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THE EFFECT OF THE SHORT-TERM APPLICATION OF MUNICIPAL SEWAGE SLUDGE ON SOME OF THE MACRONUTRIENTS, HEAVY METALS AND THE PHYSIOCHEMICAL CHARACTERISTICS OF SOIL UNDER LETTUCE CULTIVATION

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ABSTRACT

Sewage sludge (SS) is a rich source of organic matters and nutrients and can use as a fertilizer in farms. The purpose of this research is to study the effect of short-term of municipal sewage sludge on some of the physical and chemical characteristics of a soil. This research conducted in greenhouse conditions in Iran with a randomized complete block design with five treatments including control, 25, 50, 75 and 100 t/ha across four replication. According to the results, adding sewage sludge to soil increased the concentration of macronutrients, heavy metals, organic carbon content, electrical conductivity, porosity and mean weight diameter and decreased pH, bulk density, particle density, significantly. The highest amount of N, P, and K (0.1%, 213.5 and 10.85 mg/kg, respectively) and Pb and Cd (5.17 and 2.42 mg/kg, respectively) and some of the physicochemical characteristics of soil reported in the treatment of 100 t/ha.

Keywords: Sewage sludge, Macronutrients, Heavy metals, Physicochemical characteristics

INTRODUCTION

Sewage sludge (SS) is mainly produced during the treatment of wastewaters and is a type of organic waste which not only improves the physiochemical properties of soil, but it also causes elevation of the concentration of macro and micro essential nutrients for the growth of plants (*Eid, E.M. et al*. 2017 and *Wollmann, I.* 2017). Nitrogen, phosphorus, and potassium are among macro and necessary elements for the nutrition and growth of plants (*Marschner, H.* 2011). Using sewage sludge in the land may have many beneficial effects on fertility of soil, it can enrich the soil with its nitrogen, phosphorus, and micronutrient contents and modifies physicochemical, microbiological and enzymatic properties of soil, so it improves crop production (*Kumar, V, and Chopra, A.K.* 2014, *Bourioug, M.* 2015). Therefore, one of the useful effects of consumption of sewage sludge is the enrichment of soil and crops regarding nutritional elements and improvement of the quality of soil fertility.

Bai, Y. et al. (2017) have been demonstrated the positive influence of sewage sludge application on the soil properties. They have shown that one- time sewage sludge can improve initial fertility in infertile mudflat soil via increasing soil organic carbon level, bulk density, and greater nutrient content.

Although the application of urban and industrial sewages as fertilizer in agricultural is of interest regarding both economic and environmental aspects, usage of this compound brings about potential risks to crop plants, human health, and ecological system that should be evaluated before its fertilizer and economic value (*Uayanga, W.C. et al.* 2018, *Xiong, Q. et al. 2018*). The major point that should be noted when applying sewage sludge in agriculture is the relatively high concentration of some heavy metals including lead, cadmium, and nickel in these wastes as well as investigation of their microbial load. Thought SS often contains toxic heavy metals which regard to types of SS, its concentrations are varied (*Xiong, Q. et al.* 2018, *Samara, E. et al.* 2017). Due to toxical effects of heavy metals on the plants, they have negative effects on the growth and yield (*Rizwan, M. et al.* 2016, *Rizwan, M. et al.* 2017). Thus many countries have determined the heavy metal limits in SS for field application (*Uayanga, W.C. et al.* 2018). So, before application of SS in any field, SS should be evaluated for their heavy metal concentration.

Roig, N. et al. (2012) in a field trial on clay loam soil under wheat cultivation reported that in response to 16 years of usage of sewage sludge in 40 and 80 t/ha, the organic matter and soil nitrogen increased with the increase in the sludge values. *Latare, A.M. et al.* (2014) have also found that application of sewage sludge by 40 t/ha resulted in a significant increase in the available phosphorus for soil under wheat cultivation. Rahimi Alashty, S. et al. (2011) in a research to investigate the role of sewage sludge on some chemical properties of soil and the concentration of lead and cadmium elements in the soil and lettuce as well as radish, reported that with the consumption of sewage sludge, the amount of lead and cadmium increased in soil. Kumar, V. and Chopra, A.K. (2016) cultivated eggplant in two cultivation seasons and indicated that sewage sludge significantly ($p \leq 0.01$, $p \leq 0.05$) increased sodium, potassium, calcium, magnesium, and nitrogen in the soil.

