EFFECT OF ADDITION OF SECONDARY-TREATED DOMESTIC SEWAGE SLUDGE TO DIAMMONIUM PHOSPHATE FERTILIZER ON ELEMENT CONTENT OF ARTIFICIAL PASTURE HERBAGE AND THEIR AVAILABILITY IN SOIL

ARVAS, Ö.* – ÇELEBI, Ş. Z.

Field Crops Department Faculty of Agriculture Van Yuzuncu Yil University, 65080 Zeve Campus, Van, Turkey

**Corresponding author*
e-mail: osmetarvas@gmail.com; ORCID: 0000-0001-8713-2388

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Abstract. Organic matter deficiency limits plant production in arid and semi-arid areas. Secondary treated sludge is an effective source of organic waste. The effect of sewage sludge in addition to diammonium phosphate (DAP) fertilizer on nutrient and metal concentrations of herbage and soil in an artificial pasture under arid and semi-arid condition was examined in this study. The pasture consisted of *Onobrychis sativa* (35%), *Poterium sanguisorba* (40%) and *Agropyron elongatum* (25%) mixture. A total of 150 kg ha^{-1} DAP was applied to all plots with sowing. Additionally, 30, 60 and 90 tonne ha^{-1} of sewage sludge was applied in a randomized block design. The addition of the sewage sludge increased P and K concentrations, however decreased B and Pb concentrations in the herbage significantly. Fe, Cu, Zn, Co, Se, Mo, Mn, Ni, Cr concentrations also decreased, but this change was not significant. The concentration of Cd in herbage increased with increasing sewage sludge doses. Sewage sludge improved pH, electrical conductivity and organic matter at two soil depths and increased N, P and K concentrations in both the topsoil and subsoil. The addition of domestic secondary treated sewage sludge could reduce the efficacy of some DAP-sourced metals.
Keywords: *unnatural pasture, sewerage biosolid, household, chemical fertilizer, semi- arid*

Introduction

Ensuring the sustainability of natural resources and increasing their productivity (soil, water, vegetation) are possible with correct recycling of organic waste. In addition to animal and green manure the sewage sludge obtained from domestic wastewater treatment plants is used as a source of plant nutrients and to improver soil in many developed countries. Natural or artificial pastures are agricultural areas where treated sewage sludge is applied with little risk, making it possible to meet nutritional need of grazing animal with minimal environment damage. Sewage sludge production in Europe increased when treatment process became compulsory with the 91/271/ CEE directive introduced in the 1990s. The total domestic sewage sludge production in 26 European countries, including Turkey, is 304,813.829 thousand tonnes, the amount of use in agriculture is 10,665.797 thousand tonnes (Eurostat, 25.10.2020). Turkey ranks 16th in waste slugde use in agriculture at 3%, while Germany the top user of waste sludge, uses 23%. However, Turkey ranks 2nd in sewage sludge production. Data for composting and other applications in Turkey are absent. Due to its high organic matter and nutrient content, the treated sewage sludge increases water retention capacity end extends the vegetation period in arid and semi-arid regions (Arvas et al., 2011; Bai et al., 2022). It is very convenient to use domestic treated sewage sludge obtained from rural treatment plant in agriculture (Wieczorek and Fraczek, 2013; Aleisa et al., 2021). In general, this type of

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municipal sewage sludge contains high amounts of macronutrient and does not excessive amounts of heavy metals recommended for use in fertilizing cultivated plants (Alveranga et al., 2015; Nascimento et al., 2020).

Landfill of sewage sludge, especially in settlements such as basins, may mix with heavy metal leachate causing eco-toxicological contamination of freshwater sources. According to the European Commission Working Document (Turkey report, 2020), it is not permissible to use sewage sludge as fertilizer unless the concentrations of metals such as Cd, Pb, Zn and Hg which may accumulate in the soil, are reduced. A survey of around 2,559 soils samples collected in the Galicia region in northwest Spain, 38 were alkaline, and the rest were strong acids. The soil in this region is suitable for fertilization with sewage sludge, and excess Ni originating from bedrock is limiting (Mosquera-Losadra et al., 2012). Sewage sludge application increased the availability of metals in alkaline soil, however, this increase is found to be below the EU and Turkey Soil Pollution threshold (Arvas, 2005). Recovery of macro-elements from organic waste allows sustainable use of waste and can re-enter the production cycle (Elsalam et al., 2021).

