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IMPACT OF LOW-DOSE MUNICIPAL SEWAGE SLUDGE COMPOST TREATMENTS ON THE NUTRIENT AND THE HEAVY METAL CONTENTS IN A CHERNOZEM TOPSOIL NEAR ÚJKÍGYÓS, HUNGARY: A 5-YEAR COMPARISON

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Abstract

Agriculture is one of the major fields, where sewage sludge can be used. Its high nutrient content can contribute to the improvement of important soil properties, such as nutrient content, water balance and soil structure. However, sewage sludge may contain hazardous components, such as pathogens and pollutants. Therefore, it is important to monitor the effects of its field application. In this paper, we assessed the impacts of two low-dose (2.5 m^3/ha) municipal sewage sludge compost applications (in 2013 and in 2017) in a 5.6 ha arable land in southeast Hungary (near Újkígyós), located in the Hungarian Great Plain. The nutrient and the heavy metal contents in the upper soil layer (0-30 cm) of the studied Chernozem soils were compared between two sampling campaigns in 2013 (before the compost applications) and in 2018 (after the compost applications). Basic soil properties (pH, salinity, humus content, carbonate content, Arany yarn number) complemented with nutrient content (K_2O, P_2O_5, NO_2+ NO_3) and heavy metal content (Cd, Co, Cr, Cu, Ni, Pb and Zn) analyses were performed. The results show that no significant change can be noticed in the baseline parameters over the 5-year period. The slight increase in the P_2O_5, NO_2+ NO_3 content is closely related to the beneficial effects of the sewage sludge deposition. The soil-bound heavy metal load did not increase significantly as a result of the compost treatments, only nickel showed a slight increase in the topsoil. In all cases the heavy metal concentrations did not reach the contamination thresholds set by Hungarian standards. The results provided positive evidences proving that low dose municipal sewage sludge compost disposal on agricultural land is safe, and can be considered as a sustainable soil amendment for agriculture in compliance with legal requirements.

Keywords: sewage compost, treatment, heavy metal, nutrient content, agricultural application

INTRODUCTION

Sewage sludge, as a by-product of the wastewater treatment, is rich in organic and inorganic plant nutrients, therefore it can be used as an alternative to mineral fertilizers in agricultural fields (Singh 2008). Sewage sludge disposal in agriculture is an increasingly popular way of reusing sewage sludge, as it enables the recycling of valuable components, such as organic matter (Csányi et al., 2018), N, P and other nutrients (Kádár, 2013; Babcsányi et al., 2019). Besides amending the soil with plant nutrients and organic matter, sewage sludge application can introduce into the soil some hazardous pollutants, such as heavy metals (Moreno et al., 1997).

According to the 9th Technical assessment on the implementation of the Urban Waste Water Treatment Directive of the European Union (TA UWWTD, 2017), the overall reported production of sludge in EU28 in 2014 was just over 8.7 Mio T/year, from which 44% was re-used for "Soil and agriculture". According to the National Sewage Sludge Management Strategy of Hungary (2014-2023) 38% of the total amount of municipal sludge was used in agriculture as sludge, compost or compost product in Hungary in 2013 (while 46%, 5%, 2%, 9% were used for land reclamation, energy purposes, landfilling and other purposes, respectively). Land application of sewage sludge is regulated only by the concentration of heavy metals as specified in the Council Directive 86/278/EEC (CEC, 1986). Hungary, as most of the EU countries, adopted even more stringent limits for sludge use in agriculture by setting lower limits for heavy metals in comparison with the European Directive 86/278/EEC, furthermore, introduced limit values for other elements as well (Hudcová et al., 2019)

For the disposal of sewage sludge, it is essential to assess the composition and its impact on the soil as it can change the macro- and micro-nutrient content, organic matter content, adsorption capacity, soil structure and water management (Kádár, 2013). In addition, sewage sludge can be a potential source of hazard due to its heavy metal content and microbial composition (Moreno et al. 1997) (Vermes, 1997; Kocsis, 2011). Increased heavy metal content can cause a change in the soil biota (Uri et al., 2005), and can ultimately endanger human health by entering the food chain. Although nutrients (eg. N, P) are essential for plant growth, when applied excessively, however, they may accumulate in the topsoil, can be leached and transported off-site by drainage systems or can be transported by erosion posing risk to (sub)surface waters (Hudcová et al., 2019). Therefore, it is important to monitor the long-term effects of the land-application of sewage sludge.