In addition to affecting the concentration of nutrients and the heavy metals present in the soil, sewage sludge also influences the physiochemical properties of soil (Kumar, V. and Chopra, A.K. 2016. Among the most important reasons for application of organic fertilizers including sewage are improving the formation and stabilization of aggregates and providing favorable conditions regarding moisture and aeration for the activity of organisms and plant growth. Indeed, sewage sludge can improve soil porosity, increased water holding and decreased density in compacted soils. Many of the chemical properties of soil and in turn the growth of the plant as well as the activity of the soil's microorganisms along with the availability of nutrients required by the plant are dependent on the soil pH (Bohn, H. L. 2001). Application of sewage sludge may result in altering in soil pH. The extent of pH variation is dependent on soil properties including its texture and buffer capacity. The results of the research by *Saadat, K. et al.* (2012) showed that sewage sludge led to a significant reduction (at $P \leq 0.01$) in the pH of the soil of pots when compared with the control treatment.

Song, U. and Lee, E.J. (2010) by evaluating the economic and environmental aspects of consumption of sewage sludge on soil and plants reported that sewage sludge causes improved soil properties such as moisture, organic compound, porosity, and bulk density. *Angin, I. and Yaganoglu, V.* (2011) by applying 0, 40, 80, and 120 t/ha of sewage sludge in sandy loam soil with 69.4% sand particle which was under barley cultivation, reported that the bulk and particle density decreased across all of the treatments, whereas the total porosity increased. The results of the research by *Saadat, K. et al.* (2012) showed that sewage sludge led to a significant reduction (at $P \leq 0.01$) in the pH of the soil of pots when compared with the control treatment.

OBJECTIVES

With the passage of several years of the start of Khoramabad wastewater treatment plant in Lorestan province, massive quantities of sewage sludge have produced. Unlike the freeness of the sewage sludge produced by this treatment plant, the farmers of the region do not show any willingness to use it, and the obtained sewage sludge has accumulated in the yard of the treatment plant. Therefore, this research implanted with the aim of investigating the effect of municipal sewage sludge on the concentration of macro-nutrients, heavy metals and some physiochemical characteristics of soil under lettuce cultivation.

EXPERIMENTAL

This study implemented in 2015-2016 in the research greenhouse of agriculture faculty of Lorestan University (Iran). The soil under experiment prepared from a farm close to the faculty's research greenhouse from the depth of 0-30 cm. For homogeneity, this soil was passed through a 4 mm sieve and then dried when exposed to air. The experiment was laid out in a randomized complete block design with five municipal sewage sludge treatments in dry matter including zero (S_0), 25 (S_{25}), 50 (S_{50}), 75 (S_{75}), and 100 (S_{100}) t/ha across four replications. Before analysis, surface (0-30 cm) complex soil samples were collected for the initial physical and chemical soil analysis and were mixed to form a representative surface sample for analyses. Soil samples were air-dried and passed through a 2 mm sieve. Some of the principal properties of the soil including soil texture, organic carbon content, electrical conductivity, soil pH, available phosphorus, total nitrogen content, soluble calcium and magnesium, available potassium and soluble sodium were measured using hydrometry method (*Day, P.R.* 1965), Walkley and black acid digestion method, in suspension of 1:5 (soil to water) by electric conductivity meter (*Jackson, M.L.* 1973), pH meter (*Jackson, M.L.* 1973), Olsen method (*Olsen, S.R. and Sommers, L.E.* 1982), Kjeldahl method (*Jackson, M.L.* 1973), titration method (*Lanyon, L.E., Heald, W.R.* 1982), flame photometry according to (*Jackson, M.L.* 1973), respectively. The available concentration of heavy metals measured by DTPA extractor and then read by atomic absorption device plus GBC 932 model (*Lindsay, W.L. Norvell,* *W.A.* 1978). The bulk density, particle density, and porosity were obtained using cylinder method (*Blake, G.R. and Harge, K.H.* 1986a), pycnometer method (*Blake, G.R. Hartge, K.H.* 1986b) and through calculation and considering the values of particle and bulk density (*Danielson, R.E. and Sutherland, P.L.* 1986), respectively. The stability of the aggregates was evaluated using the wet sieve method, and of the mean weight diameter of aggregates (MWD) measured (*Kemper, D. and Roseau, C.* 1986). *Table 1* summarizes some of the physiochemical characteristics of the soil and sewage sludge.