Sewage sludge may be more useful source of plant nutrient than chemical fertilizers because the late decomposition of sewage sludge prevents plant nutrients from leaking into the lower parts of the soil (Rechcigl and Muchovej, 1998; Fijalkowski et al., 2017). Sewage sludge increased the amount of Mo in meadow grasses, but it did not increase to toxic levels at sampling time (Tiffany et al., 2000). Furthermore, the same authors reported that most meadow grasses need for cattle were poor in Co, Cu, Zn and Se, and sewage sludge application increased the micronutrient content of both the soil and *Paspalum notatum* without toxic effect. Treated sewage sludge increases the dry matter rate of Ray Grass (*Lolium multiflorum*) and the heavy metal concentration in the soil depth of 0-40 cm, but there is no increase in heavy metal concentration in the aboveground parts due to the roots' barrier function (Lassoued et al., 2014). Repeated sewage sludge application does not pose N and P pollution risk in the soil (Sigua, 2009). Surface application air-dried sewage sludge increased N, P, Cu, Zn, and Cd in the topsoil but not in subsoil (Bourioug et al., 2015). Application with sewage sludge has increased the metals availability in muddy soil by 35.8 to 455%. With the highest dose application (300 t ha^{-1}) the Mn concentration in *Lolium perenne* decreased by 4.3%, but the Cr concentration increased by 890%. The metal concentration in the roots more than doubled though it remained below the permitted limits for the Chinese territory (Gu et al., 2013). Sludge applied to the corn plants grown in red clay soil (terra rossa) (Zimbabwe) significantly improves the chemical properties of the soil, increases the growth, biomass production and elemental uptake in the corn plants, but reduced heavy metal uptake (Gwenzi et al., 2016). The fertilizer industry is a source of micronutrients and heavy metals, and the Cd and Pb content of the soil increases as a result of chemical fertilization in cultivated lands (Atafar et al., 2010). Long-term phosphorus and phosphorus fertilizer applications can cause heavy metal accumulation in agricultural lands and crops (Gambus and Wieczorek, 2012; Alkhader, 2015).

The aim of this study is to investigate the effects of adding secondary treated domestic sewage sludge to chemical fertilizer to artificial pastures in semi-arid regions on the concentration of macro and micronutrients and heavy metals in plants and soil.

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Materials and methods

The study was carried out at the Van Yüzüncü Yıl University Research and Application Management Directorate area (K 38^0 34′ 41″, D 43^0 17′ 24″). The experiment area altitude is 1,689 m in a continental and semi-arid with snowy in winter and rainy in spring and autumn.

According to the long-term climate data of 1938-2017, the average precipitation, temperature and humidity are 387.2 mm, 9.4 °C and 56.3%, respectively. The highest precipitation (55.9 mm), temperature (22.2 °C) and humidity (67.5%) occurred in April, July and December in long term, respectively. The lowest precipitation (3.7 mm), temperature (-3.1 °C) and humidity (41,2%) occurred in August, January and August, respectively. The total rainfall, average temperature and humidity during the study conducted, between April 2016 and November 2017, were 626.1 mm, 12.3 °C and 48%, respectively. Total precipitation in 2016 was higher than the long-term average (468.8 mm), while the year 2017 was lower (313.0). The average temperature during the experiment was also higher than the average temperature of the long-term average (9.4 °C), but the humidity was lower (*Table 1*).

Table 1. *Monthly means of climate variables for the crop seasons of 2016, 2017 and long-term average (LTA: 1938-2017) in Van, Turkey*

