Thesis of Doctoral (Ph.D.) dissertation

LONG-TERM EFFECT OF SEWAGE SLUDGE COMPOST APPLICATION ON THE PHYSICAL PROPERTIES OF SANDY SOIL

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1. BACKGROUND AND AIMS OF THE DISSERTATION

Lands used for agricultural production for increasing human population demands are restricted. Therefore the sustainable use of the natural resources, especially the protection and improvement of soil come to the front. In the agriculture the utilization of the natural materials, industrial wastes, by-products is preferred for improving the physical, chemical properties, fertility and biological activity of soils (Zebarth et al., 1999; Wang et al., 2014).

Studies show that 31% of agricultural lands of Hungary belong to the category of good water management, 26% to moderate and 43% to unfavourable water management. To the last category belong the sandy soils and brown forest soils in the Nyírség region with their shallow fertile soil layer (Várallyay, 2001).

The fertility of sandy soils is limited by their low mineral and organic colloids content and therefore their unfavourable physical and water management properties (Várallyay, 1984; Stefanovits et al., 1999). For increasing the organic and mineral content of these soils many methods were carried out, but most of them were not used in practice because of economic aspects (Westsik 1951, Egerszegi, 1953, Köhler, 1984).

The results of new experiments show that the range of potentially suitable materials may expand further with using of composted sewage sludge to increase the colloid content of sandy soils (Csubák and Mahovics, 2008; Makádi, 2010). Besides that the composting can be a solution for treatment of sewage sludge, the produced compost with high organic matter content can be used in agriculture for nutrient-supply and increasing soil fertility as well (Tamás, 1998; Zinati et al., 2001). Compost application can improve the acidic sandy soils, which are poor in mineral and organic colloids (Adani et al., 2009; Mylavarapu and Zinati, 2009). The organic matter input reduces the soil compaction, and increases the porosity and aggregate stability (Weber et al., 2007). The water management and nutrient-supply of soil are significantly improved by compost treatment (Celik et al., 2004). The increased organic matter content of soil increases its fertility and improves its structure, thereby reducing the damages in drought periods and the rate of erosion (Arthur et al., 2011).

The aims of the research work

The aim of my study was to determine the long-term effects of composted sewage sludge application on physical properties of sandy soil.

The detailed objectives of my dissertation were as followings:

To investigate:

- the effects of the compost application on the water management and erodibility of soil according to the results of water retention and infiltration measurements,
- the influence of the compost application on the air permeability of sandy soil,
- the suitability of sewage sludge for improving the structure of sandy soils based on the results of soil measurements.

2. MATERIALS AND METHODS

The research site

The experiment was established in 2003 at the Research Institute of Nyíregyháza of the University of Debrecen CAS in Hungary to study the utilization of sewage sludge compost in agriculture. In the experiment I studied the long-term effect of Nyírkomposzt (sewage sludge compost developed in cooperation with Nyírségvíz Ltd) application on physical properties of soil.

The characteristic soil type of the experiment is Arenosol (Lamellic Arenosol, Dystric).

The applied compost contained sewage sludge 40 (m/m %), straw 25 (m/m %), bentonite 5 (m/m %) and rhyolite 30 (m/m %). The quality of sewage sludge compost met the limit values of the Hungarian regulation (36/2006. (V.18.) Decree of the Ministry of Agriculture). The compost has already re-treated five times as the farmyard manure every 3rd years in the following amounts: 0, 9, 18 and 27 t ha^{-1} of dry matter. Compost was ploughed into the 20-25 cm soil layer.

In the experiment there are five blocks and the plot size is 12 x 19 m. Test plants are triticale (*x Triticosecale* Wittmack), maize (*Zea mays* L.) and green pea (*Pisum sativum* L.), which are sown in a crop rotation in every year.

Determination of bulk density and moisture content of the soil

Measurements were carried out in the soil physical laboratory of Karcag Research Institute of the University of Debrecen CAS. For measurements undisturbed soil samples of 100 cm^3 volumes were collected in five replicates from the 5-10 cm and 20-25 cm soil layers. Sampling times were in the 3rd year (November 2011, July 2012: triticale) after the third sewage sludge compost application in 2009 and in the 1st and 2nd years (July 2013: green pea; October 2014: maize) after the fourth compost application in 2012. Samples were collected in the middle plots of block V.

