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Evaluation of sewage sludge effects on soil fertility and silage maize growth

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ABSTRACT

Different methods are being tried all over the world for the safe disposal of sewage sludge. One of these methods is to evaluate the waste in plant production by applying it to the soil. In this study, the potential of using stabilized and dried sewage sludge in silage maize cultivation was investigated. Silage maize was grown by applying the sewage sludge to the soil at different rates [0 t ha^{-1} (SS0-Control), 20 t ha^{-1} (SS2), 40 t ha^{-1} (SS4), 60 t ha^{-1} (SS6), and 80 t ha^{-1} (SS8)]. Thus, the material's effects on soil fertility and plant growth were examined. According to the results, the sewage sludge enriched the soil, which contains restrictive factors in terms of fertility and on which maize growth is carried out, with humus and nutrients. However, it was observed that the material does not cause salinity problems in the soil. It was determined that sewage sludge positively affected the growth of silage maize but could not provide sufficient nutrition for the plant in terms of macronutrients. Considering the economic benefits and environmental risks, applying the sewage sludge with a maximum of 60 t ha^{-1} in silage maize growth is appropriate. However, it would be incredibly beneficial to support the material with chemical fertilizers to increase the silage yield and quality of the plant.

1. Introduction

Sewage sludge is an excellent source of nitrogen and phosphorus, and when applied to the soil, it increases the content of mineral nutrients and positively affects soil fertility (Gasco and Lobo 2007). One of the main factors limiting the use of sewage sludge in plant production is heavy metal content (Sims and Kline 1991). Although heavy metals are generally toxic to some extent, they tend to accumulate cumulatively in the food chain (Zhang and Ke 2004). In addition, the reaction of the soil (pH) where the sewage sludge is applied is another limiting factor. As a matter of fact, it was determined that sewage sludge applied to low pH soils increases heavy metal adsorption in the soil (Sauvé et al. 1997).

Silage maize (*Zea mays* L.) is an indispensable input for animal production, as it provides quality and low cultivation costs in addition to rations. The maize planting area for silage produced in Türkiye is approximately 420 thousand hectares. Total maize cultivation for silage is 20.1 million tons (Tezel 2018). However, silage maize removes many plant nutrients, especially nitrogen, from the soil where it is produced. Plant nutrients removed from the soil by plant cultivation and lost or turned into an unavailable form because of other factors, must be returned to the soil (Sağlam et al. 1993). Maintaining productivity and quality in plant cultivation is only possible by improving the physical, chemical and biological properties of the soil, in other words, by preserving soil fertility. For this reason, the use of organic wastes in agricultural production has become more and more common in recent years. Among organic wastes, especially stabilized and dried sewage sludge is an organic material/soil conditioner with strong potential due to its properties. In this study, the effects of sewage sludge amendments on soil fertility and silage maize growth were investigated.

2. Material and Methods

The experiment was carried out at Akdeniz University Faculty of Agriculture Research and Application Farm. The stabilized and dried sewage sludge was obtained from the Hurma Wastewater Treatment Plant in Antalya, Türkiye. In this context, the sewage sludge and test soil properties are given in Table 1. In the experiment area, soil tillage was carried out first, and the physical conditions were suitable for vegetative production. 6 m^2 (1.5x4) plots were created following the experiment plan. The sewage sludge was weighed by the application rates [0 t ha^{-1} (SSO)-(Control), 20 t ha^{-1} (SS2), 40 t ha^{-1} (SS4), 60 t ha^{-1} (SS6), and 80 t ha^{-1} (SS8)] and mixed homogeneously with the soil in the plots. A drip irrigation system was installed on the plots, ensuring that each plot was irrigated equally during the experiment.