Months	Temperature (°C)			Precipitation (mm)			Relative humidity (%)		
	2016	2017	LTA	2016	2017	LTA	2016	2017	LTA
January	-2.4	-3.2	-3.1	87.7	9.0	34.6	69.0	62.5	66.7
February	1.7	-3.5	-2.6	8.7	11.3	33.6	73.9	63.6	67.2
March	4.2	3.2	1.5	42.4	41.0	46.7	68.2	64.6	65.4
April	9.8	8.5	7.7	30.5	58.3	55.9	53.3	54.9	59.3
May	14.1	13.9	13.1	61.0	89.0	45.8	53.3	52.5	55.1
June	18.5	19.5	18.2	38.6	0.4	18.1	45.7	39.9	47.1
July	22.8	23.9	22.2	3.1	3.0	5.4	39.2	30.6	42.1
August	24.1	24.3	22.1	0.4	1.9	3.7	31.0	28.8	41.2
September	17.5	20.3	17.8	29.2	0.0	13.6	41.8	29.0	43.9
October	11.7	11.5	11.2	79.6	27.5	46.8	49.8	44.2	57.3
November	4.2	5.9	4.9	29.2	54.7	47.0	54.2	62.1	64.2
December	-1.8	2.8	-0.5	58.4	16.9	36.0	63.2	63.5	67.5
Yearly(M/T)*	10.4	10.6	9.4	468.8	313.0	387.2	53.6	49.7	56.3

* M: Mean, T: Total, **14th Regional Directorate of Meteorology - VAN

Experimental area soil is in the clay loam structure class, with slightly alkaline reaction, unsalted, insufficient in terms of organic matter and exchangeable potassium, and sufficient phosphorus, exchangeable calcium and magnesium content. In terms of micronutrients, iron content was moderate, copper content was sufficient, manganese content was low and zinc content was high (Alparslan et al., 2005). It is thought that the high zinc value is due to the main material. The available molybdenum content of the trial soil was adequate (Kubota, 1977), while the boron content was insufficient (Krauskopf, 1972). Lead, cadmium, chromium and nickel concentrations were found below the risk level (Anonymous, 2005). The cobalt concentration was found to be within the acceptable range (Swaine, 1955).

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The sewage sludge was obtained from a municipal just home-based secondary treatment plant and naturally dried (*Table 2*). The artificial pasture was composed of Onobrychis sativa (35%), Poterium sangiusorba (40%) and Agropyron elongatum (25%) and was established on 7 April 2016 in random blocks in 2 x 2 m plots in triplicate. The amount to be added to the mixture was determined by multiplying the sowing rate of each plant alone by the % ratio in the mixture. The sum of these determined amounts formed the total amount of seeds to be planted in hectare. Accordingly, 65 kg of seeds were planted per hectare. Diammonium phosphate (DAP) was applied 150 kg ha^{-1} to all parcels with cultivation sowing. On 10 November 2016, 30, 60 and 90 tons' ha^{-1} of secondary treated sewage sludge was applied to the plots other than the control plot. Doses were identified as Control (150 kg DAP ha^{-1}), DAP + SS_1 (150 kg DAP ha^{-1} + 30 tonne ha^{-1}), DAP + SS_2 (150 kg DAP ha^{-1} + 60 tonne ha^{-1}) and DAP + SS_3 (150 kg DAP ha^{-1} + 90 tonne ha^{-1}). Observations and measurements of plant samples were obtained between June and July in 2017. Soil samples were taken from 0-15 cm and 15- 30 cm depths and from the point where the plant samples were taken. Soil samples were taken at the end of November 2017 to better determine the effect of October and November precipitations on nutrient and metal leaching.

Table 2. *Chemical properties of secondary-treated sewage sludge and some chemical and physical attribute of the experimental area before applications*

Parameters	Chemical Sewage sludge	Chemical properties of the soil	
		0-15 cm	15-30 cm
pH	6.77	8.01	8.09
EC[1] (dS/m)	2.325	0.21	0.22
Texture	-	clay loam	clay loam
Org.Mat (%)	24.31	1.56	1.07
P (%-mg/kg)	15.5	9.02	9.80
N (%)	4.91	0.081	0.074
K (mg/kg-%)	7279	83.7	86.3
Ca (mg/kg-%)	27783	14.25	15.09
Mg mg/kg	17991	4.83	5.07
Fe mg/kg	10363	4.30	4.12
Cu mg/kg	90.51	2.22	1.98
Co mg/kg	3.60	21.80	22.03
Zn mg/kg	751.3	57.3	49.2
Se mg/kg	nd	nd	nd
Mo mg/kg	6.33	0.398	0.420
Mn mg/kg	166.2	7.93	7.01
B mg/kg	225.1	0.196	0.203
Ni mg/kg	35.06	0.112	0.109
Cd mg/kg	0.45	0.020	0.019
Pb mg/kg	11.27	3.78	3.52
Cr mg/kg	39.21	0.181	0.173