The utilized sludge (of digested by anaerobic method type) prepared from the municipal wastewater treatment plant of Khoramabad city of Lorestan, and following air drying, it passed through a 4-mm sieve. Some of its preliminary properties including pH and electrical conductivity in 1:5 (sludge to water), organic carbon, total nitrogen, concentration of macro-nutrients (available phosphorus and potassium) and available concentration of some heavy metals of the sludge (available iron, copper, cadmium, and lead) measured by the methods mentioned for the soil samples. Some of the physiochemical characteristics of the experimented soil and the utilized sewage sludge have provided in *Table 1*.

Table 1: Some of physicochemical characteristics in studied soil and sewage sludge

characteristics	**sewage sludge**	**soil**	**unit**
Texture	-	Clay loam	-
pH	6.93	7.48	-
EC	12.14	0.70	dS/m
Organic Carbon	15.60	0.428	%
Bulk density	0.44	1.3	g/cm^3
Total nitrogen	1.028	0.041	%
Available K	493	158	mg/kg
Available P	295.4	8.7	mg/kg
Mg	0.89	1.91	meq/lit
Ca	2.69	5.23	meq/lit
Na	8.97	0.92	meq/lit
DTPA-Fe	301.89	3.67	mg/kg
DTPA-Zn	69.34	0.59	mg/kg
DTPA-Cu	21.36	0.88	mg/kg
DTPA-Pb	10.38	0.71	mg/kg
DTPA-Cd	1.63	0.39	mg/kg

Plastic pots (capacity 5 kg) were used the approximate dimensions of 14 cm in diameter and 20 cm in height, which filled with soil and sludge according to the bulk density of the farm. In each pot, Lettuce *(Lactuca sativa)* was cultivated in three numbers and following 20 days of the cultivation; the shrubs thinned to one so that the plant would have enough space for growth. During growth period (50 days), we did not use mineral fertilizer and irrigation performed according. During the experiment, the soil moisture content was kept at the initial level every three days and the amount of transpiration was determined by measuring the decrease in weight of the pots (planted and unplanted) and by adding the necessary amount of water to each pot.

The statistical analysis of the data was performed using the SAS 9.1 software. Analysis of variance (ANOVA) was carried out using the randomized complete block design. The treatments means were compared using Duncan's multiple range test (DMRT) at 5% level of probability.

RESULTS AND DISCUSSION

The effect of sewage sludge on some of the macronutrients and the heavy metals of soil

The results of the analysis of variance indicated that the treatments of sewage sludge had a significant effect on the concentration of the macronutrients. *Tables 2* and three present the results of analysis of variance and comparison of the means of the sludge on soil macronutrients and the heavy metals, respectively.

Table 2: Analysis of variance (F-statistics) of sewage sludge effect on soil macro-nutrients and heavy metals

Changing sources	**df**	**Pb**	**Cd**	**P**	**K**	**N**
treatment	4	33.31^{*}	57.82^{*}	30.02^{*}	63.76^{*}	69.82^{*}
repetitions	3	1.30^{ns}	0.42^{ns}	0.37^{ns}	3.29^{ns}	0.49^{ns}
Experimental error	12	-	-	-	-	-
Coefficient of variation	-	25.49	20.50	7.36	3.33	6.56

ns and * are insignificant and significant at $P \leq 0.05$, respectively.

Total nitrogen, phosphorus and available potassium of the soil

Nitrogen: The table of analysis of variance (*Table 2*) indicated that the application of sewage sludge resulted in a significant increase (at $P \leq 0.05$) in the total nitrogen content of the soil. Comparison of the means in table 3 suggests that with the addition of the sewage sludge, the total nitrogen content increased significantly in all of the treatments receiving sewage sludge than the control treatment, such that the total nitrogen raised from 0.05% in control treatment to 0.10% in the treatment of 100 t/ha (a two-fold increase). The maximum value of nitrogen obtained in the treatment of 100 t/ha, but no significant difference observed between the 25 t/ha treatment and the control treatment (*Table 3*).