The sewage sludge applied to the soil was incubated for 3 weeks to begin mineralization with the effect of water and other factors (temperature, pH, microorganisms etc.). At the end of this period, the first soil sampling was performed from a 0-30 cm depth of each plot. Later, the seeds of the silage maize (Burak cv) were planted in plots (two for each drip). On the 10th day following the planting date, the observation was made of two maize plants per drop in each plot, and the dilution process was carried out by leaving the homogeneously growing ones in the plots. The second soil sampling was done when the plant cob tassels had completed their growth. Silage maize, which completed its vegetation period, was harvested. At the same time, third soil samples were taken, and the experiment was concluded. In addition, chlorophyll measurements of leaves were made in field conditions ten weeks after sowing. Then, samples were taken from these leaves and measured, and other plant analyses were carried out under laboratory conditions. Silage maize plants that completed their vegetation period were harvested by cutting them from the root neck. Measurements and analysis were made for the whole shoots (excluding the cob) and the cob.

The analysis made to determine the characteristics of the sewage sludge are as follows: organic matter (Kacar 2009), pH and EC (Jackson 1967), total nitrogen (N) (Kacar and İnal 2008), total phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) (U.S. EPA 2007). The experiment soils were made ready for analysis by sifting through a 2 mm sieve after they were dried. The analysis performed are as follows: Soil texture (Bouyoucos 1955), lime (Çağlar 1949), pH and EC (Jackson 1967), soil organic matter (Black 1965), total N (Kacar 2009), available P (Olsen and Sommers 1982), exchangeable K, Ca, and Mg (Kacar 2009).

For the height of the first cob in the plant, the vertical distance between the node to which the cobs are attached and the soil surface was measured. For the number of cobs, the number of cobs in the plant selected from each plot was determined in units. For the cob/plant ratio, the cobs of the plant selected from each plot were separated from the stem and leaf and weighed, and the calculation was made in proportion to the weight of the whole shoot (excluding the cob). The whole shoot (excluding the cob) and the cob were calculated by weighing them separately for wet weight. Plant samples were dried at 65°C and weighed for dry matter yield. The values obtained were calculated as kg ha^{-1}. The amount of acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude cellulose (CC) in the plants were determined according to Van Soest et al. (1991). The value of chlorophyll in the plant was measured with a chlorophyll meter (Minolta SPAD-502 plus) under field conditions. Chlorophyll-a and chlorophyll-b were determined using acetone extraction (Williams 1984). Total N, P, K, Ca, and Mg concentrations in leaves of plants were determined according to the wet digestion method (Kacar and İnal 2008). After determining the N content of the plant samples, the value obtained was calculated by multiplying the protein conversion coefficient of 6.25 for maize.

The significance levels of the obtained data were determined by analysis of variance using the MSTAT-C package program. In addition, the differences between the MINITAB package program and the means were determined in the LSD test, and the 5% significance level was taken as a basis for the letters of the different groups (Minitab 2010).

3. Results and Discussion

3.1. pH, EC, and organic matter

The change in pH values according to the sampling period was statistically significant (P<0.001). It was determined that the effect of the sewage sludge on the EC of the soil is significant at the level of 5% (Table 2). The highest EC value was measured in soils where SS6 (0.53 dS m^{-1}) and SS8 (0.57 dS m^{-1}) were applied. It is reported that the sewage sludge application causes an increase in the EC of the soil but does not reach salinity levels (Aldatmaz 2006). The data also supports that the sewage sludge application does not create any salinity risk. On the other hand, the change in EC values of the soil was found to be statistically significant according to the sampling period (P<0.001). Soil EC values decreased from the first sampling to the third. The sewage sludge takes longer to break down and mineralize in the soil than other organic substances due to the high heat it is exposed to during the drying phase. This process slows the passage of plant nutrients from the sewage sludge to the soil. Silage maize is a plant that absorbs high levels of nutrients. The results of the second and third sampling is thought to be affected by the

Table 1. Selected physico-chemical properties of the sewage sludge, experiment soil, and certificated materials