The bulk densities of undisturbed soil samples were measured after 24^{hr} drying at 105 ^{o}C. The mass of dry soil samples were measured by tare balance.

The moisture content of soil was determined at 105 ^{o}C by drying chamber method (Buzás, 1993).

Measurement of air permeability of soil

The air permeability of soil was measured by the Eijkelkamp type air permeability apparatus. The air permeameter apparatus measures the permeability of an undisturbed soil sample.

The air penetrating across the soil sample was measured at defined air pressure differences determined by flowmeters with different sensitivity (1 cm water column=0.1 kPa). To eliminate the effect of different moisture content, the air permeability was measured at the uniform moisture content of pF 2.3 considering the experience by Dunai et al. (2008). The measurements were carried out in five replicates.

Measurement of water retention

For determination the soil water retention; the sandbox, the sand/kaolin box and the pressure membrane apparatus were used.

The sandbox can be used to apply a range of pressures from pF 0 (saturation) to pF 2.0. The sand/kaolin box can be used to determine moisture percentages at pF-values from 2.0 to 2.7, while the pressure membrane apparatus can create pressures from pF 3.0 to pF 4.2.

If equilibrium between soil moisture content and pressure was reached, the samples were removed; their weights were measured and then were dried at 105 °C to a constant weight. The water content of soil to a given pressure was calculated the difference between dry weight and wet weight (Buzás, 1993).

Measurement of water infiltration and erodibility of soil

For measuring the hydraulic conductivity of soil and to characterize the erodibility of soil Eijkelkamp type small rainfall simulator was used.

The measurements were carried out two times in a year (in summer and in autumn) in the interrows of the cultivated plant. Before starting the test the plant residues were removed from surface, then a slope was created with 15^o incline. Measurements have continued for 10 minutes. The intensity of the simulated rainfall was 185 mm $hour^{-1}$ in August and 130 mm $hour^{-1}$ in October. The runoff water was collected, filtered by filter paper in laboratory then its volume was measured by measuring cylinders. The amount of infiltration was calculated as the difference between the intensity of simulated rainfall and the amount of runoff.

The soil erodibility factor (K) was determined by soil loss using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

Statistical analysis

The analysis of the results was done using MS Excel, SPSS 13.0 and ORIGIN programs. The data obtained were statistically analysed by analysis of variance. For pairwise comparison of the means Tukey's test were used after ANOVA. The significance level was $p<0.05$.

For describing and evaluation the relationship between the examined soil properties correlation and linear regression analysis were used.

3. RESULTS

The soil physical effects of composted sewage sludge were investigated during four years.

The organic matter and the bentonite component of composted sewage sludge formed directly and indirectly the soil structure. Bulk density depends on soil structure and it is an indicator of soil compaction. Based on the bulk density values it was found, that the compost application had an impact on soil compaction in both studied soil layers in the first two years after compost re-treatment (Fig. 1-2).