Table 3: Effect of different sewage sludge treatments on Pb, Cd, P, K, N.

Treatment		**Pb**	**Cd**	**P**	**K**	**N**
S_0		0.92[c]	0.36[c]	6.42[d]	152.75[e]	0.05[d]
S_{25}		1.04[c]	0.44[c]	7.62[c]	165[d]	0.05[d]
S_{50}		1.75[c]	0.89[b]	8.85[b]	183.25[c]	0.06[c]
S_{75}		3.77[b]	1.22[b]	9.90[a]	197[b]	0.08[b]
S_{100}		5.17[a]	2.42[a]	10.85[a]	213.5[a]	0.1[a]

Values followed by different superscript letters in the same column are significantly different at P≤0.05 level.
S_1: control, S_2: 25, S_3: 50, S_4: 75 and S_5: 100 t/ha sewage sludge

The reason for the increase in the total nitrogen content can be the high nitrogen content in the sewage sludge (1.028%). Several authors have emphasized that sewage sludge increases nitrogen in organic fraction of soil (*Mazen, A. et al. 2010, Bourioug, M. et al.* 2014). Organic nitrogen changes to mineral nitrogen gradually which is usable by plants (*Warman, P.R. and Termee, W.C.* 2005). The increase of the soil organic matter in response to the application of sewage sludge is another factor in enhancing the total nitrogen content of the soil. The reason is that an organic compound is essentially from residues of living organisms, and since nitrogen is a component of the living organisms body, therefore organic matter is the main source of soil nitrogen (*Malakouti, M.J. and Homaee, V.M.* 2004). *Boostani, H.R. and Ronaghi, A.* (2012) in their greenhouse experiment, reported a significant increase in the soil total nitrogen content in three textures of soil including (sand, sandy loam, and clay loam) under the influence of application of sewage sludge in a lime soil after harvesting corn by adding different levels of sewage sludge. In this regard, that study was in line with this research.

Phosphorus: Comparison of the means suggests that with the addition of sewage sludge to the soil across all of the treatments, the available soil phosphorus significantly has increased when compared with the control treatment. According to the results, a significant P enrichment of soil improved with sewage sludge. In this study the soil of both 75 and 100 t/ha treatments have 1.54 and 1.69 times more available phosphorous, respectively, than control treatment. The maximum and minimum phosphorus concentration observed at 100 t/ha treatment and control treatment (10.85 and 6.42 mg/kg), respectively. The phosphorus concentration did not show any significant difference between the 75 and 100 t/ha of sludge (*Table 3*). The probable reason for this increase can attribute to the high phosphorus level, organic carbon and the organic acids present in the sewage sludge (*Table 1*). The degree of solubility of phosphate can increase between 10 to 1000 units with the presence of organic acids such as maleate, citrate, and oxalate given the type of the soil and the concentration of organic acid (*Malakouti, M.J. et al.* 2004). On the other hand, organic acids resulting from sewage sludge are adsorbed as ligand exchange and compete with phosphorus for the sites at which absorption takes place, eventually resulting in the increased usability of phosphate. The research of *Latare, A.M. et al.* (2014) as with this study, indicated that application of sewage sludge resulted in a significant increase in the available phosphorus by soil. The results agree with those reported by *Belhaj, D. et al.* (2016) and *Bourioug, M. et al.* (2018) after using sewage sludge at doses ranging from 25 to 125 t/ha.

Available potassium: According to the results of analysis of variance (*Table 2*), it is evident that the application of sewage sludge resulted in a significant increase in the available potassium level of the soil. Comparison of the means also showed that the addition of sewage sludge significantly increased the available potassium level in comparison with the control sample across all of the treatments. In this regard, the potassium level increased from 152.75 mg/kg in the control treatment to 213.50 mg/kg in the 100 t/ha treatment (*Table 3*). Increasing soil K level in response to usage of sewage sludge was in less than that observed for phosphorus and nitrogen, which can attribute to the low potassium level in comparison with phosphorus and nitrogen present in the sludge. The main reason for this phenomenon is probably the high solubility of potassium that causes to remain as soluble in the effluent following separation of sludge off the wastewater, and thus the sludge part becomes deprived of potassium (*Barahimi, N.* 2009). Our findings revealed that sewage sludge enhances the available potassium in the amended soil which is in agreement with *Saruhan, V. et al.* (2010) and *Bourioug, M. et al.* (2018).

