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Influence of treated sewage sludge applications on total and available heavy metal concentration of sandy clay soil

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A B S T R A C T

The objective of this study is to determine influence of treated sewage sludge (TSS) rates on total and available heavy metal concentrations in a sandy clay soil. The experiment was conducted in the experimental fields of Ege Agricultural Research Institute in Menemen, İzmir, Turkey. The field study was conducted in 20 parcels in a randomized-block design with four repetitions and five different applications including control, mineral fertilizer, TSS 12.5 t ha^{-1}, 25.0 t ha^{-1}, 37.5 t ha^{-1} as dry matter. The parcels dimensions were 3 m × 3 m. Corn (*Zea mays*) was planted as the first crop and wheat (*Triticum durum*) was planted as the second crop. Increasing TSS applications to this soil resulted in significantly increased concentrations of total Cr and Zn in soil as average of five sampling periods. However, concentrations of total Cu, Cd, Ni and Pb in soil did not significantly change. Total heavy metal concentrations in soil were found under threshold values. Increasing TSS applications to this soil resulted in significantly increased available (diethylenetriaminepentaacetate-DTPA-extractable) concentrations of Cu, Cr, Ni and Zn in soil. However, available Cd and Pb concentrations in soil did not change significantly.

Keywords: Heavy metals; Sandy clay soil; Treated sewage sludge; Temporal variations

1. Introduction

Water is essential for maintaining life. Humans and animals usually settle around permanent sources of water. However, the exploitation of water resources around human settlements increases the pressure on the environment and the risk of desertification. There are several causes of desertification, including frequent droughts, deforestation, overgrazing and intensive farming [1]. The influence of organic matter (OM) on soil biological and physical fertility is well known. OM affects crop growth and yield either directly by supplying nutrients or indirectly by modifying soil physical properties, such as stability of aggregates, porosity and water holding capacity, that can improve the root environment and stimulate plant growth [2]. Agricultural recycling of organic wastes is an interesting solution since it enables a reduction of the quantities of mineral fertilizers applied and an improvement of OM content of soil. Nevertheless, it is fundamental to control and limit the environmental impact of these practices since they can result in organic or inorganic contamination of natural resources. Among the pollutants, heavy metals have been critically examined since they can be toxic to humans, animals and plants [3]. Treated sewage sludge (TSS) is an ultimate product of municipal wastewater treatment plant and highly enriched in OM. It may be deposited in landfills, under the soil surface, or (to a certain extent) in the air as a consequence of incineration. In addition, TSS can be recycled in various ways, including its use as fertilizer, as a soil conditioner in farmland, in forests and in home gardens [4]. The long-term land application of TSS and compost from waste materials may be limited by accumulation of harmful heavy metals and pathogens in soil. To eliminate the pathogens, sewage sludge (SS) may be taken into thermal

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drying process or the pH of the sludge can be increased above 11 by the addition of lime [5]. TSS contains macronutrients and trace elements. These attributes potentially make TSS an excellent fertilizer at very low cost for agricultural land in Turkey which is generally rich in lime, low in OM. The positive effect of SS on soil properties has been evidenced in numerous papers by researchers [6–8]. Municipal SS is also a source of micronutrients. However, special care should be taken with respect to micronutrients and heavy metals so as not to introduce excessive amounts of these elements, which could have an adverse effect on the environment, especially when soil is acidic [8–10]. The purpose of this work was to evaluate the effect of municipal TSS doses on the concentration of total and available forms of Cu, Cd, Cr, Ni, Pb and Zn in a sandy clay soil during five different periods in 2 years.

2. Materials and methods

2.1. Experimental site

The experiment was conducted at the research field of Aegean Agricultural Research Institute in Menemen plain, İzmir, Turkey (38°56′29.02″–38°56′37.59″N; 27°05′23.08″–27°05′30.74″E). The experimental site is in the Western Anatolia region of Turkey (Fig. 1), where the Mediterranean climate prevails with a long-term mean annual temperature of 16.8°C. Long-term mean annual precipitation is 542 mm, representing about 75% of rainfalls during the winter and spring, and the mean relative humidity is 57%. Long-term mean annual potential evapotranspiration is 1,570 mm [11]. Twenty-five surface soil samples were collected from different areas of the experimental site from Ap horizon (cultivated) (18 cm) and a mixture of these soils was used for analysis. Also, five TSS samples were taken and a mixture of these samples was used for analysis. The investigated soil is characterized by sandy clay texture with slightly alkaline reaction and classified as a typic xerofluvent [12]. Some selected properties and total heavy metal concentrations in the experimental soil and TSS used in the experiment are given in Tables 1 and 2.

