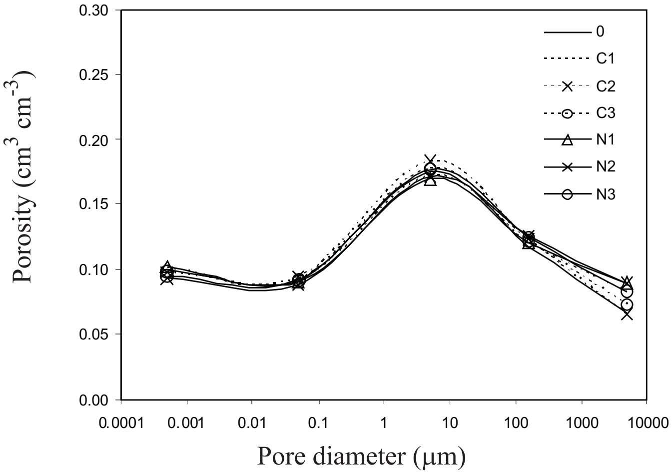

Fig. 2. The influence of biowaste compost (C) and mineral nitrogen fertilization (N) on the continuous pore-size distribution.

of macropores of approximately 10% with respect to untreated. A similar effect was found by Celik *et al*. (2004) who determined that compost amendment changed the porosity by 32% compared with the control, which had a total porosity of 0.39 $cm^3 cm^{-3}$ and macroporosity 0.14 $cm^3 cm^{-3}$. The hydraulic conductivity in the latter study increased from 19.2 to 62.9 cm day^{-1}. These results were confirmed by Pagliai *et al*. (2004).

The K_S data obtained at this experiment showed considerable variation among the samples, a feature that is typical for the upper, ploughed layer of agricultural soils. Temporal and spatial variations in the hydraulic conductivity may be caused by the growth and decay of plant roots (Meek *et al*., 1992), the activity of soil organisms (Willoughby *et al*., 1996), precipitation leading to surface crusting, alternate shrinking and swelling processes (Bagarello *et al*., 1999), and such agricultural activities as tillage and wheel-traffic compaction (Logsdon and Jaynes, 1996). Because many factors influence the hydraulic conductivity of a soil, temporal patterns are often difficult to identify (Logsdon, 1993).

The results presented in this paper indicate that both compost and mineral fertilization did not change the hydraulic properties of the Mollic-gleyic Fluvisol in our study. They also confirm our previous results (Głąb *et al*., 2008) concerning soil structure and soil macroporosity in that compost application did not play a significant role in soil structure formation as compared to soil without compost amendment, and did not significantly influence the macropore characteristics.

CONCLUSIONS

1. Results show that the long-term application of compost and nitrogen fertilization to a silty loam Mollic-gleyic Fluvisol did not significantly affect the hydraulic properties of the soil.

2. A total of 13 years of crop rotation with compost application did not lead to permanent changes in soil porosity, water retention and hydraulic conductivity in comparison with the untreated soil.

3. The main reasons for a lack of differences between compost and mineral fertilization, and with the untreated control, are believed to be (i) the low rate of compost used, (ii) the period of time after compost application and (iii) the silty loam texture and high porosity of the soil used in this study.

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