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Effect of a Long-Term Compost Treatment on the Water Management of Sandy Soil

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Background: The large part of sandy soils in Hungary has unfavorable water management properties. Studies have shown that the sewage sludge compost, due to its high organic content, is suitable for improving structure and water management of these soils. The aim of our study was to determine the effects of the application of sewage sludge compost on physical properties of sandy soil.
Materials and Methods: The experiment was established in 2003 at the Research Institute of Nyíregyháza of the University of Debrecen in Hungary to study the utilization of sewage sludge compost in agriculture. In this study, however, the changes of water retention and erodibility of soil were measured for three periods. The soil type of the experiment is Arenosol (Dystric Lamellic Arenosol). The applied compost contained sewage sludge of 40%, straw of 25%, bentonite of 5% and rhyolite of 30%. The compost is applied every 3rd year in the following amounts: 0, 9, 18 and 27 Mg ha^{-1} of dry matter.
Results: The compost treatment had a beneficial effect on soil structure thereby reducing the runoff and sediment loss under high intensity rainfall (130 mm h^{-1}). However, in the control plot there was significantly higher water erosion. The water retention of soil was slightly increased after compost application.
Conclusions: The compost application improved the water management properties of sandy soil, which is connected with organic matter addition into soil. The compost treatment had a beneficial effect on soil structure thereby reducing the runoff and sediment loss.

Keywords: *Erosion, Sandy Soil, Sewage Sludge Compost, Water Management*

1. Background

Soil is the key part of the earth system as they regulate the biological, geological, erosional, hydrological and chemical cycles. As a key to the sustainability of the earth, soil provides good services and resources to humankind (1). The area of fertile soils for agricultural activities is continuously becoming limited that has made the sustainable use of the natural resources, especially the protection and improvement of soil come to the front. In agriculture, the utilization of the natural materials, by-products and industrial wastes is preferred for improving the physical and water management properties of soils (2, 3, 4, 5). Soil fertility provides the ability of the soil to supply essential plant nutrients and water in adequate amounts for plant growth. Fertile soil support a diverse and active biotic community, which helps the soil resist environmental degradation. Being dependent on microbial biomass activity, biological and biochemical parameters of soil are considered to be the most sensitive indicators even to slight modifications in soil (6, 7, 8). The soil fertility is strongly influenced by the soil water management, which can be well characterized by hydraulic conductivity and water retention. Studies have shown that 31% of Hungary agricultural lands belong to the category of good water management, 26% to moderate and 43% to unfavourable water management. The last category includes the sandy soils and brown forest soils in Nyírség region with their shallow fertile soil layer. The fertility of sandy soils is limited by their low mineral and organic colloids content and, therefore, their unfavourable physical and water management properties (9). The results of new experiments show that the range of potentially suitable materials may expand further with using of compost to increase the colloid content of sandy soils (10, 11, 12). Besides that, the composting can be a solution for treatment of sewage sludge, the high organic content of which can be used in agriculture for nutrient-supply and increasing soil fertility as well (13). Compost application can improve the acidic sandy soils, which are poor in mineral and organic colloids (14, 15). The organic matter input reduces the soil compaction and increases the porosity and aggregate stability (16). The water management and nutrient-supply of soil are significantly improved by compost treatment (17). The small portable rainfall simulators are able to reproduce infiltration and interrill-erosion processes on field. These devices are very common in soil erosion research because of low costs, easy handling, low water consumption and easy transport on field (18, 19). The erodibility of soils is inversely related to the stability of the soil aggregates. The increased organic matter content of soil increases its fertility and improves its structure, thereby reducing the damages in drought periods and the erosion rate (20, 21).

2. Objective

The aim of this work was to investigate the effect of regular sewage sludge compost application in a long-term experiment to find out the long-term changes in soil physical properties in this part of Hungary.