Table 1
Some selected properties and total heavy metal concentrations of experimental soil

Sand, %	44.84
Silt, %	16.44
Clay, %	38.72
Texture	Sandy clay
Salt, %	0.167
$CaCO_3$, %	0.51
Organic matter, %	0.94
pH (saturation paste)	7.53
Pb, mg kg^{-1}	15.93
Cu, mg kg^{-1}	16.30
Zn, mg kg^{-1}	51.16
Cd, mg kg^{-1}	0.62
Cr, mg kg^{-1}	13.43
Ni, mg kg^{-1}	23.75

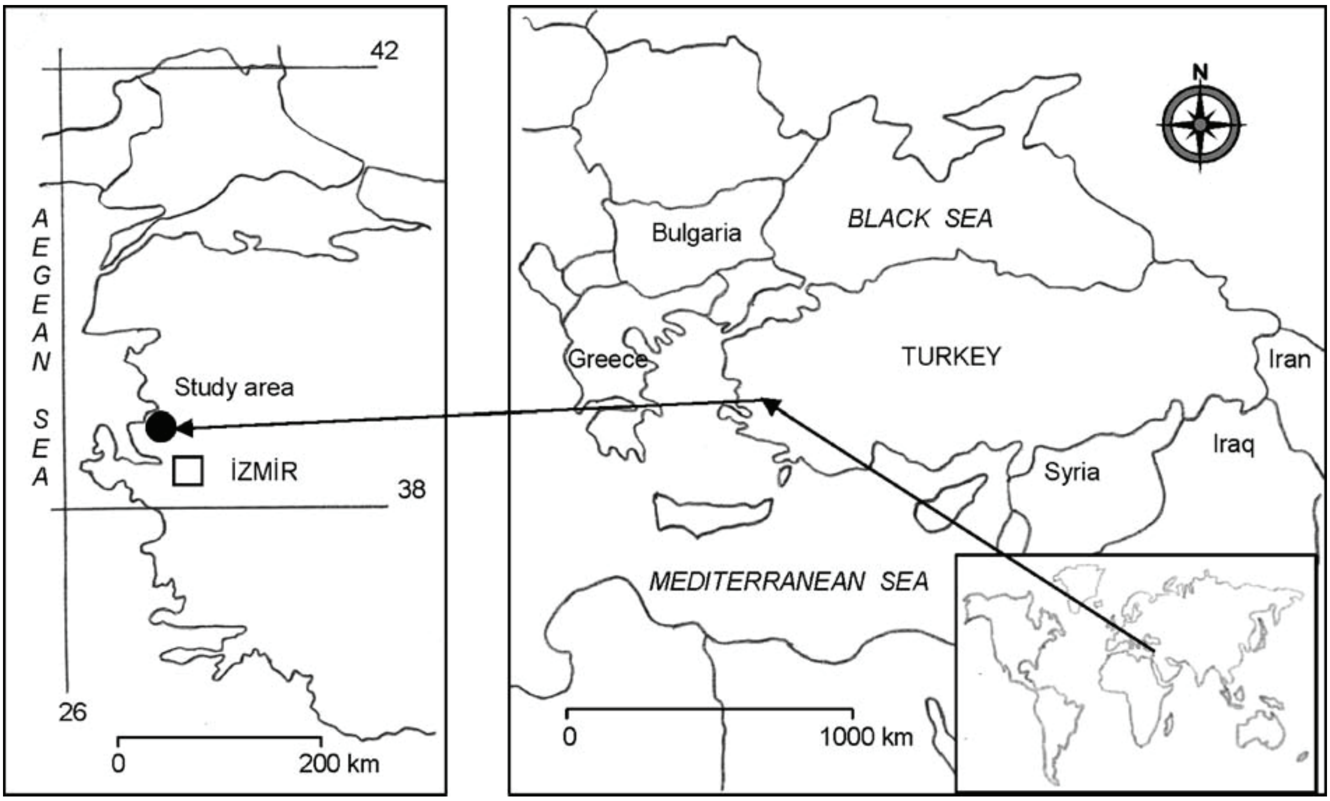

Fig. 1. Location of study area.