This study investigates the impacts of two applications of municipal sewage sludge compost (in 2013 and in 2017) on Chernozem soils based on comparing soil parameters between 2013 and 2018. For this purpose, potential changes in the basic soil physical and chemical features were assessed (pH, salt content, humus content, carbonate content, Arany yarn number, nutrient and heavy metal content). The specific objective is to evaluate if the low dose application of municipal sewage sludge compost causes a significant increase in the soil-bound heavy metal concentrations and how the nutrient content is affected.

STUDY AREA AND METHODS

The study area is located near Újkígyós, a settlement in the Trans-Tisza region of the Hungarian Great Plain (Fig. 1). The studied plot is an 5.6 ha arable land with highly fertile Chernozem soils, where municipal sewage sludge compost was spread twice in 2013 and in 2017 (2.5 m^3/ha). The parameters of the deposited sludge compost are presented in Table 1. Prior to the first sludge compost application in 2013, a soil protection plan was compiled for the study area based on a detailed soil survey (according to the Hun. Decree 40/2008. (II. 26.), the results of which provide the basis for the comparison with data from 2018. In 2013, composite samples were collected from the upper soil (0–30 cm) from 5 sampling areas of 2500 m^2 each within the study area.

The arable land was re-surveyed in March 2018, when 6 composite samples were taken from the upper soil (0-30 cm). During the designation of the sampling areas in 2018, a special attention was paid to include areas affected by sewage sludge compost disposal (1,2, 3,4 plots in Fig.1.) and also unaffected ones (6,7plots in Fig.1.) (Kézér, 2018; Pálffy et al., 2018).

Prior to measurements, samples were dried in the laboratory at 40°C in an oven and powdered (< 2 mm) after removing larger organic debris and foreign material. The pH (H_2O) was determined using a WTW inoLab 720p pH-meter, the total water soluble salt content was determined by measuring the conductivity (OK-104 conductivity meter) of the saturated soil paste, the carbonate content ($CaCO_3$) was determined using the Scheibler type calcimeter according to the Hungarian standard procedure (MSZ-08-0206-2: 1978). To measure texture of the samples, Arany yarn test was carried out based on the MSZ-08-0205-1978 Hun. standard. Humus content was measured by colorimetry using Helios γ type spectrophotometer based on the MSZ 21470-52:1983 standard. The macronutrients P_2O_5 and K_2O were extracted using ammonium-lactate, while the nitrogen forms (NO_2^- + NO_3^--N) were extracted with KCl-solution according to standard procedures (MSZ20135:1999), measured by FIA spectrometer. Prior to total metal analyses, soil samples were oven-dired again at 105°C for 24 hours. Powdered soil samples (0.5 g) were digested in aqua regia (hydrochloric acid : nitric acid = 3 : 1) in closed vessels in a microwave oven (Anton ar Multiwave 3000) The metal concentrations in the digested samples were measured by an inductively coupled plasma atomic/optical emission spectrometer (Perkin Elmer ICP-OES Optima 7000 DV) (according to the standard: MSZ 21470-50:2006).