3. Materials and Methods

3.1. Study area

The experiment was conducted at Nyíregyháza Research Institute, University of Debrecen, Hungary. The long-term mean annual temperature and precipitation of the area are 9.8 ºC and 562 mm, respectively. The experiment performed in 2003 on the characteristic soil type (Dystric Lamellic Arenosols (87.69% sand, 2.67% silt, 9.64% clay) of Nyírség Region. The main physical and chemical properties of sandy soil before starting the experiment in 2003 are presented in Table 1.

3.2. Field experiment

In the experiment there were five blocks. The Figure 1 shows the design of one block of the experiment.

Table 1 Soil characteristics before starting the experiment (2003) (22)

$pH_{(KCl)}$	$pH_{(H2O)}$	Soil organic matter (SOM) (%)	NO_3-N (mg kg^{-1})	AL-K_2O (mg kg^{-1})	AL-P_2O_5 (mg kg^{-1})	Soil plasticity according to Arany
5.3	6.2	0.9	9.6	183.3	240.1	28.0

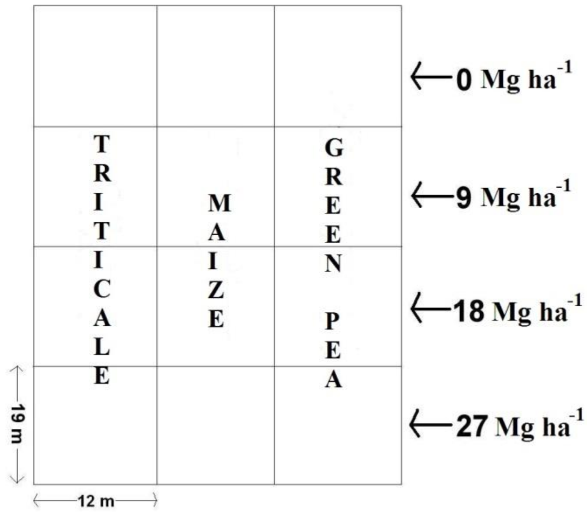

Figure 1 Experimental design

The applied compost contained 40% sewage sludge, 25%straw, 5%bentonite, 30%rhyolite, and a high organic matter content of 25-30%. The composition of sewage sludge compost met the limit values of the Hungarian regulation (36/2006. (V.18.) Decree of the Ministry of Agriculture). The plots were treated with compost every 3 years from 2003 at ratios of 0, 9, 18 and 27 Mg ha^{-1} of dry matter. Test plants, including triticale (*x Triticosecale* Wittmack), maize (*Zea mays* L.) and green pea (*Pisum sativum* L.), were sown in a crop rotation.

3.3. Soil sampling and analysis

The long-term application of composted sewage sludge on soil physical properties were examined from year 2011 by taking about 100 $cm^3$of undisturbed soil samples from the 5-10 cm layer in five replicates, after harvesting. The sandbox, sand/kaolin box and pressure membrane apparatus were used to determine the soil water retention. The sandbox can be used to apply a range of pressures from pF (suction) 0 to pF 2.0 (100 hPa). The sand/kaolin box can be used to determine moisture percentages at pF-values from 2.0 (100 hPa) to 2.7 (500 hPa), while the pressure membrane apparatus can create pressures from pF 3.0 (1000 hPa) to pF 4.2 (15000 hPa) (23). Eijkelkamp rainfall simulator was used with rainfall intensity of 130 mm h^{-1} for measuring the hydraulic conductivity and characterizing the erodibility of soil. The rainfall simulator consisted of a sprinkler with a built-in pressure regulator for production of a standard rain shower; an adjustable support for the sprinkler and an aluminium ground frame that prevents the lateral movement of water from the test plot to the surrounding soil (24). The measurements were carried out in autumn in the inter-rows of the cultivated plots. Before starting the test, the plant residues were removed from surface with slope of 27%. The measurements created in interval of 10 min. The soil erodibility factor (K) was determined using the Universal Soil Loss Equation (USLE) (25).The results analysis was done using Excel and SPSS 13.0 software. The obtained data were analysed using comparison of the means. Tukey’s test were used after ANOVA. The significance level was $p<0.05$ (26).