Table 2
Some selected properties and total heavy metal concentrations of treated sewage sludge used in the experiment

EC, dS m^{-1}	16.35
$CaCO_3$, %	10.24
Organic matter, %	70.32
Organic C, %	40.79
N[a], %	5.33
P[a], %	1.33
K[a], %	0.68
Ca[a], %	3.74
Mg[a], %	0.68
Na[a], %	0.59
Fe, %	1.14
Cu, mg kg^{-1}	268.8
Zn, mg kg^{-1}	1,335
Mn, mg kg^{-1}	298.6
B, mg kg^{-1}	35.2
Co, mg kg^{-1}	14.2
Cd, mg kg^{-1}	4.1
Cr, mg kg^{-1}	250.6
Ni, mg kg^{-1}	115.4
Pb, mg kg^{-1}	199.4

[a]Total.

2.2. Field experiment

The field study was conducted in 20 parcels in a randomized-block design with four repetitions, during 2011–2012. The parcel dimensions were 3 m × 3 m. The TSS used in the experiment was obtained from the wastewater treatment plant of Metropolitan Region, İzmir city. It may produce around 600 mg (moist basis) SS per day. Calcium oxide (CaO) was added to raise the efficiency of the dewatering process of SS. In addition, the SS produced presented a pH varying between 10 and 13, what increased the pathogen control and decreased the heavy metal availability by added calcium oxide. TSS was added only once during experiment to the soil under investigation at the rates of 12.5 t ha^{-1}, 25.0 t ha^{-1}, 37.5 t ha^{-1} as dry matter on July 8, 2011. Also, 150 kg N, 150 kg P_2O_5, 150 kg K_2O ha^{-1} (1,000 kg ha^{-1} 15.15.15. composed fertilizer) were applied to the only mineral fertilizer parcels at the same time and mixed with soil to 15 cm depth by rototiller. Control parcels were not treated. Corn seeds (*Zea mays* L. var. ZP 737) were sown with seeding machine on rows 18 cm and in rows 70 cm apart. Drop irrigation was provided when required. Harvest of corn was done by hands on November 17, 2011. Wheat seeds (*Triticum durum* L. var. Ege 88) were sown with seeding machine on November 22, 2011 to 5 cm of soil depth as second crop. Also, 80 kg N and 80 kg P_2O_5 ha^{-1} (400 kg ha^{-1} 20.20.0. composed fertilizer) were applied to the only mineral fertilizer parcels at the same time and mixed with soil to 15 cm depth before wheat seeding. Wheat was harvested with machine on July 10, 2012. Second year, without applying any TSS (for determination of its second year effect), corn seeds were planted with seeding machine on July 18, 2012. Also, 150 kg N, 150 kg P_2O_5, 150 kg K_2O ha^{-1} were applied to the only mineral fertilizer parcels at the same time and mixed with soil to 15 cm depth by rototiller before corn seeding. Harvest of second year's corn was done by hands on November 23, 2012.

2.3. Soil sampling and analyses

During the experiment, all soil samples were taken from several different points in the center area (to eliminate the side effect from each side as 50 cm) of each parcel in 18 cm depth (Ap horizon) in five different periods (first, August 11, 2011 – 3 weeks after sowing of corn; second, November 17, 2011 – after corn harvest; third, July 11, 2012 – after wheat harvest; fourth, August 7, 2012 – 3 weeks after sowing of second year corn; fifth, November 1, 2012 – after corn harvest of second year). The samples were air-dried and sieved using 2-mm sieve. The macronutrients (N, P, K, Ca, Mg and Na) and heavy metal (Fe, Cu, Mn, Zn, Cd, Cr, Ni and Pb) concentrations of soil were determined. Particle size distribution of experimental soil was determined by the Bouyoucos hydrometer method [13]. Total salt, OM concentration, $CaCO_3$, pH, total N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Cd, Cr, Ni and Pb concentrations of soil samples and TSS were all determined according to Page et al. [14]. Available P in soil was determined by the Mo blue method in a $NaHCO_3$ extract [15]. Available Ca, Mg, K and Na were analyzed with 1 N NH_4OAc extract method. Ca, K and Na were determined by flame emission spectrometry and Mg was determined by flame atomic absorption spectrometry (AAS) [16]. Mn, Zn, Cu, Cd, Cr, Ni and Pb were extracted using DTPA (diethylenetriaminepentaacetate) solution [17]. The concentrations of these elements in the extracts were determined by AAS [18].