1) EC. electrical conductivity

Preparation of samples for analysis

Soil samples were collected according to the method described by Jackson (1958) and air dried, then passed through a 2 mm sieve and stored in plastic containers with lids during analysis. Texture was determined according to hydrometer method (Bouyoucous, 1951), soil reaction according to the 1:2 soil-water mixture method (Gavlak et al., 1994),

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organic matter according to modified Walkey Black method (Walkey, 1947), nitrogen according to Kjeldahl method (Kacar, 1994). Total macro and microelements and metals in soil, sewage sludge and plants were extracted using nitric-hydrochloric digestion (Khan and Frankland, 1983) and then identified using ICP-OES (ICAP6300 DUO) (Daş and Kara, 2016).

Data analysis

Data were analyzed using analysis of variance (ANOVA) at a significance level of $P < 0.05$ in SPSS v. 20 (SPPS, Inc., Chicago, II, USA). Differences among means were identified using the Duncan multiple range test.

Results and discussion

Soil macronutrients

N, P, K, Ca and Mg concentrations in the topsoil (0 - 15 cm) increased with treated sewage sludge doses (*Table 3*).

While the effects of DAP+SS_1 (0.080 %) and DAP+SS_2 (0.080%) application on topsoil nitrogen were insignificant relative to the control (0.074 %), whereas the effect of DAP+SS_3 (0.096%) application was significant relative to DAP+SS_1, DAP+SS_2, and the control. P and K concentrations were significantly lower in the control than the sewage sludge treated plots (*Table 3*) in the subsoil. The effect of sewage sludge application on N, K, Ca and Mg concentrations in the subsoil was insignificant (15-30 cm). The increases may not be statistically significant, however improved soil fertility regardless. Previous research has shown that the application of sewage sludge increases the amount of total N, P, and Mg in soil in later years (Kepka et al., 2016; Pegoraro et al., 2020). Long-term treatment sewage sludge application increases the bioavailability of soil N, P, K, Ca and Mg (Arvas, 2005; Serrao et al., 2010; Çakır et al., 2018). Nutrients were released and increased in the soil solution depending on the duration of mineralization (Lehman et al., 2003; Da Silva et al., 2021). It is estimated that the total precipitation in 2017 is lower than the total precipitation in 2016 and the precipitation long-term (*Table 1*), causing the N, P, K, Ca and Mg concentrations between both soil depths to be insignificant. The high clay of the experimental soil can be considered as another factor that prevents the elements leaching into the subsoil.

Soil micronutrients and metals content

Micronutrients are essential in terms of plant, animal and human health, and must be present in the soil in trace amounts and taken up the minimum levels. In general, sewage sludge did not increase the concentration of micronutrients in the topsoil except Co and Ni. While the Co concentration increased only at the SS_3 (24.51 ppm) level compared to the control (22.1 ppm), the increases with other application levels were insignificant. The gradual increase in Ni concentration was significant only at the SS_3 (204.7 ppm) treatment compared to SS_1 (189.9 ppm) and control (187.1 ppm) (*Table 3*).

In the subsoil (15-30 cm), Ni concentration increased significantly with the addition of treated sewage sludge. The lowest Ni concentration was found in control (186.34 ppm), and the highest Ni concentration was found after SS_3 (208.59 ppm) application. The concentration of Ni in the subsoil was dose-dependent, and similar to that of topsoil (*Table 3*).

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Table 3. *Effect of treatment sewage sludge and diammonium phosphate application on topsoil and subsoil macro and micro nutrient content (N%, others nutrients and metals are ppm)*