Parameter		Sewage sludge	Soil	Certificated Clay loam soil material (RTC CRM052)		Certificated Sewage sludge material (CRM029-50G)		Certificated Plant material (Peach Leaves) (CRM-1547)	
				Referance range	Value	Referance range	Value	Referance range	Value
pH		6.42	7.06	-	-	-	-	-	-
EC dS m^{-1}		5.44	0.44	-	-	-	-	-	-
$CaCO_3$ %		-	43	-	-	-	-	-	-
Texture		-	Clay loam	-	-	-	-	-	-
Organic Matter %		74	1.39	-	-	-	-	-	-
Tot.[1]	N %	4.9	0.13	3.97±0.562	3.42	3.26±0.56	4.58	2.94	3.09
	P mg kg^{-1}	16144	118	168±30.7	102.67	2.11±0.26	1.51	1371	1184
	K mg kg^{-1}	4484	8226	2390 ±76.2	1858.40	3540±290	3604	24330	24120
	Ca mg kg^{-1}	61400	53512	2860±118	1680.97	51600±1650	55620	15590	16744
	Mg mg kg^{-1}	6506	4267	1690±74.8	1593.10	10400±395	10428	4320	4326
Avai.[2]	P mg kg^{-1}	-	3.14	-	-	-	-	-	-
Exc.[3]	K mg kg^{-1}	-	250	-	-	-	-	-	-
	Ca mg kg^{-1}	-	410	-	-	-	-	-	-
	Mg mg kg^{-1}	-	210	-	-	-	-	-	-

[1]Total concentration, [2]Available concentration, [3]Exchangeable concentration.

absorption of ions that can accumulate in the soil and cause salinity by the plant. This result may explain the relatively higher EC value of the first sampling period. Göçmez (2006) observed an increase in soil EC with increasing rates of sewage sludge and found the highest EC value in the highest sewage sludge application. However, he reported that the increase in soil EC is far from changing the salinity level of the soil.

The effect of increasing rates of sewage sludge on the organic matter was found to be statistically significant at the level of 5% (Table 2). The sewage sludge increased the organic matter compared to the control. The highest organic matter value was determined in the soil treated with SS2 (2.77%). The sewage sludge used in the experiment has higher organic matter content (74%) than many organic fertilizers or soil conditioners. In addition, the fact that the experiment soil is poor in humus (1.39%) explains the increase in the sewage sludge compared to the control. The change in organic matter values according to the sampling period was also statistically significant (P<0.001). Although organic matter values determined in the second and third sampling periods were similar, it was determined that they increased compared to the first. One of the most important benefits of applying sewage sludge in soils where the organic matter content is low and decomposition is intense, due to the climate, is the improvement provided in the organic matter. A multi-year study by Angın (2008) shows that sewage sludge application supports organic matter for the following two years.

3.2. Total N, available P, and exchangeable K, Ca, Mg

The effect of the sewage sludge on the total N of the soil was found to be statistically significant at the level of 1% (Table 3). When the total N content of the soil was evaluated according to Loue (1968), it was at a reasonable level at the beginning, while 20 t ha^{-1} and more sewage sludge made it to an outstanding level (0.130%<). In addition, in the soil analysis before the experiment was established, the total N was determined as 0.130%, and the highest soil N value was determined in SS6 (0.21%) and SS8 (0.20%) of the sewage sludge. In this way, an increase of 61.5% was achieved in the N content of the soil compared to the beginning. It was reported that increasing sewage sludge rates regularly increased the soil's total N content (Navas et al. 1998). The change in the total N values according to the sampling period was statistically significant (P<0.001). While the N value of the soil was in the same statistical group in all application rates at the first and second sampling periods, it was determined as a different group and lower in the third sampling. This situation may have been caused by the increase in nutrient absorption during the growth of the maize. In addition, the N released by mineralization may have partially evaporated (due to high pH) and leached losses.