2.4. Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 17 [19]. Tukey test was used to find if differences in the treatments were significant at $P \leq 0.01$ or $P \leq 0.05$ [20].

3. Results and discussion

Influence of TSS applications on total Cu, Cd, Cr, Ni, Pb and Zn (mg kg^{-1}) concentrations of sandy clay soil are given in Table 3.

According to the results, the average total Cu, Cd, Ni and Pb concentrations of the soil samples taken at five different periods in 2 years from the experimental soil did not show statistically significant changes with increasing doses of TSS applications when compared with control. In other words, total Cu, Cd, Ni and Pb concentrations of the experimental soil were not increased by the application of TSS doses. These insignificant increases in soil can be attributed to the low levels of these heavy metals in TSS. On the other hand, the average total Cr and Zn concentration of the soil samples taken at five different periods in 2 years from the experimental soil showed statistically significant changes with increasing doses of TSS applications when compared with control. This increase was due to the high amount of Cr and Zn contained in the sludge (250.6 mg kg^{-1} Cr; 1,335 mg kg^{-1} Zn) can be said. Despite these increases, total Cr and Zn concentrations of experimental soil were found under the threshold values in

Table 3
Influence of treated sewage sludge (TSS) applications on total Cu, Cd, Cr, Ni, Pb and Zn (mg kg^{-1}) concentrations of sandy clay soil

Applications	Average of five periods	Soil sampling periods										
		1		2		3		4		5		
Total Cu Tukey: $P \leq 0.01$; $P \leq 0.05$												
Control	19.04 a[1]	16.61 a	B[2]	18.57 b	B	22.07 a	A	18.24 a	B	19.71 a	AB	**
Fertilizer	19.36 a	17.85 a	B	18.65 b	B	22.26 a	A	18.42 a	B	19.63 a	AB	**
12.5 t ha^{-1} TSS	19.16 a	17.15 a	B	19.49 ab	AB	21.50 a	A	17.61 a	B	20.05 a	AB	**
25.0 t ha^{-1} TSS	19.50 a	18.26 a	B	20.00 ab	AB	21.16 a	A	18.77 a	AB	19.34 a	AB	*
37.5 t ha^{-1} TSS	20.66 a	18.05 a	B	22.23 a	A	22.52 a	A	19.15 a	AB	21.36 a	AB	**
				**								
Total Cd Tukey: ns												
Control	0.57 a[1]	0.63 a	A[2]	0.60 a	A	0.64 a	A	0.61 a	A	0.65 a	A	
Fertilizer	0.59 a	0.67 a	A	0.62 a	A	0.69 a	A	0.61 a	A	0.65 a	A	
12.5 t ha^{-1} TSS	0.57 a	0.65 a	A	0.60 a	A	0.63 a	A	0.60 a	A	0.67 a	A	
25.0 t ha^{-1} TSS	0.58 a	0.68 a	A	0.66 a	A	0.60 a	A	0.65 a	A	0.65 a	A	
37.5 t ha^{-1} TSS	0.61 a	0.67 a	A	0,70 a	A	0.71 a	A	0.62 a	A	0.71 a	A	
Total Cr Tukey: $P \leq 0.01$; $P \leq 0.05$												
Control	16.86 ab[1]	13.62 a	B[2]	12.14 ab	B	18.71 a	A	20.85 a	A	18.99 a	A	**
Fertilizer	16.70 b	14.00 a	B	11.90 b	B	18.81 a	A	20.57 a	A	18.20 a	A	**
12.5 t ha^{-1} TSS	17.10 ab	13.62 a	B	12.92 ab	B	19.16 a	A	20.32 a	A	19.46 a	A	**
25.0 t ha^{-1} TSS	17.52 ab	14.50 a	C	13.42 ab	C	18.55 a	B	22.08 a	A	19.05 a	AB	**
37.5 t ha^{-1} TSS	18.51 a	14.68 a	B	14.96 a	B	20.22 a	A	21.83 a	A	20.88 a	A	**
	*			*								
Total Ni Tukey: ns												
Control	23.58 a[1]	24.01 a	A	23.35 a	A	23.96 a	A	23.38 a	AB	23.22 a	A	
Fertilizer	23.63 a	24.06 a	A	24.15 a	A	23.34 a	A	23.48 a	AB	23.16 a	A	
12.5 t ha^{-1} TSS	23.77 a	23.48 a	A	23.67 a	A	23.84 a	A	24.21 a	A	23.66 a	A	
25.0 t ha^{-1} TSS	24.31 a	24.49 a	A	23.98 a	A	24.56 a	A	24.36 a	B	24.18 a	A	
37.5 t ha^{-1} TSS	24.43 a	24.56 a	A	24.43 a	A	24.54 a	A	24.15 a	AB	24.48 a	A	
Total Pb Tukey: $P \leq 0.01$												
Control	16.91 a[1]	15.71 a	B[2]	12.84 a	C	19.00 a	A	18.09 a	AB	18.90 a	A	**
Fertilizer	16.95 a	17.03 a	AB	12.50 a	C	19.84 a	A	16.78 a	B	18.59 a	AB	**
12.5 t ha^{-1} TSS	16.42 a	15.96 a	B	12.43 a	C	19.00 a	A	16.09 a	AB	18.62 a	AB	**
25.0 t ha^{-1} TSS	16.46 a	16.56 a	A	12.50 a	B	17.78 a	A	16.71 a	A	18.75 a	A	**
37.5 t ha^{-1} TSS	16.75 a	16.18 a	B	13.15 a	C	18.75 a	AB	16.34 a	B	19.31 a	A	**
Total Zn Tukey: $P \leq 0.01$; $P \leq 0.05$												
Control	53.09 ab[1]	52.96 a	AB[2]	39.00 b	B	61.40 a	A	56.00 a	AB	56.12 b	AB	**
Fertilizer	51.80 b	45.70 a	AB	38.65 b	B	62.05 a	A	58.34 a	A	54.28 b	AB	**
12.5 t ha^{-1} TSS	56.42 ab	44.84 a	B	41.51 ab	B	66.11 a	A	58.21 a	AB	71.40 a	A	**
25.0 t ha^{-1} TSS	56.23 ab	50.98 a	AB	46.14 ab	B	64.02 a	A	62.62 a	A	57.37 ab	AB	*
37.5 t ha^{-1} TSS	61.24 a	44.94 a	B	57.78 a	AB	67.46 a	A	68.71 a	A	68.21 ab	A	**
	*			**						*		

