INFLUENCE OF TREATED SEWAGE SLUDGE APPLICATIONS ON TOTAL AND AVAILABLE HEAVY METAL CONCENTRATION OF SANDY CLAY SOIL

Sezai Delibacak[1*], Ali Rıza Ongun[1],
[1]Ege University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition
35100 Bornova İzmir Turkey
sezai.delibacak@gmail.com Phone: +90 232 311 2653 Fax: +90 232 388 9203

ABSTRACT

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 during 2011-2012 in Menemen-İzmir. Study area is in the Western Anatolia region of Turkey (38°56′29.02″-38°56′37.59″N; 27°05′23.08″-27°05′30.74″E). The field study was conducted in 20 parcels in a randomized-block design with four replications and five different applications including control, mineral fertilizer, treated sewage sludge 12.5 $Mg.ha^{-1}$; 25.0 $Mg.ha^{-1}$; 37.5 $Mg.ha^{-1}$ as dry matter. The parcels dimensions were 3 m width and 3 m length. Corn (*Zea mays* L. var. ZP 737) was planted as the first crop. On the other hand, wheat (*Triticum durum* L. var. Ege 88) was planted as the second crop. During the experiment, soil samples were taken five times in two years. Increasing TSS applications to this soil resulted in significantly increased concentrations of total Cr and Zn in soil as average of 5 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 for all sampling periods. Increasing TSS aplications were significiantly increased available (diethylenetriaminepentaacetate-DTPA-extractable) Cu, Cr, Ni and Zn concentrations in soil as average of 5 sampling periods when compared with control. However, available Cd and Pb concentrations in soil did not change significantly. Therefore, we concluded that TSS could be used to improve for soil properties and especially Zn deficiencies in soils of Turkey
KEYWORDS: Heavy metals, Sandy clay soil, Treated sewage sludge, Temporal variations

1. INTRODUCTION

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 and porosity, that can improve the root environment and stimulate plant growth [1]. 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 [2]. Treated Sewage Sludge (TSS) is an ultimate product of municipal wastewater treatment plant and highly enriched in OM. It may be deposited in landfills, in the sea (ocean disposal), 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 [3]. 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, increase of the pH in sewage sludge above pH 11 by the addition of lime, or by thermal drying of sewage sludge [4]. TSS contains macronutrients, trace elements and heavy metals. 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 sewage sludge on soil properties has been evidenced in numerous papers by researchers [5, 6, 7]. Municipal sewage sludge 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 [7, 8, 9]. The purpose of this work has been 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 two years (1st, August 3, 2011-3 weeks after sowing of corn; 2nd, December 15, 2011-after corn harvest; 3rd, July 11, 2012-after wheat harvest; 4th, August 7, 2012-3 weeks after sowing of second year corn; 5th, November 23, 2012- after corn harvest of second year).

2. MATERIALS AND METHODS

2.1. Experimental site

*Corresponding author

The experiment was conducted at the research field of Aegean Agricultural Research Institute in Menemen plain, Izmir, 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 [10]. The investigated soil is characterized by sandy clay texture with slightly alkaline reaction and classified as a Typic Xerofluvent [11]. Some selected properties and total heavy metal concentrations in the experimental soil and TSS used in the experiment are given in Table 1 and 2.