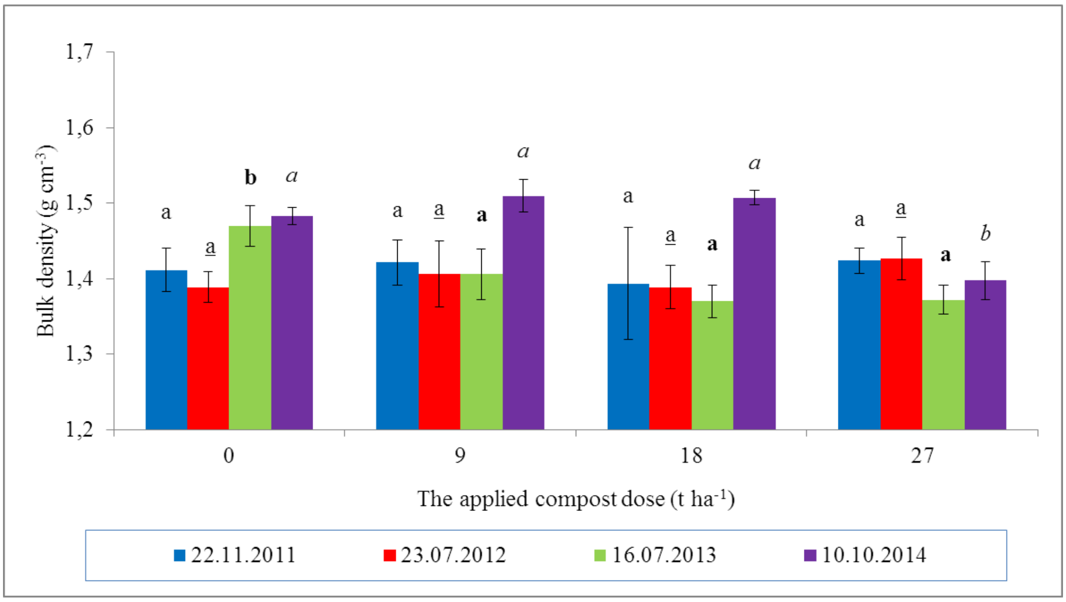

Figure 1. Changes in the bulk density of soil in treatments with increasing doses of compost at the soil depth of 5-10 cm

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

However, in the 3rd year after compost application it was not found any statistically significant change in bulk density, probably because the organic matter was degraded due to the rapid mineralization processes taking place in sandy soil.

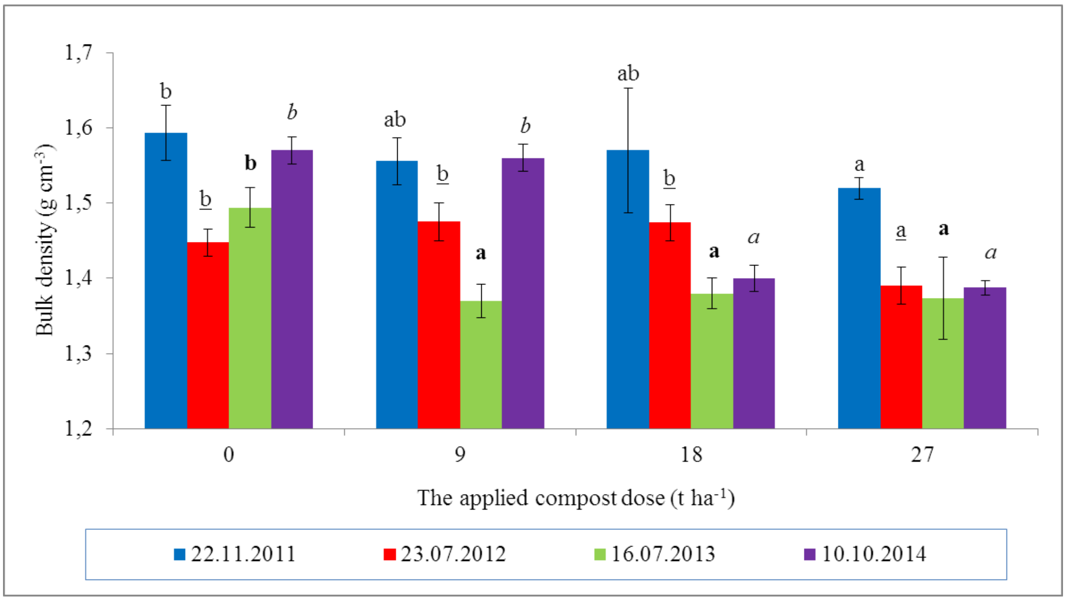

Figure 2. Changes in the bulk density of soil in treatments with increasing doses of compost at the soil depth of 20-25 cm

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

The linear regression analysis of measured data showed strong (r^2= –0.6564) linear correlation between the bulk density and the soil organic matter content (Fig. 3).