Topsoil (0-15 cm)														
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Cu**	**Co**	**Zn**	**Se**	**Mo**	**Mn**	**B**	**Ni**
DAP	0.074[b]	498.1[b]	343.8[b]	3881	708.7	8617	27.81	22.21[b]	101.3	2.037	0.563	775.8	106.7	187.1[b]
DAP+SS_1	0.080[b]	570.2[ab]	443.5[ab]	3924	739.5	7728	28.76	22.46[ab]	116.0	2.070	0.370	800.5	93.31	189.9[b]
DAP+SS_2	0.080[b]	574.3[ab]	442.2[ab]	4060	739.8	8944	29.78	22.95[ab]	108.6	2.017	0.610	800.9	114.8	193.7[ab]
DAP+SS_3	0.096[a]	631.9[a]	470.0[a]	4005	786.2	7915	32.49	24.51[a]	129.8	2.193	0.426	852.2	121.9	204.7[a]
Mean	0.082	568.6	424.9	3969	743.5	8301	29.71	23.03	113.9	2.080	0.493	807.4	121.9	193.9
Std. Dev.	0.010	58.73	72.63	131.37	132.4	866.9	3.15	2.75	21.90	0.25	0.465	102.6	45.21	23.15
Subsoil (15-30 cm)														
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Cu**	**Co**	**Zn**	**Se**	**Mo**	**Mn**	**B**	**Ni**
DAP	0.067	511.9	391.5	3940	702.0	8152	28.40	22.10	95.82	1.94	0.490	797.1	144.2	186.3[c]
DAP+SS_1	0.074	600.7	399.3	3924	731.2	8128	30.18	23.13	107.8	2.00	0.363	818.7	102.4	194.2[bc]
DAP+SS_2	0.074	522.1	397.0	4085	797.9	8097	29.89	23.81	111.0	2.13	0.603	838.4	103.6	200.5[ab]
DAP+SS_3	0.079	545.5	410.9	3975	836.7	8427	31.83	24.74	105.9	2.13	0.353	865.5	82.26	208.6[a]
Gen. Mean	0.074	545.0	399.7	3981	767.0	8201	30.08	23.44	105.1	2.05	0.453	829.9	108.1	197.4
Std. Dev.	0.009	86.97	48.66	113.3	136.4	723.7	2.80	3.10	15.63	0.31	0.480	108.8	34.89	25.15

[*]Values are means of triplicate determinations except General Means and Std.Dev. (n = 12). Cd, Pb and Cr are given in Table 4. [**] Means with different letters in the same column are significantly different, columns without letters are insignificant (P <0,05), according to Duncan multiple comparison test

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The reduction Cd and Pb concentration caused by the treatment sludge application in the subsoil was insignificant (*Table 4*). The treated sewage sludge application effected only the subsoil Cr concentration significantly. The subsoil Cr content increased significantly relative to control (182.97 ppm) only with the application of SS_1 (220.28 ppm) (*Table 4*). The concentration trace elements at 20-40 cm soil depth increased due to sewage sludge application, but these increased were remained below the allowable limits (Cherfouh et al., 2018). Likewise, heavy metal concentrations observed in this study were below the allowable limits (Anonymous, 2010, 2014).

Table 4. *Effect of treatment sewage sludge and diammonium phosphate application on topsoil and subsoil (0-15 cm and 15-30 cm) heavy metal content and some physical and chemical properties of soil (Metals unit is mg/kg, EC unit dS.m^{-1} and OM unit % C)*

Treatment	Topsoil (0-15 cm)						Subsoil (15-30 cm)					
	Cd	**Pb**	**Cr**	**pH**	**EC**	**OM**	**Cd**	**Pb**	**Cr**	**pH**	**EC**	**OM**
DAP	0.62	12.48	185.0	8.09^{a}	249.7	0.83	1.13	14.91	183.0^{b}	8.67^{a}	226.3	0.88
DAP+SS_1	0.70	13.99	184.8	7.85^{ab}	207.3	0.84	0.72	14.12	220.8^{a}	7.96^{b}	228.7	0.84
DAP+SS_2	0.68	13.61	193.4	7.91^{ab}	195.0	1.07	0.83	16.02	199.7^{ab}	7.93^{b}	229.0	0.98
DAP+SS_3	0.73	14.66	199.9	7.74^{b}	223.7	1.17	0.70	13.62	204.9^{ab}	7.87^{b}	252.7	0.90
Mean	0.68	13.69	190.8	7.90	218.9	0.98	0.85	14.67	202.6	8.11	234.2	0.90
Std. Devi.	0.15	2.61	17.94	0.18	42.56	0.23	0.41	4.32	25.23	0.59	31.07	0.12