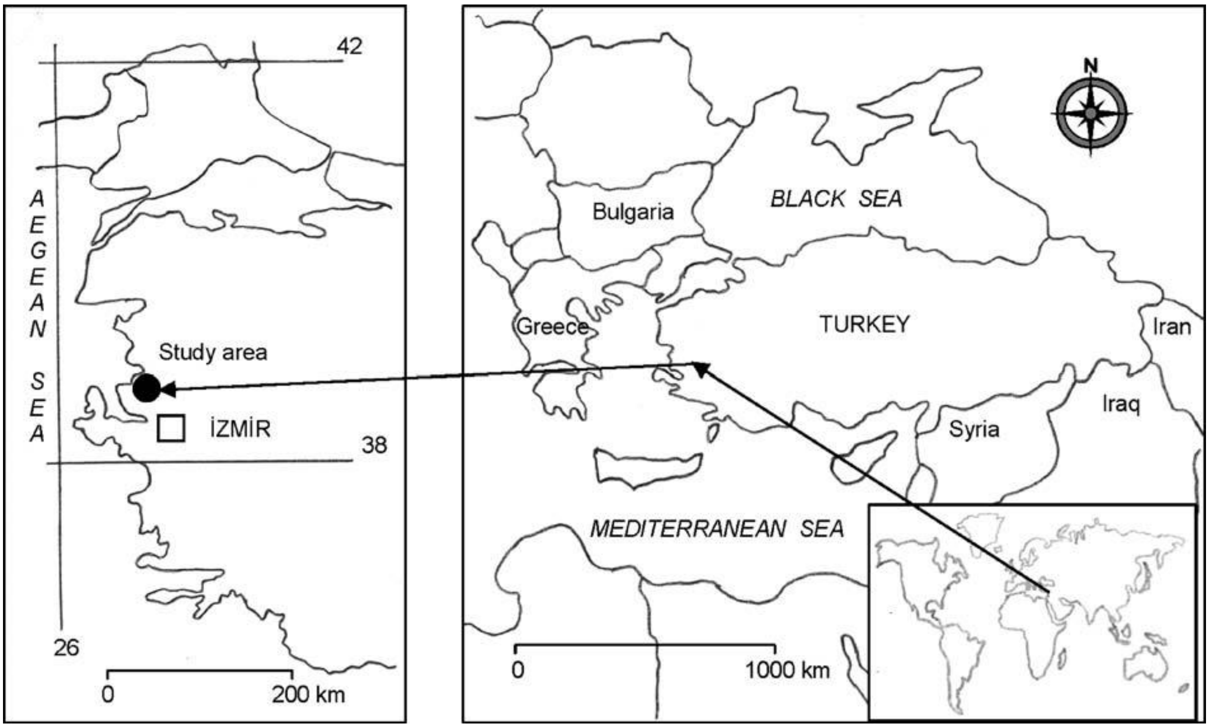

Fig. 1- Location of study area

Table Error! No text of specified style in document.- Some selected properties and total heavy metal concentrations of experimental soil

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

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

EC	dS/m	16,35	Fe	%	1,14
$CaCO_3$	(%)	10,24	Cu	mg/kg	268,8
Org. matter	(%)	70,32	Zn	mg/kg	1335
Org. C	(%)	40,79	Mn	mg/kg	298,6
N[1]	(%)	5,33	B	mg/kg	035,2
P[1]	(%)	1,33	Co	mg/kg	014,2
K[1]	(%)	0,68	Cd	mg/kg	004,1
Ca[1]	(%)	3,74	Cr	mg/kg	250,6
Mg[1]	(%)	0,68	Ni	mg/kg	115,4
Na[1]	(%)	0,59	Pb	mg/kg	199,4

[1]Total

2.2 Field experiment

The field study was conducted in 20 parcels in a randomized-block design with four replications, during 2011-2012. The parcel dimensions were 3 m width and 3 m length. The TSS used in the experiment was obtained from the wastewater treatment plant of Metropolitan Region, Izmir city. It may produce around 600 Mg (moist basis) sewage sludge per day. Calcium oxide was added to raise the efficiency of the dewatering process of sewage sludge. 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 $Mg.ha^{-1}$; 25.0 Mg. ha^{-1}; 37.5 $Mg.ha^{-1}$ as dry matter on July 8, 2011. Also 150 kg N, 150 kg P_2O_5, 150 kg K_2O ha^{-1} (1000 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. 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 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, soil samples were taken from the center of each parcel in five different periods (1st, August 11, 2011-3 weeks after sowing of corn; 2nd, November 17, 2011-after corn harvest; 3rd, July 11, 2012-after wheat harvest; 4th, August 7, 2012-3 weeks after sowing of second year corn; 5th, 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 [12]. 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. [13]. Available P in soil was determined by the Mo blue method in a $NaHCO_3$ extract [14]. Available Ca, Mg, K and Na were analyzed with 1N NH_4OAc extract method. Ca, K and Na were determined by flame emission spectrometry and Mg was determined by flame atomic absorption spectrometry (AAS) [15]. Mn, Zn, Cu, Cd, Cr, Ni and Pb were extracted using DTPA (diethylenetriaminepentaacetate) solution [16]. The concentrations of these elements in the extracts were determined by AAS [17].