The effect of the sewage sludge on the available P content of the soil was found to be statistically significant at the 0.1% level, and the available P content of the soil increased in all other application rates compared to the control (Table 3). The available P of the soil sample taken before the experiment was determined as 3.14 mg kg^{-1}. The highest value was determined in SS6 (12.30 mg kg^{-1}), and an increase of 292% was achieved compared to the control. In addition, when evaluated according to Olsen and Sommers (1982), the soil available P content, which was in the low level (5 mg kg^{-1}>) with 3.14 mg kg^{-1}, had increased to the high level (10<) with 12.30 mg kg^{-1}. The change in the available P values of the soil according to the sampling period was significant (P<0.001). From the first sampling to the third, the available P value of the soil increased. It is thought that during the mineralization process of the sewage sludge, the release of P increases with time and that the P uptake by the maize takes place. The effect of sewage sludge application on the P content of the soil was evaluated among the most critical agricultural benefits of the material (Schowanek et al. 2004).

Table 2. Effects of sewage sludge on soil pH, EC, and organic matter

Application	pH	EC (dS m^{-1})	Organic matter (%)
SS0	7.36	0.33c[2]	2.24d
SS2	7.35	0.41b	2.77a
SS4	7.33	0.46b	2.45c
SS6	7.27	0.53a	2.65b
SS8	7.23	0.57a	2.66b
		ANOVA	
Sewage Sludge (SS)	NS[5]	*[4]	*
Sampling period (SP)	***	***	***[3]

[1]Values are the means of three different soil sampling period, [2]Means in the same column followed by the same letter are not significantly different at the 5% level according to LSD test, [3]*** P<0.001, [4]* P<0.05, [5]NS: Not significant.

Table 3. Effects of sewage sludge on macronutrients of soil

Application	Total					Exchangeable			Available
	N %	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	P mg kg^{-1}
SS0	0.13c[2]	115d	7724b	84102a	4540a	230ab	4500	230c	2.52d
SS2	0.17b	138c	8226a	87489a	4380b	270a	4800	260b	8.89c
SS4	0.18b	157b	7821b	63952c	4360b	200b	4500	280a	10.38b
SS6	0.21a	161a	8577a	60571c	4359b	230ab	4600	290a	12.30a
SS8	0.20a	156b	6847c	80141b	4213c	190c	4600	260b	10.04b
					ANOVA				
Sewage Sludge (SS)	**[4]	***	***	***	***	***	NS[6]	***	***[3]
Sampling period (SP)	***	***	***	***	***	***	*[5]	***	***

[1]Values are the means of three different soil sampling period, [2] Means in the same column followed by the same letter are not significantly different at the 5% level according to LSD test, [3] *** P<0.001, [4]** P<0.01, [5] * P<0.05, [6] NS: Not significant.

It was determined that the effect of the sewage sludge on the exchangeable K content of the soil is statistically significant at the level of 0.1% (Table 3). Considering the differences between application rates, the highest exchangeable K value SS2 (0.027% - 270 mg kg^{-1}) was determined in the applied soil. When evaluated according to Pizer (1967), it was determined that the exchangeable K content of the control soil was 0.024% (230 mg kg^{-1}), and it was at a reasonable level (199-249 mg kg^{-1}). The change of K values of the soil according to the sampling period was found to be significant (P<0.001). Since the maize seed was planted at the end of the incubation period of the material in the soil, the second and third samplings are within the plant's growing period. Considering that the plant meets the K requirement in this process, the soil's K content is expected to decrease gradually. There was a 26.08% decrease in exchangeable K values from 270 mg kg^{-1} to 190 mg kg^{-1}. It was reported that the sewage sludges are poor in K compared to the significant amount of N and P they contain (Angın and Yağanoğlu 2009).

The sewage sludge on the exchangeable Ca content of the soil were statistically insignificant (Table 3). On the other hand, the change in Ca values in terms of sampling periods was significant (P<0.05). The effect of the sewage sludge on the exchangeable Mg content of the soil was found to be statistically significant at the 0.1% level (Table 3). Considering the Mg values between the application rates, the highest value was determined in the soils where SS4 (0.028%) and SS6 (0.029%) were applied. When evaluated according to Loue (1968), the exchangeable Mg content of the control soil is 0.023% (230 mg kg^{-1}), and it is at a reasonable level (114 mg kg^{-1}<). Similarly, it was determined that the sewage sludge brought the exchangeable Mg content of the soil to a reasonable level and provided increases ranging from 13.04% to 26.08%. The change in the Mg values of the soil was also found significant in terms of sampling period (P<0.001). The values decreased by 0.027% (272 mg kg^{-1}) in the first sampling, 0.026% (261 mg kg^{-1}) in the second, and 0.025% (252 mg kg^{-1}) in the third. Considering that the plant meets the Mg requirement in this process, it is usual to decrease the exchangeable Mg content of the soil. The content of exchangeable Mg has decreased by 7.56% from 272 mg kg^{-1} to 252 mg kg^{-1}.