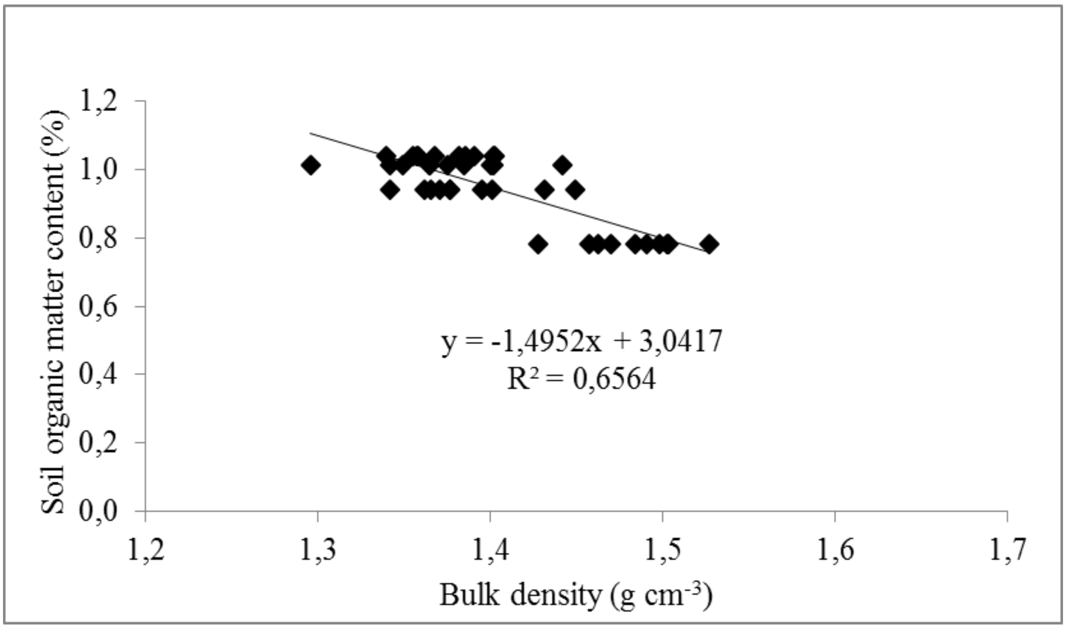

Figure 3. Relationship between the bulk density and the soil organic matter content in 2013 (N=40); represented the results of the two studied soil layers

Based on the results of air permeability measurements, the compost application had a significant effect on the air management of the soil. In accordance with the decrease in bulk density, the air permeability of soil increased after compost re-treatment (Table 1).

Table 1. Changes in the air permeability (10^{-3} cm s^{-1}) of soil after increasing doses of compost treatments

Compost dose ($t\ ha^{-1}$)	**Depth (cm)**	**2011**	**2012**	**2013**	**2014**
0	5-10	53.8 ab	53.16 **a**	35.2 *a*	37.1 ***a***
9		55.0 ab	46.98 **a**	40.0 *b*	39.6 ***a***
18		63.1 b	51.94 **a**	47.3 *c*	37.1 ***a***
27		50.9 a	57.14 **a**	52.6 *d*	55.0 ***b***
0	20-25	20.8 a	34.1 **ab**	33.7 *a*	36.2 ***a***
9		29.3 b	40.1 **bc**	49.2 *b*	33.4 ***a***
18		21.9 a	31.7 **a**	56.1 *d*	59.4 ***c***
27		17.1 a	45.2 **c**	52.6 *c*	51.9 ***b***

a-d indexes mean different groups of means according to the Tukey's test at the significance level of $p<0.05$

The air permeability was significantly higher in the compost treatments than in control in both studied soil layers in the 1^{st} year after compost re-treatment (2013), because the addition of organic and mineral materials to soil improved soil structure and reduced soil bulk density.

The air permeability was significantly higher in the 18 t ha^{-1} and 27 t ha^{-1} compost treatments in the second year (2014) after compost application. The reason is that the organic matter was degraded in the upper soil layer, so it did not contribute to the improvement of soil structure. The air management of sandy soil was improved by the increased quantity of macropores after compost application, but its negative effect is the rapid mineralization of organic matter.