2.4. Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 17 [18]. Tukey test was used to find if differences in the treatments were significant at $P \leq 0.01$ or $P \leq 0.05$ [19]

3. RESULTS AND DISCUSSION

Influence of treated sewage sludge applications on total Cu, Cd, Cr, Ni, Pb and Zn (mg/kg) concentrations of sandy clay soil were given on Table 3.

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

Total Cu Tukey: P≤ 0,01; P≤ 0,05

Applications	Average of 5 periods	Soil sampling periods										
		1		2		3		4		5		
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$TSS	20,66 a	18,05 a	B	22,23 a	A	22,52 a	A	19,15 a	AB	21,36 a	AB	**
				**								

Table 3-Continued

Total Cd Tukey:P≤ 0,01

Applications	Average of 5 periods	Soil sampling periods 1	2	3	4	5	
Control	0,57 a[1]	0,63 a A[2]	0,30 a B	0,64 a A	0,61 a A	0,65 a A	**
Fertilizer	0,59 a	0,67 a A	0,31 a B	0,69 a A	0,61 a A	0,65 a A	**
12.5 $Mg.ha^{-1}$TSS	0,57 a	0,65 a A	0,30 a B	0,63 a A	0,60 a A	0,67 a A	**
25.0 $Mg.ha^{-1}$TSS	0,58 a	0,68 a A	0,33 a B	0,60 a A	0,65 a A	0,65 a A	**
37.5 $Mg.ha^{-1}$TSS	0,61 a	0,67 a A	0,35 a B	0,71 a A	0,62 a A	0,71 a A	**

Total Cr Tukey:P≤ 0,01; P≤ 0,05

Applications	Average of 5 periods	Soil sampling periods 1	2	3	4	5	
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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

Applications	Average of 5 periods	Soil sampling periods 1	2	3	4	5
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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≤ 0.01

Applications	Average of 5 periods	Soil sampling periods 1	2	3	4	5	
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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≤ 0.01; P≤ 0.05

Applications	Average of 5 periods	Soil sampling periods 1	2	3	4	5	
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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≤ 0,01 or * P≤ 0,05 level indicated by different letters. [1]Small letter in column for applications, [2]capital letter in row for periods, ns: not significant.

According to the results, the average total Cu, Cd, Ni and Pb concentrations of the soil samples taken at 5 different periods in 2 years from the experimental soil did not show statistically significant changes with increasing doses of treated sewage sludge 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 treated sewage sludge 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 total Cr and Zn concentration of the soil samples taken at 5 different periods in 2 years from the experimental soil showed statistically significant changes with increasing doses of treated sewage sludge 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; 1335 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 all sampling periods in this study. Bozkurt and Cimrin [20] found out that the total Zn concentration for 0-30 cm soil depth was increased from 44.4 mg.kg^{-1} to 71.6 mg.kg^{-1} with sewage sludge application in their experiment. But sewage sludge applications did not significantly increase total Fe, Cu, Ni, Cd and Cr concentrations in their experimental soil. Lopez-Mosquera et al. [21] suggested that short or medium term application of sludge did not lead to harmful accumulation of heavy metals, but Selivanovskaya et al. [22] stated that Cu, Cr, Pb, Cd, Ni and Zn concentrations in soil increased with sludge addition.

Influence of treated sewage sludge applications on available (diethylenetriaminepentaacetate-DTPA-extractable) Cu, Cd, Cr, Ni, Pb and Zn (mg/kg) concentrations of sandy clay soil were given on Table 4.

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

Available Cu Tukey:P≤ 0,01

Applications	**Average of 5 periods**	**Soil sampling periods** 1		2		3		4		5		
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 Mg.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 Mg.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 Mg.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≤ 0,01

Applications	**Average of 5 periods**	**Soil sampling periods** 1		2		3		4		5		
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 Mg.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 Mg.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 Mg.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≤ 0,01

Applications	**Average of 5 periods**	**Soil sampling periods** 1		2		3		4		5		
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 Mg.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 Mg.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 Mg.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≤ 0,01

Applications	**Average of 5 periods**	**Soil sampling periods** 1		2		3		4		5		
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 Mg.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 Mg.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 Mg.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	**
	**	**		**		**		**				

Table 4-Continued

Available Pb Tukey:P≤ 0,01

Applications	Average of 5 periods	Soil sampling periods										
		1		2		3		4		5		
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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≤ 0,01

Applications	Average of 5 periods	Soil sampling periods										
		1		2		3		4		5		
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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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 $Mg.ha^{-1}$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≤ 0,01 or * P≤ 0,05 level indicated by different letters. [1]Small letter in column for applications, [2]capital letter in row for periods.