*Values are means of triplicate determinations except General Means and Std. Dev. (n = 12). ** Means with different letters in the same column are significantly different, columns without letters are insignificant (P <0,05), according to Duncan multiple comparison test

Soil pH, EC, and organic matter content

Treated sewage sludge applications reduced soil pH in both soil depths significantly. The topsoil pH was highest in control (8.09), whereas it was the lowest in SS_3 (7.74) application. The similar result was determined in the subsoil. However, SS application increased the pH more remarkable in the subsoil. The sewage sludge increased of H ions 0.35 unit in the topsoil, but 0.80 unit in the subsoil according to control (*Table 4*). Increasing or decreasing the ambient pH by one unit corresponds to the 10-fold change of H^+ ions concentration (Quora, 2022). A decrease in the pH of alkaline soils increases the cation exchange capacity of flora, especially contains legumes in its mixture (Uzoh et al., 2019). Thus, the availability of the cation micronutrients increases (Jones, 2012). Salinity is one of the most important abiotic limiting plant cultivation. Treated domestic sewage sludge application decreased topsoil EC, insignificantly. It is estimated that the decreased EC in the topsoil is due to the high organic matter content of the sewage sludge (24.3%), which increases the humidity and limits evaporation.

Domestic sewage sludge increased its organic matter in a one-year period in both soil depths, more in the topsoil, although insignificantly (*Table 4*). Soil organic matter increases with the application of sewage sludge containing high organic matter in the previous study (Triberti et al., 2016; Cherfouh et al., 2018; Pegoraro et al., 2020). As same researchers indicated that low temperature and precipitation has slow down the mineralization, because in cold and semi-arid climates, more time is required for organic matter decomposition (Fantappie et al., 2011). The cold climate in the region where this research was conducted may have caused mineralization to slow down, so there was no

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significant increase in organic matter. In the previous study of the author of this article, it was stated that after two years, sewage sludge significantly increased the organic matter content of the soil at 0-20 and 20-40 cm depths (Arvas et al., 2011).

Herbage macronutrient content

The P and K concentrations of artificial pasture herbage increased significantly with the addition of secondary treated domestic sewage sludge (*Table 5*). While the effect of sewage sludge on plant Ca content was not significant compared to control (60.30 ppm), the differences between their doses were significant. As a matter of fact, the increase in SS2 (64.95 ppm) and SS3 (67.71 ppm) applications compared to SS1 (39.07%) was significant. While the increases and decreases compared to the control were insignificant, only SS3 (24.40 ppm) significantly increased the mg content of the herb compared to SS1 (12.50 ppm). The addition of SS_2 (203.7 ppm and SS_3 (217.3 ppm) increased P concentration significantly relative to the control (123.1ppm). In general, the increase in the P content of the herbage was sever dose-dependent of sewage sludge than that of N. The mineralization process, which depends on environmental factors (temperature, solar radiation, precipitation amount and soil conditions) (Wei et al., 2022), directly affects organic fertilizer effectiveness and the chemical composition of plants (Ahmed et al., 2010; Xiao et al., 2012). The climate characteristics of the region where this study was carried out may cause mineralization to slow down and may contribute to the available of nutrients in subsequent years. In addition, since the experimental material consisted of leaves and stems, the N ratio of the herbage was higher (*Table 5*). Since P is stored in grains at high concentrations (Kepka et al., 2016), the P concentration in herbage was low.

Herbage micronutrients and heavy metal content

The decrease in Fe, Cu, Co, Zn, Se, Mo, Mn and B, Ni, Pb and Cr concentrations of the forage relative to the control was insignificant, except for Fe, B and Pb. The micronutrient content of the herbage at all treatment levels of the sewage sludge was lower than the control, although insignificant in many elements. Sewage sludge addition increased Cd content of the herbage only at the highest application of SS_3 (90 tonne ha^{-1}) significantly. The herbage Pb content decreased significantly relative to the control (0.923 ppm), but there were no differences between sewage sludge treatments. The irregular increases and decreases in the Cr content of the grass with the addition of sewage sludge were insignificant (*Table 5*). The use of diammonium phosphate (DAP) fertilizer together with the sewage sludge significantly increase the herbage Cd content. The use of high amounts of DAP, triple superphosphate (TSP) and other P fertilizers can increase plant production, but may also result in greater accumulation of Cd, which has higher solubility and mobility than other metals, in soil and plants (Hooda and Alloway, 1993; Asri et al., 2007; Nino-Savala et al., 2019). The results obtained from this study are similar to the findings that phosphorus fertilizers cause Cd accumulation in the plant (Singh et al., 2017; Suciu et al., 2022). In addition to slowing down the mineralization process in semi-arid and cold climatic conditions (Ahmed et al., 2010; Vourlitis et al., 2022), it is estimated that sewage sludge with high organic matter content adsorbs micronutrients and heavy metals and limits their uptake (Hamon et al., 1999; Liu et al., 2018; Zalewska et al., 2020). The alkalinity of the soil of the experimental area is another factor that reduces the micronutrient availability (Seven et al., 2018).