The air management of sandy soil was improved as well by the increased quantity of pores, thereby ensuring a good soil condition. This claim is confirmed by a strong (r^2= –0.5444) linear correlation between the bulk density and the air permeability of the soil (Fig. 4).

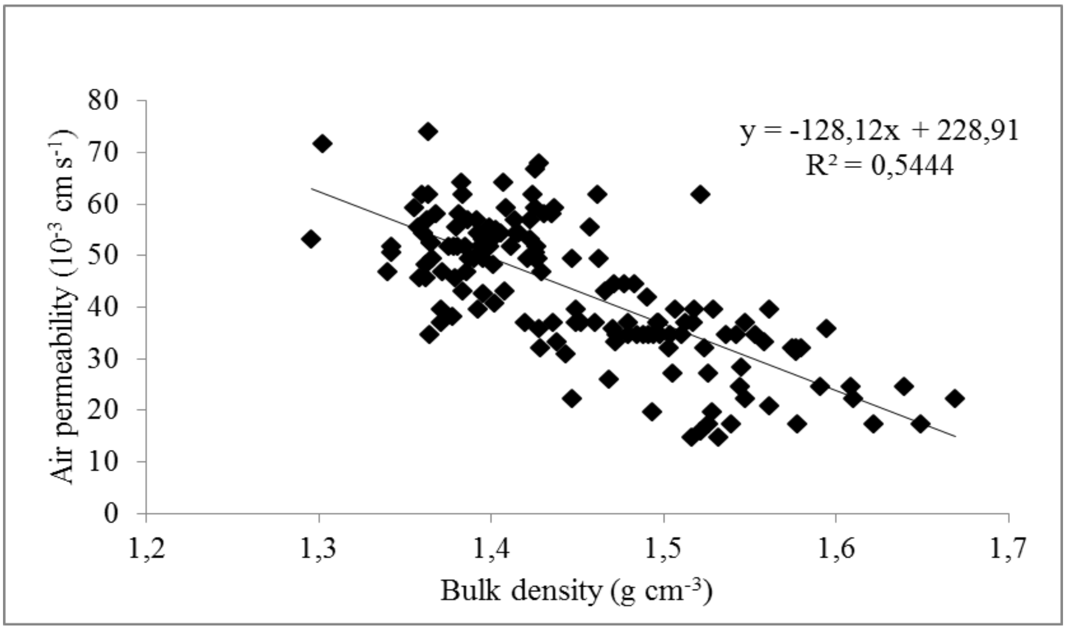

Figure 4. Relationship between the bulk density and the air permeability of soil in 2011-2014 (N=150); represented the results of the two studied soil layers

The studied soil had a "high" permeability at 1.6 g cm^{-3} bulk density, indicating that the air transport function of the investigated sandy soil is not limited at this bulk density value.

The total porosity of soil increased to 50 V/V% in all studied years after compost re-treatment, based on the water holding capacity results. The total porosity was increased by the increased quantity of macropores, which had a significant effect on air management of soil.

The rate of capillary pores was changed less after compost application, because the quantity and quality of organic and mineral materials of compost were not enough to form the microcapillaries, which play an important role in water sorption of plants. The plant-available water content (PAWC) was slightly increased but only in the first two years after compost application (Fig. 5).