The average available Cd and Pb concentrations of the soil samples taken at 5 different periods in 2 years from the experimental soil did not show statistically significant changes with increasing doses of treated sewage sludge 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 treated sewage sludge doses. On the other hand, the average available Cu, Cr, Ni and Zn concentrations of the soil samples taken at 5 different periods in 2 years from the experimental soil showed statistically significant changes with increasing doses of treated sewage sludge applications. In other words, available Cu, Ni and Zn concentrations of the experimental soil increased by the application of treated sewage sludge. Analogously to our study, Delibacak et al. [7] found out an increase in the concentrations of soluble Cu and Zn in soil caused by increasing doses of sewage sludge introduced to soil. In contrast, Pascual et al. [9] showed depressed concentrations of available forms of Cu and Zn in soil under the influence of a higher dose of sewage sludge (140 $Mg.ha^{-1}$). Such discrepancies, reported by different authors, in the effect of sewage sludge on the content of Cu and Zn in soil may be substantiated, for example, by different concentrations of this metal in sewage sludge. Sienkiewicz and Czarnecka [23] reported that as the dose of sewage sludge added to soil increased, so did the content of soluble zinc in soil. The highest dose of sewage sludge (280 $Mg.ha^{-1}$) caused an over 36% increase in the concentration of this element in soil compared to the control soil in their research. Bozkurt and Cimrin [20] also found that extractable Zn concentration of topsoil approximately increased fifty five-fold with sewage sludge 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 sewage sludge, which contained considerable quantities of these metals [24]. Also Soriano-Disla et al. [25] 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, sorptive properties of soil, and especially the content of organic matter, can affect the availability of heavy metals in soil. It is remarkable 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 to loamy or clayey soils [26, 27, 28, 29].

4.CONCLUSION

Treated Sewage Sludge (TSS) is an ultimate product of municipal wastewater treatment processes, is composed of organic compounds, macro and micro nutrients and heavy metals. Disposal trend of sewage sludge 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 sewage sludge 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 offical limits at the end of the study. Therefore, we concluded that TSS could be used to improve for soil properties and especially Zn deficiencies in soils of Turkey when the heavy metal concentrations there are taken into consideration. Consequently, such TSS has a considerable potential in agriculture and other applications such as reforestation, and can be used as organic matter and macro and micro nutrients resource. 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.

ACKNOWLEDGEMENTS

We thank the Scientific and Technical Research Council of Turkey (TUBITAK) for financial support (Project no: 108G167).

The authors have declared no conflict of interest.

REFERENCES

[1] Darwish O.H., Persaud, N. Martens, D.C.: Effect of longterm application of animal manure on physical properties of three soils. Plant Soil 176:289-295 (1995). doi:10.1007/BF00011793

[2] Baize, D., and Sterckeman, T.: Of the necessity of knowledge of the natural pedo-geochemical background content in the evaluation of the contamination of soils by trace elements. Sci Total Environ 264(1–2):127–139 (2001). doi:10.1016/S0048-9697(00)00615-X

[3] Dolgen, D., Alpaslan, M.N. and Delen, N.: Agricultural recycling of treatment-plant sludge: a case study for a vegetable-processing factory. J. Environ. Manage., 84(3):274–281 (2007). doi: 10.1016/ j.jenvman. 2006. 06.013

[4] Weemaes, M., Verstraete, W.: Processing, disposal, utilization. In: Spinosa L, Vesilind A (eds) Sludge into biosolids. IWA Publishing, London, pp 365–383(2001).

[5] Klasa, A., Gotkiewicz, W., Czapla, J.: Modifications of physico-chemical soil properties following application of sewage sludge as soil amendment. J. Elementol., 12(4): 287-302 (2007).

[6] Singh, R. P., Agrawal, M.: Potential benefits and risks of land application of sewage sludge. Waste Manage., 28: 347-358 (2008).

[7] Delibacak, S., Okur, B., Ongun A. R.: Influence of treated sewage sludge applications on temporal variations of plant nutrients and heavy metals in a Typic Xerofluvent soil. Nutr. Cycl. Agroecosyst., 83: 249-257 (2009).