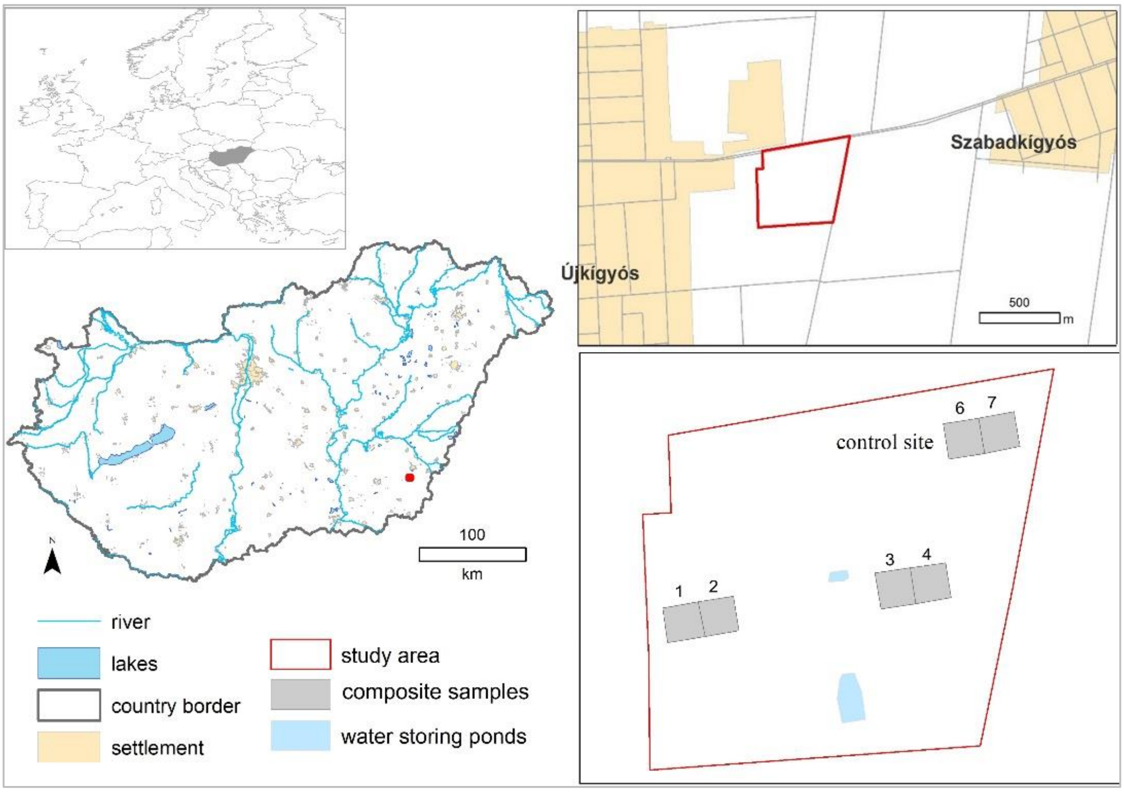

Fig. 1 Location of the study area (Újkígyós, Hungary)

Table 1 The quality of the applied municipal sewage sludge compost in 2013 and in 2017. The displayed Hungarian threshold for sewage sludge compost applied in agricultural land is specified in the Government Decree 40/2008. (II. 26.)

Parameters	Compost quality in 2013	Compost quality in 2017	Hungarian threshold
pH (d.w.)	7.64	8.48	-
Dry matter (mg/kg)	181000	24600	-
Organic matter (m/m%)	13.2	5.7	-
Total nitrogen (mg/kg dry w.)	59100	128700	-
Total phosphorus (P_2O_5 mg/kg dry w.)	19500	16500	-
Total potassium (K_2O mg/kg dry w.)	2560	5860	-
TPH (mg/kg)	<25	2588	1000
As (mg/kg)	67.6	15.5	25
Cd (mg/kg)	0.53	<1	5
Co (mg/kg)	<1	2.31	50
Total Cr (mg/kg)	14.2	17.6	350
Cu (mg/kg)	81.1	103	750
Hg (mg/kg)	0.64	0.46	5
Mo (mg/kg)	6.74	6.35	10
Ni (mg/kg)	12.4	15.1	100
Pb (mg/kg)	18.7	16.3	400
Se (mg/kg)	<1	<1	50
Zn (mg/kg)	444	542	2000

RESULTS AND DISCUSSION

The topsoil in the study area is characterized by slightly alkaline pH (7.0-8.1), low salt content (0.02%), moderate humus content (1.53 – 2.52%), low carbonate content (0.14-3.56 %) and a sandy loam texture (Fig. 2). There was no statistically significant change in these basic soil parameters between 2013 and 2018 ($p \leq 0.05$). As a result of the compost treatment, we would expect the humus content to increase, however a slight decrease can be noticed in the soil humus content in 2018. This observation may be explained by the intensive agricultural production. Another possible explanation may be the low-dose and short-term application of the compost at our study site. A previous field study found that a longer term (50 year-long) annually repeated treatment of arable land with organic amendments may be needed for a significant increase in the soil organic carbon pool (Sleutel et al., 2006).

There is a marked increase in the bioavailable N- and P- contents between 2013 and 2018, whereas no significant change can be observed in the K content (Fig. 3). These observations confirm that the sludge compost treatments supply with valuable plant nutrients agricultural soils and can be a convenient alternative for mineral fertilizers. Moreover, the compost treatment has a longer-term effect compared to mineral fertilizers, because the applied composts supply plants with macronutrients via a slow decomposition process of the organic compost components including the conversion of macronutrients (N, P, S, etc.) into inorganic (and mostly plant available) forms by microorganisms (Diacono and Montemurro, 2011).