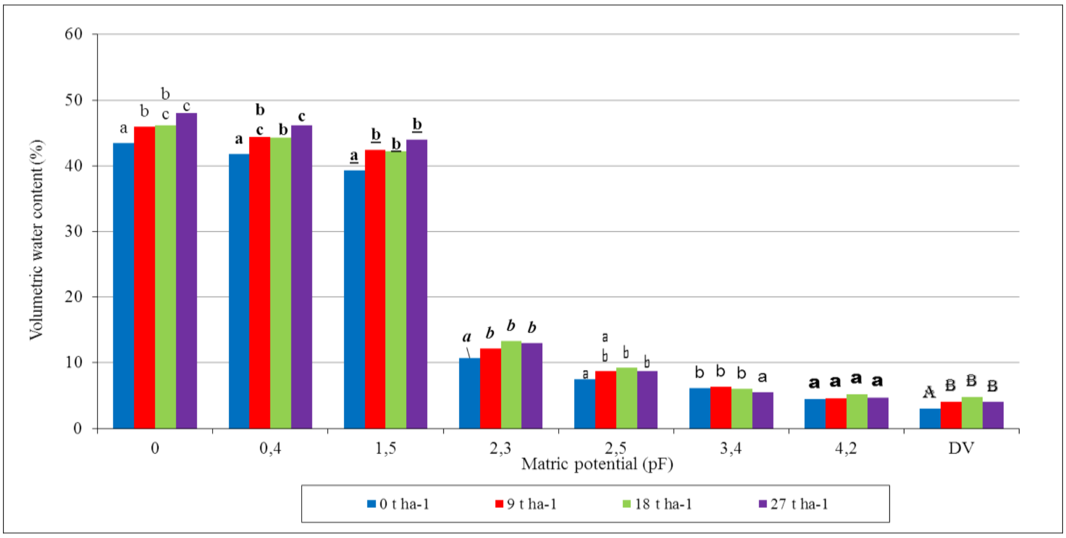

Figure 5. Changes in water retention of soil after increasing doses of compost treatments at the soil depth of 5-10 cm (16.07.2013)

a-c, A-B indexes mean different groups of means according to the Tukey's test at the significance level of p<0.05

The water infiltration into soil was improved by the compost application therefore reducing the water erosion from the sandy hills. The rate of infiltration was increased in the compost treatments by the increased rate of macropores and the water stable soil structure (Table 2).

Table 2. The results of the measurements with rainfall simulator

Compost dose (t ha^{-1})	The intensity of simulated rainfall (mm h^{-1})	Runoff (ml m^{-2} 10 minutes^{-1})	The rate of runoff/rainfall (%)	Erosion (g m^{-2} 10 minutes^{-1})	Erosion/rainfall (g m^{-2} mm^{-1})	Soil erodibility (K)-factor
0	185	11040 b	36.6 **a**	643 b	21.4 ***a***	0.4493 *b*
9		2164 a	7.2 **a**	76 a	2.5 ***a***	0.0528 *a*
18		196 a	0.65 **a**	8 a	0.3 ***a***	0.0058 *a*
27		122 a	0.4 **a**	5 a	0.2 ***a***	0.0035 *a*
0	130	8299 b	38.4 **a**	183 b	8.5 ***a***	0.2877 *b*
9		363 a	1.7 **a**	6 a	0.3 ***a***	0.0094 *a*
18		424 a	1.9 **a**	11 a	0.5 ***a***	0.0168 *a*
27		187 a	0.8 **a**	5 a	0.2 ***a***	0.0075 *a*

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

The intensity of infiltration was not decreased by the extreme high intensity rainfalls (130 mm h^{-1} and 185 mm h^{-1}). The 9 t ha^{-1} and 18 t ha^{-1} compost doses already had a significant effect on water infiltration, but the 27 t ha^{-1} compost dose did not resulted in further increase of the infiltration intensity. However, in the control plot there was significant water erosion.

The compost treatments increased the intensity of infiltration and changed the infiltration characteristic curves, as well. The phase of the quick water transition and the phase of stable water permeability were clearly separated in control plot, but the separation of two phases was not distinct in the compost treatments, because of the infiltration rate remained high and virtually unchanged during the measurement (Fig. 6).