3.3. Plant Growth and Yield

The analysis results of the sewage sludge regarding the first cob height, number of cobs, cob/plant ratio, wet weight, dry weight, and dry matter yield of silage maize are given in Table 4. The effect of the sewage sludge on the first cob height was found to be statistically significant at the level of 0.1%. As the applied sewage sludge rates increased, the height of the first cob increased. The highest value was obtained in SS8 with 153.2 cm. The effect of sewage sludge on the number of cobs was found to be statistically significant at 5%. In the SS6 application, the highest number of cobs occurred, with an average of 8. It was determined that the effect of sewage sludge on the cob/plant ratio was statistically 0.1%. While the highest cob/plant ratio is under control, these values decrease as the application rates increase. The effects of the sewage sludge on the plant's wet and dry weight values were found to be statistically significant at a 0.1% level. According to this, the wet weight in the whole shoots was determined as 3808 g in SS8.

When the wet and dry weights of the cob samples were examined, the values were higher in the control and SS2, while the wet and dry weights of the cob samples decreased as the application rates increased. The effect of the sewage sludge on the dry matter yield of whole shoots and cob samples was found to be statistically significant at the level of 0.1%. It was determined that the sewage sludge applied at increasing rates increased the dry matter yield in the whole shoots and decreased the dry matter yield in the cob samples. The highest dry matter yield was detected in SS8 with 19000 kg ha^{-1} in the whole shoot samples. In the cob samples, the highest yield was observed in SS2 with 3900 kg ha^{-1}. Hallauer and Miranda (1987) reported that the morphological characteristics of maize, plant height and first cob height mainly depend on genetic factors. In addition, factors such as the amount of light, intensity, and plant nutrients are influential on the first cob height and plant height. In rotations sensitive to maize, if the net assimilation rate of the plant slows down due to light and nutrients, the cob stalk is negatively affected by this situation (Uyanık 1984).

3.4. ADF, NDF, CC and Chlorophyll (a, b, SPAD value)

The effect of sewage sludge on ADF, NDF and CC values in whole shoots samples was found to be statistically insignificant (Table 5). The ADF values of the cob samples were found to be statistically significant at the 0.1% level. It was determined that the highest ADF value was 32.0% in SS6. The effect of the sewage sludge on the NDF values of the cob samples was found to be statistically significant at a 5% level. It is seen that the highest NDF value is 60.6% in SS6. The effect of the sewage sludge on the amount of CC of the cob samples was found to be statistically insignificant. Khan et al. (2015) reported that NDF and ADF contents of maize silages decreased as they progressed from early maturity to 2/3 milk maturity period but did not change from 2/3 milk to full maturity. It is reported that the water-soluble dry matter, NDF, ADF, and crude protein contents of the corn plant decreased while the dry matter and starch contents of the corn plant increased as the vegetation period progressed (Dwyer et al. 1998).

The effect of sewage sludge on chlorophyll-a, chlorophyll-b, and SPAD value of silage maize was statistically significant at the level of 0.1% (Table 5). Accordingly, in SS6 and SS8, the chlorophyll content of the plant doubled compared to the control and other application rates. It is known that there is an important relationship between the N, which is a critical element in the chlorophyll molecule, and the chlorophyll content. The chlorophyll content of plants with good N nutrition is also expected to be relatively high (Türkan 2008). The obtained chlorophyll results show that the N nutritional status of the plants in the SS6 and SS8 applied plots is better than the others. It is thought that even at these high rates, it will not cause stress in the plant because it is known that the chlorophyll content of plants decreases due to increasing stress conditions (Manios and Stentiford 2003).