Heavy metal load did not increase significantly as a result of the sewage sludge compost applications between 2013 and 2018 (Fig. 4). Among the investigated heavy metals, only nickel showed a slight increase in the topsoil. The heavy metal concentrations are far beyond the contamination thresholds according to the Hungarian standards for soil quality (6/2009. [IV. 14.] KvVM-EüM-FVM). Our results are in line with the outcome of a similar study conducted over a 6-year period that demonstrated that urban sewage sludge compost (mixed with poplar bark) treatments with similar heavy metal contents presented no danger in the short/medium term either to the environment or to crops even when applied in higher doses (80-160 t/ha) compared to the doses in the present field survey (Pinamonti et al., 1997). An incubation experiment also found that the increase in the total metal content following a single sludge addition (48 t/ha) was negligible in an agricultural calcareous silt loam soil using a mixture of sewage sludge (primary aerobic sludge) and cotton waste (Sánchez-Monedero et al., 2004). Similarly, Fang and coworkers (2016) observed no significant increase in the total metal content of a farmland alluvial soil displaying slightly alkaline pH due to a single application of sewage sludge compost at a rate of 48 t/ha. Nevertheless, they found that application intensified the leaching of heavy metals due to the increase in the dissolved organic matter of the soil solution. Depending on the metal content of the applied sewage sludge compost a significant increase in the total metal content of amended soils may be observed, which raises concerns about the long-term applicability of sewage sludge composts (Khadhar et al., 2020).

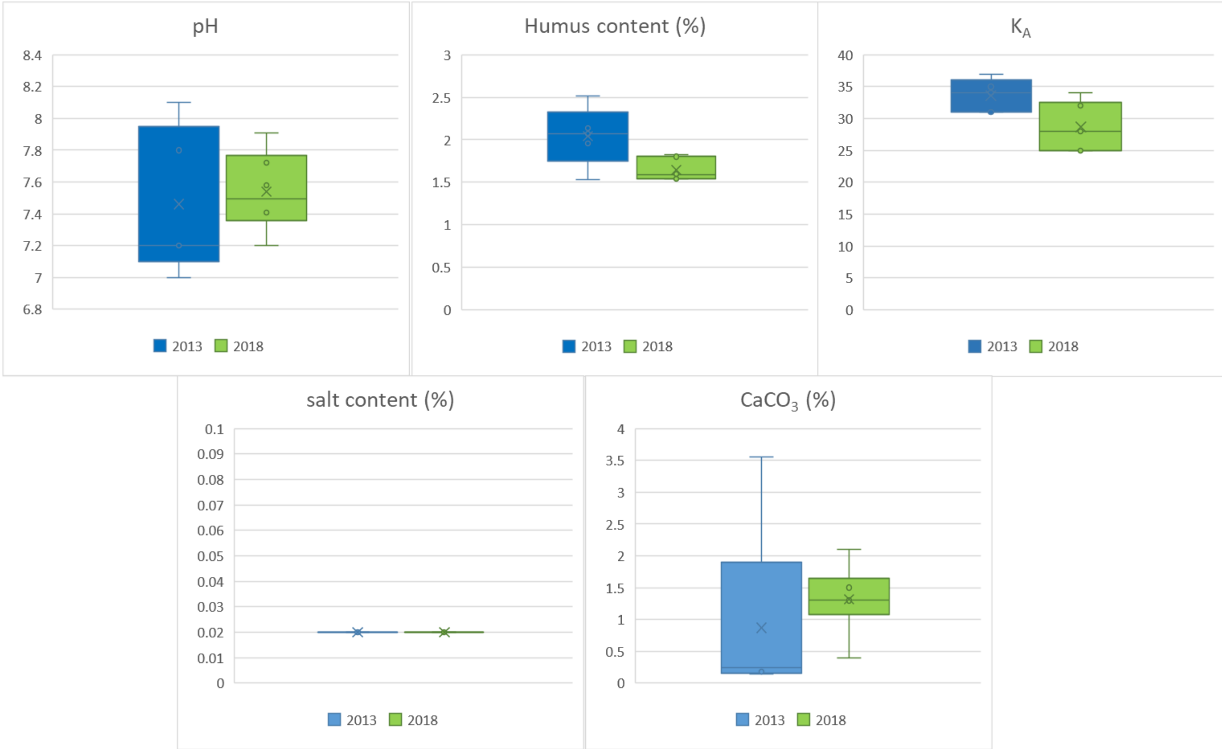

Fig. 2 Basic soil parameters between 2013 and 2018 (before the compost treatments and afterwards) in the topsoils of the study area near Újkígyós (Hungary)