[8] Mercik, S., Stêpieñ, W., Gêbski, M.: Uptake by plants and solubility of Cu,Zn,Pb and Cd in different extraction solutions depending on soil acidity. Zesz. Probl. Post. Nauk Rol., 493: 913-921 (2003).

[9] Pascual, I., Antolín, M. C., García, C., Polo A., Sánchez-Díaz, M.: Plant availability of heavy metals in a soil amended with a high dose of sewage sludge under drought conditions. Biol. Fertil. Soils, 40: 291-299 (2004).

[10] IARTC: Weather Station Climate Datas of International Agricultural Research and Traning Center. Menemen, İzmir (2012).

[11] Soil Survey Staff: Keys to soil taxonomy. 10th ed. Washington DC, USA: US Government Printing Office (2006).

[12] Bouyoucos, G. J.: Hydrometer method improved for making particle size analysis of soil. Agronomy Journal, 54(5), 464–465 (1962).

[13] Page, A.L., Miller, R.H. and Keeney, D.R.: (Eds.), In:Methods of soil analysis. Part 2. Chemical and microbiological properties, 2nd ed. Agron. Monogr. 9. ASA-SSA, Madison, USA (1982).

[14] Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A.: Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S. Dep. Agric.Circ.939, USDA Washington, DC (1954).

[15] Kacar, B.: Chemical analysis of plant and soil: III soil analysis. Ankara University, Faculty of Agriculture, Education Res. & Extension Found. Publications: 3 Ankara (in Turkish) (1994).

[16] Lindsay, W.L. and Norvell, W.A.: Development of a DTPA test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42, 421-428 (1978).

[17] AOAC: Official methods of analysis In: Helrich K (ed) Association of official analytical chemists, Washington, DC (1990).

[18] SPSS 17.0: SPSS 17.0 for Windows. Chicago, IL, SPSS Inc. (2008).

[19] Steel R.G.D. and Torrie, J.H.: Principles and Procedures of Statistics, Second Edition, New York: McGraw-Hill Book Co. (1980).

[20] Bozkurt, M.A. and Cimrin, K.M.: The Effects Of Sewage Sludge Applications on Nutrient And Heavy Metal Concentration in a Calcareous Soil. FEB/ Vol 12/ No 11, pages 1354-1360 (2003).

[21] Lopez-Mosquera, M.E., Moiron, C. and Carral, E.: Use of dairy industry sludge as fertiliser for grasslands in northwest Spain: heavy metal levels in the soil and plants. Resources, Conservation and Recycling 30, 95-109 (2000).

[22] Selivanovskaya, S.Y., Latypova, V.Z., Kiyamova, S.N. and Alimova, F.K.: Use of microbial parameters to access treatment methods of municipal sewage sludge applied to grey forest soils of Tatarstan. Agriculture, Ecosystem and Environment 86, 145-153 (2001).

[23] Sienkiewicz, S. and Czarnecka, M. H.: Content of available Cu, Zn and Mn in soil amended with municipal sewage sludge. j. Elem. 17 (4) s. 649–657 (2012).

[24] Neilsen, G.H., Hogue, E.J., Forge, T. and Neilsen, D.: Surface application of mulches and biosolids affect orchard soil properties after 7 years. Canadian Journal of Soil Science, 83, 131-137 (2003).

[25] Soriano-Disla, J.M., Gómez, I., Guerrero, C., Jordan, M. M. and Navarro-Pedreño, J.: Soil factors related to heavy metal bioavailability after sewage sludge application. FEB/ Vol 17/ No 11, pages 1839- 1845 (2008).

[26] McBride, M.B.: Toxic metals in sewage sludge amended soils: has promotion of beneficial use discounted the risks? Advances in Environmental Research 8, 5–19 (2003).

[27] Hooda, P.S. and Alloway, B.J.: The plant availability and DTPA extractability of trace metals in sludge-amended soils. Science of the Total Environment 149, 1–2, 39–51 (1994).

[28] Planquart, P., Bonin, G., Prone, A. and Masiani, C.: Distribution, movement and plant availability of trace metals in soils amended with sewage sludge composts: Application to low metal loadings. Science of the Total Environment 241, 161-179 (1999).

[29] Basta, N.T., Ryan, J.A. and Chaney, R.L.: Trace element chemistry in residual-treated soils: key concepts and metal bioavailability. Journal of Environmental Quality 34, 49–63 (2005).