4. Results

In this study, the results of the 3rd year of the three successive years of compost application (2009 to 2011) and also the results for the years 2013 and 2014 (after the compost application in 2012) are presented. The Table 2 shows the changes of water retention (%) in soil upon compost treatment.

In saturation state (pF-0), each pore is saturated with water and the volumetric water content (%) is equal to total porosity. As shown in Table 2, in all years the total porosity was higher in the compost treatments than the control treatment and increased from 45 to 52%. A similar trend was also observed in the water content in the range from pF 1.5 to pF 2.5, showing the quantity of macro-pores increased significantly after compost treatment. The water content at the wilting point (pF 4.2) increased in the compost treatments in all studied years as compared with the control. The plant-available water content (PAWC), calculated as a difference between the field capacity water (pF 2.5) and water content at wilting point (pF 4.2), was slightly increased but only in the first two years after compost application. In the second year (2014) after compost application, the water retention significantly increased in the 18 Mg ha^{-1} and 27 Mg ha^{-1} compost treatments. Based on the results, the quantity of macro-pores, which are responsible for gravitational water flow, increased significantly after compost treatment, but the quantity of micro-pores playing an important role in water retention changed less. The plant-available water content (PAWC) was slightly increased after compost application.

Table 3 shows the results of the measurements with rainfall simulator after compost application.

Table 2 Changes in water retention (%) in soil upon treating with various compost ratios

Year	Compost dose (Mg ha^{-1})	Suction (pF)				
		0	1.5	2.5	4.2	PAWC
2011	0	49.0 a	37.5 a	9.0 a	3.9 a	5.1 a
	9	52.0 b	41.0 b	10.7 c	4.6 b	6.1 c
	18	50.9 ab	41.3 b	9.8 b	4.5 b	5.4 ab
	27	51.7 b	45.3 c	9.8 b	4.0 a	5.8 bc
2013	0	43.4 a	39.3 a	7.5 a	4.5 a	3.1 a
	9	45.9 b	42.4 bc	8.7 ab	4.6 a	4.1 b
	18	46.2 bc	42.2 b	9.3 b	5.2 a	4.8 b
	27	48.0 c	43.9 c	8.8 b	4.7 a	4.1 b
2014	0	43.9 a	39.7 a	7.6 a	4.5 a	3.2 a
	9	45.7 b	43.7 bc	8.0 a	4.8 ab	3.3 ab
	18	44.8 ab	42.4 b	8.7 b	4.9 b	3.8 b
	27	48.6 c	44.9 c	9.0 b	4.4 a	4.6 c

a-c letters mean different groups of means according to the Tukey's test at the significance level of $P<0.05$ and PAWC is plant-available water content

Table 3 Results of the measurements with rainfall simulator after compost application

Compost dose (Mg ha^{-1})	Intensity of simulated rainfall (mm h^{-1})	Runoff (ml m^{-2} 10 minutes^{-1})	Erosion (g m^{-2} 10 minutes^{-1})	Soil erodibility factor (K)
0	130	8299 b	183 *b*	0.287 ***b***
9		363 a	6 *a*	0.009 ***a***
18		424 a	11 *a*	0.016 ***a***
27		187 a	5 *a*	0.007 ***a***

a-b letters mean different groups of means according to the Tukey's test at the significance level of P<0.05

The compost treatment had a beneficial effect on soil structure, thereby reducing the runoff and erosion under high intensity rainfall (130 mm h^{-1}). The lowest compost of 9 Mg ha^{-1} dose already had a beneficial effect on soil, but in the control plot there was significant runoff and water erosion. So, the water resistance of soil structure was increased as the result of compost application under high intensity rainfalls.

5. Discussion

The increased total porosity of soil after compost application could be explained by improved soil structure and thereby the increased quantity of micro- and macro-pores in soil (27, 28, 29). The water retention increased in the range from pF 1.5 to pF 4.2 after compost treatment, because the added organic matter into soil adsorbed more water molecules on its surface (15), which was in correspondence with earlier works (11, 16) that had shown improved water retention only in a short time after compost application due to rapid mineralization processes.