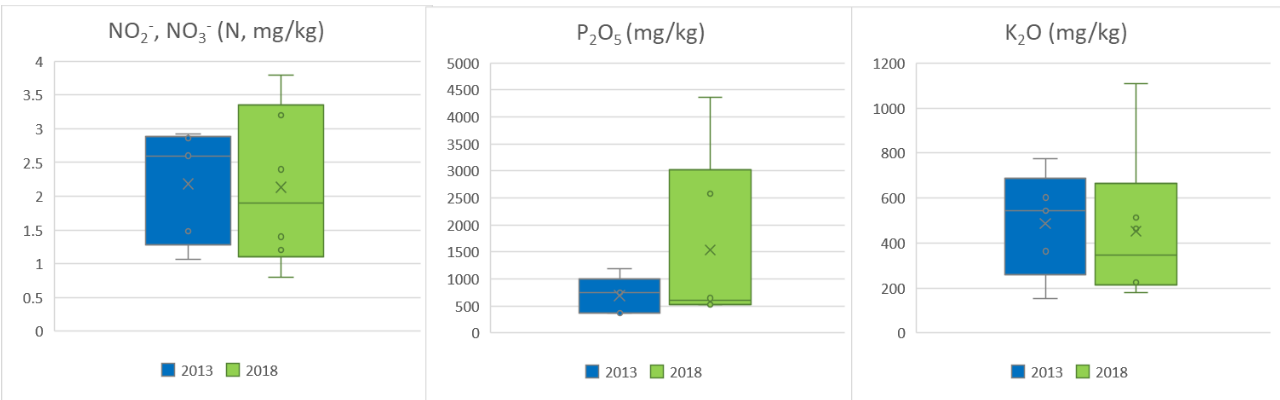

Fig. 3 Changes in the nitrogen, phosphorus and potassium contents between 2013 and 2018 of the topsoil as a result of the two compost treatments

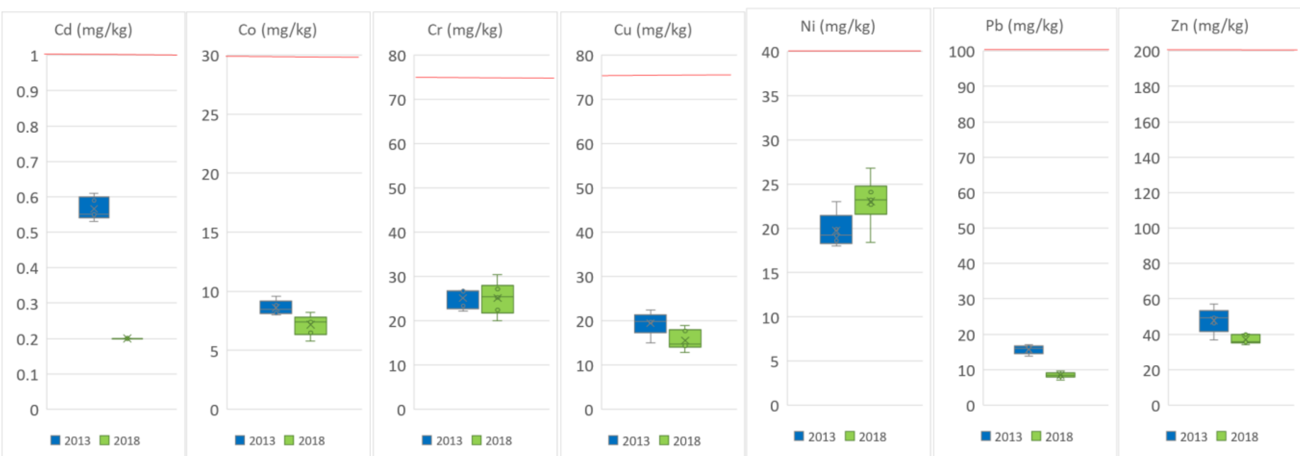

Fig. 4 Evolution of the soil-bound heavy metal contents (Ni, Co, Cr, Cd, Zn, Pb, Cu and As) between 2013 and 2018 at the study site (the red linestands for the contamination thresholds according to the Hungarian standards for soil quality (6/2009. [IV. 14.] KvVM-EüM-FVM)

The beneficial effects of the compost treatment can also be clearly identified if we compare the N-, P- and K-nutrient content of the control and the treated sampling areas in 2018 (Fig. 5). If we separate affected sites according to the timing of the disposal, it can be identified that 1,2 sampling sites (under disposal in 2018) show higher phosphorus content compared to 3,4, where there was no disposal in 2018 (only before). There is no significant difference between 1,2 and 3,4 in case of the nitrate and potassium. Among the heavy metals, copper and zinc show slightly higher concentrations in the soil samples affected by the compost treatment compared to the control soil, which can be explained by their higher concentration in the applied sewage sludge compost as compared to their level in the untreated soils.