Significant differences between treatments at $^{**}P \leq 0.01$ or $^{*}P \leq 0.05$ level indicated by different letters. [1]Small letters in column for applications. [2]Capital letters in row for soil sampling periods. ns: not significant.

all sampling periods in this study. Bozkurt and Cimrin [21] found out that the total Zn concentration for 0–30 cm soil depth was increased from 44.4 to 71.6 mg kg^{-1} with SS application in their experiment. But SS applications did not significantly increase total Fe, Cu, Ni, Cd and Cr concentrations in their experimental soil. Lopez-Mosquera et al. [22] suggested that short- or medium-term application of sludge did not lead to harmful accumulation of heavy metals, but Selivanovskaya et al. [23] stated that Cu, Cr, Pb, Cd, Ni and Zn concentrations in soil increased with sludge addition. Threshold values of heavy metals in soil were given in official gazette of Turkey as 100 mg kg^{-1} Pb, 1.5 mg kg^{-1} Cd, 100 mg kg^{-1} Cr, 100 mg kg^{-1} Cu, 70 mg kg^{-1} Ni and 200 mg kg^{-1} Zn, respectively [24]. Influence of TSS applications on available (diethylenetriaminepentaacetate-DTPA-extractable) Cu, Cd, Cr, Ni, Pb and Zn (mg kg^{-1}) concentrations of sandy clay soil are given in Table 4.