3.5. Mineral nutrition status of plant

The effect of sewage sludge on both the total N concentration and protein amount of leaf samples was found to be statistically significant at a 0.1% level (Table 6). The protein and N content of the plant similarly increased due to sewage sludge. SS8 (2.22%) and SS6 (2.19%) had the highest total N values. The effect of the sewage sludge on P concentrations was found to be statistically significant at 0.1% level. It was determined that as the application rates increased, the P concentration also

Table 4. Effects of sewage sludge on growth and yield of silage maize

Application	First cob height (cm)	Number of cob	Cob/Plant ratio	Wet weight (g)		Dry weight (g)		Dry matter yield (kg ha^{-1})	
				Whole shoots	Cob	Whole shoots	Cob	Whole shoots	Cob
SS0	110.50c[1]	5b	0.30a	2270e	682b	1078e	353b	10780c	3500b
SS2	132.05b	6b	0.22b	3373d	718a	1625d	392a	16000b	3900a
SS4	138.75ab	6b	0.13c	3474c	486d	1628c	277c	16000b	2770c
SS6	146.80ab	8a	0.14c	3651b	500c	1666b	244d	16000b	2430d
SS8	153.20a	7ab	0.13c	3808a	482e	1906a	241e	19000a	2410e
ANOVA (LSD 5%)									
Sewage sludge (SS)	***[2]	*[3]	***	***	***	***	***	***	***

[1] Means in the same column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test, [2] *** P<0.001, [3] * P<0.05.

Table 5. Effects of sewage sludge on acid detergent fiber (ADF), neutral detergent fiber (NDF), crude cellulose (CC), and chlorophyll of silage maize

Application	ADF (%)	NDF (%)	CC (%)	Chlorophyll		
				a (mg kg^{-1})	b (mg kg^{-1})	SPAD value
SS0	21.8c[1]	50.7b	18.6	6.630b	2.888b	30.025c
SS2	22.7bc	47.2b	19.8	5.801b	2.701b	38.095b
SS4	25.9b	53.7ab	22.2	6.990b	3.128b	42.495b
SS6	32.0a	60.6a	22.8	12.322a	4.550a	47.795a
SS8	25.7bc	47.5b	19.4	10.496a	4.414a	47.880a
ANOVA (LSD 5%)						
Sewage sludge (SS)	***[2]	*[3]	NS[4]	***	***	***

[1] Means in the same column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test, [2] *** P<0.001, [3] * P<0.05, [4] NS: Not significant.

Table 6. Effects of sewage sludge on concentration of nutrient elements of silage maize

Application	Protein (%)	Total (%)				
		N	P	K	Ca	Mg
SS0	9.40d[1]	1.51c	0.17c	1.67b	0.71c	0.13c
SS2	11.85c	1.90b	0.19bc	1.92a	0.97ab	0.16bc
SS4	12.57bc	2.02b	0.20b	2.00a	0.98ab	0.20ab
SS6	13.06ab	2.19a	0.24a	1.92a	0.92b	0.21ab
SS8	13.89a	2.22a	0.26a	1.97a	1.02a	0.24a
ANOVA (LSD 5%)						
Sewage sludge (SS)	***	***	***[2]	**[3]	***	**

[1] Means in the same column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test, [2] *** P<0.001, [3] ** P<0.01.

increased. The highest P values (0.26%) were determined in SS8 and (0.24%) SS6. The effects of the sewage sludge on K concentrations were found to be statistically significant at the level of 1%. The sewage sludge increased the K concentration of the leaves compared to the control, but all application doses were in the same group.