CONCLUSIONS

The present study investigated the effects of sewage sludge compost applications on Chernozem soils in Hungary. Our study confirmed that there were no significant changes in either the basic soil parameters or the heavy metal load in the topsoil (0-30 cm) over the studied 5-year-period. In contrast, sludge compost treatment added to the soil an excess of slowly decomposing organic matter, rich in macronutrients (eg. nitrogen, phosphorus). Thus, properly designed sludge spreading on agricultural land in compliance with legal requirements can improve the nutrient and organic matter content of soils in a sustainable way. The accumulation of heavy metals with potential environmental and human health risks could not be identified. According to our results in 2018, the samples affected by sewage sludge compost applications showed an increased nitrogen and phosphorus content compared to the control areas, while the heavy metals zinc and copper showed somewhat higher values in the samples affected by the compost treatments. Our results are in line with previous studies who also did not identify a significant increase in heavy metal concentrations as a result of low doses of sewage sludge disposals (Pinamonti et al., 1997; Sánchez-Monedero et al., 2004). The resulting data also provide evidence that in case the applied sewage sludge composts meet the quality guidelines and requirements for the treatment doses set in the Government Decree 40/2008. (II. 26.), their field application as fertilisers can be considered as a sustainable management practice of secondary raw materials. The study confirmed the safe applicability of low dose municipal sewage sludge composts in a Hungarian study area. Further study sites are under investigation to investigate the impact of regular low-dose municipal sewage disposal within the broader study area.

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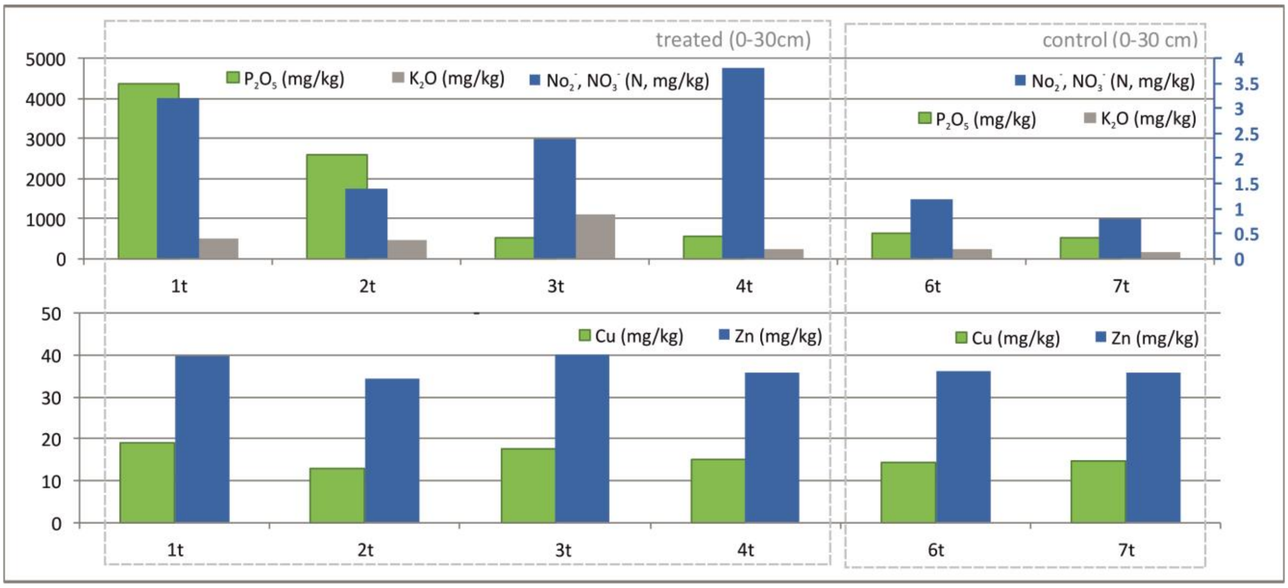

Fig. 5 N-, P- and K-nutrient and heavy metal contents are compared between the compost treated and the control sites in soil samples from the survey in 2018

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