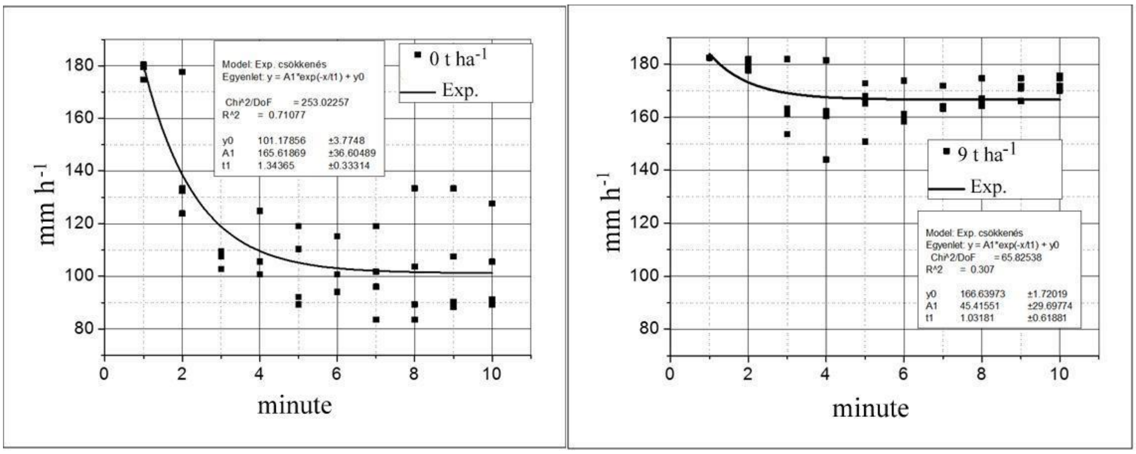

Figure 6. The rate of water infiltration (mm h^{-1}) on the control (0 t ha^{-1}) and compost treated plot (9 t ha^{-1}) under high intensity (185 mm h^{-1}) rainfall

The beneficial effect of compost application on soil structure can be more expressed in the future, when, as the impacts of climate change in the Carpathian Basin, the increasing frequency of the high-intensity precipitation events could cause major erosion damage on sand hills.

Based on the results of the four studied years, the composted sewage sludge is suitable for improving the structure of sandy soils with low fertility. The direct effects of sewage sludge compost application were the improved soil structure and water management. The indirect effects of sewage sludge compost application were the improved soil physical condition, which effected on the water and air management, and therefore had a positive impact on the yields as well.

According to the results it can be concluded, that the composted sewage sludge influenced positively the soil physical properties, but the duration of the effect can be expected only up to two years.

4. NEW SCIENTIFIC RESULTS OF DISSERTATION

My new scientific thesis are the followings:

1. The quantity of macropores, which are responsible for gravitational water flow, increased significantly after compost treatment, but the quantity of micropores playing an important role in water retention changed less.

2. The plant-available water content (PAWC) was slightly increased but only in the first two years after compost application.

3. The bulk density of soil was significantly decreased by the compost application in both studied soil layers in the first year. In the second year after compost application the bulk density decreased significantly only in the 18 t ha^{-1} and 27 t ha^{-1} compost treatments. In the 3^{rd} year there was not any treatment effect.

4. It was proved that the compost treatment had a significant effect on air management of soil. The air management of sandy soil was improved by the increased quantity of macropores after compost application, but its negative effect may be the rapid mineralization of organic matter.

5. For sandy soils, one unit (1 g cm^{-3}) decrease/increase in bulk density affects approximately 30 % increase/decrease in air permeability.

6. The water resistance of soil structure and the rate of water infiltration into the soil were significantly increased by the effect of compost application under high intensity rainfalls.

7. The transport processes of soil (increase of water- and air permeability) were improved by the effect of compost application, but the plant-available water content (PAWC) was less changed.

8. According to the results of the bulk density-, the air permeability- and the water retention measurements, the duration of the effect of compost application takes for two years.

9. Based on the results of water- and air permeability measurements the value of critical compaction of the studied sandy soil is higher than 1.5 g cm^{-3}.

5. PRACTICAL UTILIZATION OF RESULTS

1. Composting can be a solution for treatment of sewage sludge, which is considered as a waste, than the compost can be utilized in an environmentally-sound way in the agriculture as soil improving material.

2. The high organic matter containing sewage sludge compost, next to the decreased quantity of farmyard manure, is suitable for organic matter supply of soils.

3. The improved air management of soil by the effect of compost application could increase the crop yield and crop safety.

4. The improved soil structure after the compost treatment can significantly reduce the damage of water erosion.

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7. PUBLICATION RELATED TO THE DISSERTATION

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List of publications related to the dissertation

Hungarian book chapter(s) (1)

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