The average available Cd and Pb concentrations of the soil samples taken at five different periods in 2 years from the experimental soil did not show statistically significant changes with increasing doses of TSS applications when compared with the control. In other words, available Cd and Pb concentrations of the experimental soil were not increased by the application of TSS doses. On the other hand, the average available Cu, Cr, Ni and Zn concentrations of the soil samples taken at five different periods in

Table 4
Influence of treated sewage sludge applications on available (DTPA-extractable) Cu, Cd, Cr, Ni, Pb and Zn (mg kg^{-1}) concentrations of sandy clay soil

Applications	Average of five periods	Soil sampling periods										
		1		2		3		4		5		
Available Cu Tukey: $P \leq 0.01$												
Control	1.35 c[1]	1.92 b	A[2]	1.28 c	BC	1.57 a	AB	1.04 a	C	0.97 a	C	**
Fertilizer	1.34 c	1.88 b	A	1.30 c	BC	1.57 a	AB	1.05 a	C	0.91 a	C	**
12.5 t ha^{-1} TSS	1.52 bc	2.22 b	A	1.88 b	AB	1.50 a	B	1.04 a	C	0.97 a	C	**
25.0 t ha^{-1} TSS	1.58 b	2.25 b	A	2.06 b	A	1.55 a	B	1.09 a	C	0.96 a	C	**
37.5 t ha^{-1} TSS	1.94 a	2.75 a	A	2.69 a	A	1.77 a	B	1.29 a	C	1.19 a	C	**
	**	**		**								
Available Cd Tukey: $P \leq 0.01$												
Control	0.04 a[1]	0.03 a	B[2]	0.02 a	B	0.07 a	A	0.02 a	B	0.05 a	A	**
Fertilizer	0.04 a	0.03 a	B	0.02 a	B	0.07 a	A	0.02 a	B	0.04 ab	B	**
12.5 t ha^{-1} TSS	0.03 a	0.03 a	B	0.03 a	B	0.07 a	A	0.02 a	B	0.03 b	B	**
25.0 t ha^{-1} TSS	0.04 a	0.03 a	B	0.03 a	B	0.07 a	A	0.02 a	B	0.03 b	B	**
37.5 t ha^{-1} TSS	0.04 a	0.03 a	BC	0.03 a	BC	0.07 a	A	0.03 a	C	0.05 a	B	**
										**		
Available Cr Tukey: $P \leq 0.01$												
Control	0.73 d[1]	0.81 c	A[2]	0.73 b	AB	0.76 b	AB	0.68 b	AB	0.65 b	B	**
Fertilizer	0.83 c	0.89 bc	A	0.83 ab	AB	0.90 b	A	0.78 ab	AB	0.74 ab	B	**
12.5 t ha^{-1} TSS	0.88 bc	0.95 bc	AB	0.84 ab	BC	1.10 a	A	0.80 ab	C	0.71 ab	C	**
25.0 t ha^{-1} TSS	0.93 ab	1.01 ab	AB	0.91 a	BC	1.11 a	A	0.83 a	C	0.77 ab	C	**
37.5 t ha^{-1} TSS	0.99 a	1.14 a	A	0.96 a	B	1.17 a	A	0.88 a	B	0.82 a	B	**
	**	**		**		**		**		**		
Available Ni Tukey: $P \leq 0.01$												
Control	0.45 c[1]	0.51 b	A[2]	0.43 c	A	0.42 b	A	0.44 b	A	0.46 a	A	
Fertilizer	0.48 bc	0.53 b	A	0.46 bc	A	0.49 ab	A	0.44 b	A	0.46 a	A	
12.5 t ha^{-1} TSS	0.50 bc	0.63 ab	A	0.55 abc	AB	0.43 b	C	0.46 b	AB	0.45 a	C	**
25.0 t ha^{-1} TSS	0.56 ab	0.67 ab	A	0.62 ab	AB	0.52 ab	AB	0.52 ab	AB	0.49 a	C	**
37.5 t ha^{-1} TSS	0.65 a	0.78 a	A	0.69 a	A	0.62 a	AB	0.66 a	AB	0.51 a	B	**
	**	**		**		**		**				
Available Pb Tukey: $P \leq 0.01$												
Control	0.69 a[1]	1.00 a	A[2]	0.56 a	B	1.26 a	A	0.44 a	BC	0.20 a	C	**
Fertilizer	0.69 a	1.01 a	A	0.55 a	B	1.16 a	A	0.38 a	B	0.34 a	B	**
12.5 t ha^{-1} TSS	0.72 a	0.97 a	A	0.64 a	B	1.23 a	A	0.42 a	BC	0.33 a	C	**
25.0 t ha^{-1} TSS	0.69 a	1.01 a	A	0.58 a	B	1.13 a	A	0.42 a	B	0.32 a	B	**
37.5 t ha^{-1} TSS	0.74 a	1.04 a	A	0.65 a	B	1.19 a	A	0.44 a	BC	0.36 a	C	**
Available Zn Tukey: $P \leq 0.01$												
Control	1.54 a[1]	2.15 c	A[2]	0.93 c	C	1.91 b	AB	1.56 bc	ABC	1.16 b	BC	**
Fertilizer	1.46 a	2.08 c	A	1.12 c	BC	1.86 b	AB	1.36 c	ABC	0.89 b	C	**
12.5 t ha^{-1} TSS	2.44 b	3.44 b	A	3.07 b	A	2.03 b	B	2.07 abc	B	1.58 ab	B	**
25.0 t ha^{-1} TSS	2.88 b	3.76 b	A	4.01 a	A	2.53 ab	B	2.48 ab	B	1.64 ab	B	**
37.5 t ha^{-1} TSS	3.77 a	5.66 a	A	4.84 a	A	3.02 a	B	2.90 a	B	2.45 a	B	**
	**	**		**		**		**		**		