The rate of infiltration was increased in the compost treatments by the increased rate of macro-pores and the water stable soil structure (20).Increase in water infiltration should be regarded as a result of increased total porosity in soil after compost application (16). The decreased water erosion upon compost treatments could be explained by the improved soil structure and increased aggregate stability as a consequence of increased microbial activity in soil after compost application (30, 31). The organic matter of sewage sludge compost is a good nutrient source for soil bacteria and fungi, which play an important role in the improvement of soil structure by binding soil particles into aggregates (32). The higher organic content and biological activity of soil lead to an increase in macro-pores and preferential flow along those macro-pores (33). The increased microbial respiration and mineralization quotient in the municipal solid waste (MSW) compost treated soils resulted in higher levels of water stable aggregates and more macro-pore fraction, leading to greater hydraulic conductivity (34). However, Mamedov *et al.* (35) showed that the runoff volume and sediment loss increased with increasing clay contents. The effects of organic amendments on runoff volume and erosion are soil dependent, because the response of the soils to the amendments is associated with their buffer capacity.

6. Conclusion

The sewage sludge, often considered as a waste, had been composted and applied in the sandy soils of low fertility in Nyírség Region of Hungary. The experiments have shown that the compost, due to its high organic content, is suitable for improving structure and water management properties of the sandy soils in the region. The compost treatment had a beneficial effect on soil structure, thereby significantly reducing the runoff and sediment loss under simulated high intensity rainfall. The water retention of soil was slightly increased after compost application. However, due to mineralization processes, beneficial effects of organic matter decreased with time. The beneficial effect of composted sewage sludge lasts only for two years in sandy soil.

Conflicting of Interest

The Authors have no conflict of interest.

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Authors' Contributions

All authors contributed extensively to the work presented in this paper.

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اثر تیمار طولانی مدت کمپوست در مدیریت آب در خاک شنی

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مقدمه: بخش عمده‌ای از خاک‌های شنی در مجارستان تحت مدیریت آب نامطلوب قرار دارد. مطالعات نشان داده است که کمپوست لجن فاضلاب، به علت محتوای مواد آلی بالا، مناسب برای بهبود ساختمان و مدیریت آب این خاک‌ها است. هدف از این مطالعه تعیین تأثیر کاربرد کمپوست لجن فاضلاب بر خصوصیات فیزیکی خاک شنی است.

مواد و روش‌ها: این آزمایش در سال ۲۰۰۳ در موسسه تحقیقاتی *Nyíregyháza* از دانشگاه *Debrecen* در مجارستان برای مطالعه استفاده از کمپوست لجن فاضلاب در کشاورزی انجام شد. در این مطالعه تغییرات نگه‌داشت آب و فرسایش‌پذیری خاک در سه دوره اندازه‌گیری شد. نوع خاک مورد آزمایش *Arenosol* (*Dystric Lamellic Arenosol*) بود. کمپوست به‌کار برده شده شامل ۴۰ درصد لجن فاضلاب، ۲۵ درصد کاه، ۵ درصد بنتونیت و ۳۰ درصد ریولیت بود. کمپوست هر ۳ سال یکبار در مقادیر صفر، نه، ۱۸ و ۲۷ تن ماده خشک در هکتار اعمال می‌شود.

نتایج: تیمار کمپوست اثر مثبتی بر ساختمان خاک داشته و در نتیجه پس از بارندگی با شدت زیاد (۱۳۰ میلی‌متر در ساعت) رواناب و رسوب کاهش یافت. در کرت شاهد فرسایش آبی به طور معنی‌داری بیشتر بود. ظرفیت نگه‌داشت آب در خاک پس از افزودن کمپوست به مقدار کمی افزایش یافت.

نتیجه‌گیری: کاربرد کمپوست مدیریت آب خاک شنی را بهبود می‌بخشد که ناشی از افزودن مواد آلی به خاک است. تیمار کمپوست اثر مثبتی بر روی ساختمان خاک داشته و باعث کاهش رواناب و رسوب شد.

کلمات کلیدی: خاک شنی، فرسایش، کمپوست لجن فاضلاب، مدیریت آب