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Table 5. *Effect of treatment sewage sludge and diammonium phosphate (DAP) application on the macro and micronutrient metals content of herbage (N%, others nutrients and metals are ppm)*

Treatment	N	P	K	Ca	Mg	Fe	Cu	Co	Zn	Se	Mo	Mn	B	Ni	Cd	Pb	Cr
DAP	1.707	123.1^{b}	131.5^{c}	60.30^{ab}	18.92^{ab}	277.9^{a}	10.22	0.847	39.65	0.527	1.490	83.41	93.13^{a}	14.99	0.077^{b}	0.923^{a}	19.71
DAP+SS$_1$	1.520	173.4^{ab}	135.2^{c}	39.07^{b}	12.50^{b}	123.5^{ab}	5.457	0.387	34.20	0.463	0.863	54.94	60.57^{ab}	12.62	0.103^{b}	0.627^{b}	21.19
DAP+SS$_2$	1.593	203.7^{a}	181.0^{b}	64.95^{a}	18.03^{ab}	130.5^{ab}	7.103	0.580	38.67	0.530	1.140	62.55	65.01^{ab}	8.90	0.103^{b}	0.750^{ab}	11.91
DAP+SS$_3$	1.853	217.3^{a}	240.9^{a}	67.71^{a}	22.40^{a}	112.6^{ab}	7.670	0.660	37.90	0.517	0.826	64.87	48.15^{b}	12.07	0.147^{a}	0.623^{b}	15.80
Mean	1.668	179.4	172.1	58.10	17.96	161.1	7.612	0.618	37.60	0.509	1.080	66.43	66.72	12.14	0.110	0.731	17.15
Std. Devi.	0.235	46. 12	47.38	18.97	5.050	91.48	4.941	0.425	6.254	0.073	0.445	24.11	24.26	4.253	0.035	0.216	6.831

[**]Values are means of triplicate determinations except General Means and Std.Dev. (n = 12). [**] Means with different letters in the same column are significantly different, columns without letters are insignificant (P <0,05), according to Duncan multiple comparison test

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Conclusions

One of the main reasons limiting the use of wastewater treatment sludge in agriculture is the concern that the heavy metals it contains may enter the food chain. The use of secondary treated domestic sewage sludge by adding to the DAP fertilizer improved the physico-chemical properties of the soil. Its impact was more favorable than that of DAP fertilizer alone. Moreover, it was observed that even the highest 90 tonne ha^{-1} dose of secondary treated domestic sewage sludge did not exceed threshold values specified in EPA and Regulation on the Use of Domestic and Urban Sewage Sludge in the Soil of Turkey. Treatment sewage sludge was found to carry less risk than the DAP fertilizer by limiting the uptake of heavy metals to the herbage and their availability in the soil. The clayey soil of the trial area is thought to be one of the factors causing this situation. Since there is no significant difference between 60 and 90 tonne ha^{-1} levels of treatment sewage sludge in terms of the concentration of macro and micronutrients in the herbage and availability in the soil, the 60 tonne ha^{-1} application is can be recommended in semi-arid conditions. Generally, the addition of secondary treated sewage sludge decreased the uptake of heavy metals originated in DAP fertilizer, except for Cd. However, further research is required to understand how domestic secondary treated sewage sludge can positively affect parameters related to increasing profitably and sustainability of various crop productions by reducing the availability of metals originated from chemical fertilizer under different climatic and soil conditions.

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