Significant differences between treatments at $^{**}P \leq 0.01$ or $^{*}P \leq 0.05$ level indicated by different letters. [1]Small letters in column for applications. [2]Capital letters in row for soil sampling periods. ns: not significant.

2 years from the experimental soil showed statistically significant changes with increasing doses of TSS applications. Analogously to our study, Delibacak et al. [8] found out an increase in the concentrations of soluble Cu and Zn in soil caused by increasing doses of SS introduced to soil. In contrast, Pascual et al. [10] showed depressed concentrations of available forms of Cu and Zn in soil under the influence of a higher dose of SS (140 t ha^{-1}). Such discrepancies, reported by different authors, in the effect of SS on the content of Cu and Zn in soil may be substantiated, for example, by different concentrations of this metal in SS. Sienkiewicz and Czarnecka [25] reported that as the dose of SS added to soil increased, so did the content of soluble zinc in soil. The highest dose of SS (280 t ha^{-1}) caused an over 36% increase in the concentration of this element in soil compared with the control soil in their research. Bozkurt and Cimrin [21] also found that extractable Zn concentration of top soil approximately increased fifty-five-fold with SS effect, whereas the total Zn concentration did not increase as far as the available one. In another study, available soil Cu, Zn, Fe and Mn were increased by application of SS, which contained considerable quantities of these metals [26]. Also, Soriano-Disla et al. [27] found that the results obtained in the soil incubation show a general pattern of slight increase in the concentrations of extractable with DTPA heavy metals after sludge application. On the other hand, the sorptive properties of soil can affect the availability of heavy metals due to varying content of organic colloids in soil. It is remarkable that the importance of texture for controlling heavy metal availability. It has been demonstrated by several works the lower sorption capacity for heavy metals in sandy soils compared with loamy or clayey soils [28–31].

4. Conclusion

TSS is an ultimate product of municipal wastewater treatment processes. It is composed of organic compounds, macronutrients and micronutrients and heavy metals. Disposal trend of SS is going towards agricultural use (recycling) and incineration. Incineration turns the TSS to ash, which can then be used for landfilling, but in most cases, supplementary fuel is needed to burn the TSS, which makes this method less economical. For these reasons, recycling of TSS for agricultural purposes seems to be an appealing solution for the sustainable management of TSS in the coming years. The beneficial effects of using sludge on agriculture have been proven by numerous researchers. On the other hand, the application of TSS to soil must obey the limited regulations. After the analysis of SS and soil, a governmental permission is needed to apply them to agricultural lands. In our study, we found that all total heavy metal levels of soil were under threshold values of official limits at the end of the study. Therefore, we concluded that TSS could be used to improve soil properties and to prevent possible Zn deficiencies in soils of Turkey with taking into consideration of heavy metals in TSS for environmental concerns. Consequently, the recycling of SS to agricultural lands may be recommended as a positive activity in accordance with the sustainability of good agricultural practices. We suggest that applying SS and other organic materials to lands, for agricultural benefit or ecological improvement, is likely to be the best practicable environmental option in most circumstances, although the suitability of sludge spreading will vary depending on local conditions. However, further studies must be carried out in the next years to confirm the positive long-term effects of TSS in order to maintain and improve soil properties.

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