The effect of sewage sludge on Ca concentrations in leaf samples was found to be statistically significant at 0.1%. The highest Ca was determined with the value of 1.02% in SS8. The effects of the sewage sludge on Mg concentrations in leaf samples were found to be statistically significant at 1%. The Mg value, which was 0.13% in the control, increased as the application rates increased, and the highest concentration of 0.24% was determined in SS8. According to Yılmaz (2004), the normal limits for macronutrients in silage maize plants according to leaf analysis are as follows: N 3.50-5.0%, P 0.35-0.60%, K 3.0-4.50%, Ca 0.30-1.0%, Mg 0.25-0.50%. Accordingly, sewage sludge could not nourish the plant sufficiently regarding the nutrients (excluding Ca) examined. It is known that a plant with high vegetative and generative yield potential, such as silage maize, exploits high amounts of nutrients from the soil in a short time. Therefore, it is thought that the sewage sludge should be supplemented with chemical fertilizers.

4. Conclusion

As well as maintaining the fertility of the soil, it is imperative that the yield and quality of the plant grown on it is high. For this reason, the fertilizing materials (organic or chemical) must be in a suitable composition for both the soil and the plant. For this purpose, the effects of sewage sludge on soil fertility and plant growth in silage maize, a forage crop, were investigated. According to the results, all application rates of sewage sludge increased the soil fertility where maize was grown. While this material enriches the soil with humus and plant nutrients, it was determined that it does not cause salinity risk. However, it was determined that sewage sludge positively affected the growth of silage maize but could not provide sufficient nutrition for the plant in terms of macronutrients. As a result, considering the economic benefits and environmental risks, it is appropriate to apply sewage sludge as a soil conditioner at a maximum of 60 t ha^{-1} in silage maize cultivation. However, applying the sewage sludge and chemical fertilizers would significantly benefit the plant's silage yield and quality. In this way, soil fertility would be preserved, and there will be no decrease in plant yield and quality using sewage sludge. It is thought that it would be beneficial to continue extensive studies using this material to increase the reliability of the results obtained from existing scientific studies and eliminate the uncertainties regarding the use of sewage sludge in plant cultivation.

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References

Aldatmaz G (2006) Toprağa uygulanabilir nitelikteki arıtma çamurlarının topraktaki bazı enzim aktiviteleri üzerine etkileri. Yüksek lisans tezi, Uludağ Üniversitesi, Bursa, s. 108.

Angın İ (2008) Arıtma çamurlarının fiziksel ve kimyasal toprak düzenleyicisi olarak kullanımı. Doktora tezi, Atatürk Üniversitesi, Erzurum.

Angın İ, Yağanoğlu AV (2009) Arıtma çamurlarının fiziksel ve kimyasal toprak düzenleyicisi olarak kullanımı. Ekoloji 19(73): 39-47.

Black CA (1965) Methods of Soil Analysis. Part 2. AmericanSociety of Agronomy Inc., Publisher Madison, Wisconsin, USA.

Bouyoucos GJ (1955) A Recalibration of the Hydrometer Method for making mechanical analysis of the soils. Agronomy Journal 4(9): 434.

Çağlar KÖ (1949) Toprak Bilgisi. Ankara Üniversitesi Ziraat Fakültesi Yayınları, Sayı: 10.

Dwyer LM, Stewart DW, Glenn F (1998) Silage yields of leafy and normal hybrids. Com and Sorghum Conf. Am. Seed Trade. Assoc.Washington D.C.

Gasco G, Lobo MC (2007) Composition of a Spanish sewage sludge and effects on treated soil and olive trees. Waste Management 27(11): 1494-1500.

Göçmez S (2006) Menemen Ovası Topraklarında İzsu Kentsel Arıtma Çamuru Uygulamalarının Mikrobiyal Aktivite ve Biyomas ile Bazı Fiziksel ve Kimyasal Toprak Özellikleri Üzerine Etkisi. Doktora Tezi, Ege Üniversitesi Fen Bilimleri Enstitüsü, Toprak Anabilim Dalı, İzmir.

Hallauer AB, Miranda JB (1987) Quantitative Genetics in Maize Breeding. Lowa State Unıv. Press, Ames, Lowa, pp. 118-119.

Jackson ML (1967) Soil Chemical Analysis. Prentice Hall of India Private Limited, New Delhi, India.

Kacar B, İnal A (2008) Bitki Analizleri. Nobel Yayınları, Ankara, No: 1241.

Kacar B (2009) Toprak Analizleri. Nobel Yayın No: 1387, Fen Bilimleri: 90, Nobel Bilim ve Araştırma Merkezi Yayın No. 44 ISBN 978-605-395-184-1. s. 467.

Khan NA, Yu P, Ali M, Cone JW, Hendriks WH (2015) Nutritive value of maize silage in relation to dairy cow performance and milk quality. Journal of the Science of Food and Agriculture 95(2): 238-252.

Loue A (1968) DiagonisticPetiolaire de Prospection. Etudes Sur la Nutrition et al Fertilisation Potassiques de la Vigne. Societe Commerciale des Potasses d'Alsace Sevices Agronomiques pp. 31-41.

Manios T, Stentiford E (2003) The effect of heavy metals accumulation on the chlorophyll concentration of typha latifolia plants growing in a substrate containing sewage sludge compost and watered with metalliferous water. Ecological Engineering 20: 65-74.

Minitab (2010) Minitab Inc. MINITAB: Minitab for Windows Version Release 17. State College, PA, USA: Minitab Inc.

Navas A, Bermudez F, Machin J (1998) Influence of sewage sludge application on physical and chemical properties of Gypsisols. Geoderma 87: 123-135.

Olsen SR, Sommers LE (1982) Phosphorus. In: Page, A.L., Miller, R.H. and Keeney, D.R., Eds., Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties, American Society of Agronomy, Inc., Madison, pp. 403-427.

Pizer NH (1967) Some advisory aspects of potassium and magnesium. Technology Bulletin 14: 184.

Sağlam MT, Bahtiyar M, Cangir C, Tok HH (1993) Toprak Bilimi. Trakya Üniversitesi Tekirdağ Ziraat Fakültesi Toprak Bölümü Ders Kitabı, Anadolu Matbaa Tic. Koll. Şti., Tekirdağ.

Sauvé S, McBride MB, Hendershot WH (1997) Copper solubility and speciation of in-situ contaminated soils: effect of copper level, pH and organic matter. Water, Air and Soil Pollution 100: 133-149.

Schowanek D, Carr R, David H, Douben P, Hall J, Kirchmann H, Patria H, Sequi P, Smith S, Webb S (2004) A risk-based methodology for deriving quality standards for organic contaminants in sewage sludge for use in agriculture conceptual framework. Regulatory Toxicology and Pharmacology 40: 227-251.

Sims JT, Kline JS (1991) Chemical fractionation and plant uptake of heavy metals in soil amended with co-composted sewage sludge. Journal of Environmental Quality 20: 387-395.

Tezel M (2018) Türkiye'de silajlık mısır üretimi ve hayvan beslemede yeri. TÜRKTOB Dergisi 25: 17-19.

Türkan İ (2008) Bitki Fizyolojisi, Palme Yayınları: 455, Palme Yayıncılık.

U.S. EPA (2007) Method 3051A (SW-846): Microwave Assisted Acid Digestion of Sediments, Sludges, and Oils. Revision 1. Washington, DC.

Uyanık M (1984) Mısır Bitkisinin Botanik Özellikleri. Karadeniz Bölge Zirai Araştırma Enstitüsü Yayınları No: 1984-1, Samsun.

Van Soest PJ, Robertson JB, Lewis BA (1991) Method for Dietary Fiber, Neutral Detergent Fiber, and Nostarch Polysaccharides in Relation to Animal Nutrition. Journal of Dairy Science 74: 3583-3597.

Williams S (1984) Official Methods of Analysis of the Association of Official Analytic Chemists. Published by the Association of Official Analytical Chemists. Inc. Wircini, 22.209, USA, pp. 59-60.

Yılmaz C (2004) Bitkisel Üretimde Besin Elementleri. Hasad Yayıncılık, ISBN 975-8377-36-1, İstanbul.

Zhang MK, Ke ZX (2004) Heavy metals, phosphorus and some other elements in urban soils of Hangzhou City, China. Pedosphere 14(2): 177-185.