Increased nutrient available in the soil is related to two reasons. Firstly, the high concentration of such elements in the sludge sewage used which were provided in the available forms or released from organic matter via mineralization *(Bourioug, M. et al.*

2014). Secondly, it happens due to remobilization of some elements initially existent in soil by lowering the pH (*Cornwell, D.A. and Koppers, H.M.M. 1990*).

DTPA-lead and DTPA-cadmium

Lead: Comparison of means in *Table 3* indicates that the value of lead has had a significant increase with the addition of sewage sludge to the soil (except for 25 and 50 t/ha treatment) when compared with the control treatment. The maximum concentration of lead (5.17 mg/kg) has related to 100 t/ha sludge, while the minimum has associated with the control sample (0.92 mg/kg). *Kabata-Pendias, A.* (2001) has reported that lead can form strong and stable complexes with organic matters and the reason of the presence of lead in the surface layers of soil is considered to be an accumulation of organic compounds at the soil surface. The results of the present research are in line with this study. *Dai, L. et al.* (2014) reported that addition of sewage sludge resulted in a significant increase (at $P \leq 0.05$) in the lead concentration in soil.

Cadmium: According to the results of analysis of variance (*Table 2*), it is evident that the application of sewage sludge led to a significant increase in the available cadmium content present in the soil. Comparison of the means (*Table 3*) also indicates that the available cadmium content has had a significant increase (at $P \leq 0.05$) with the addition of sewage sludge to the soil (except for 25 t/ha treatment) when compared with the control treatment. Application of 100 t/ha indicated the maximum cadmium content (2.42 mg/kg), while the control treatment showed the minimum cadmium content (0.36 mg/kg) (*Table 3*). Increasing the level of this metal in response to the application of sewage sludge can be associated with increased organic matter content in the soil with the use of high levels of sewage sludge. In response to this growth, metals form bonds with organic compounds as unstable forms and comfortably change into absorbable forms (*Antoniadis. V, and Alloway, B.J.* 2002). Other researchers also believe that organic fertilizers (sewage sludge and urban waste compost) are the most important sources for heavy metals such as cadmium and nickel in soil (*Abdul khaliq, S.J. et al.* 2017).

The significant increase in concentrations of Pb and Cd was observed at all the ratios of sewage sludge as compared to unamended soil which may be because of several factors such as nature and degradability of organic matter, type of soil, and pH (*Moreira, R.S. et al.* 2013). One of the main characteristics to determine the availability of heavy metals is pH (*Zhao K.L. et al.* 2010). Decreasing soil pH leads to the increased availability of many heavy metals (*Eid, E.M. and Shaltout, K.H.* 2016). The results of this study showed congruence with the research by *Belhaj, D. et al.* (2016) reporting that the addition of sewage sludge to soil increases the availability of many heavy metals.

The effect of usage of sewage sludge on some physical characteristics of soil

Tables 4 and 5 present the results of analysis of variance and comparison of the means on some of the physical properties of the soil.

Table 4: Analysis of variance (F-statistics) of sewage sludge effect on some of soil physical characteristics

Changing sources	**df**	**Aggregate stability**	**porosity**	**Particle density**	**Bulk density**
Treatment	4	90.73^{*}	3.30^{*}	45.23^{*}	31.58^{*}
Repetition	3	0.95^{ns}	0.15^{ns}	0.36^{ns}	0.22^{ns}
Experimental error	12	-	-	-	-
Coefficient of variation	-	2.39	2.84	2.26	4.09

ns and * are insignificant and significant at $P \leq 0.05$, respectively.

Table 5: Effect of different sewage sludge treatments on Aggregates stability, Porosity, Particle density, Bulk density

Treatment	Aggregates stability	Porosity	Particle density	Bulk density
S_0	0.44^{c}	0.59^{c}	2.53^{a}	1.03^{a}
S_{25}	0.52^{b}	0.60^{cb}	2.24^{b}	0.90^{b}
S_{50}	0.52^{b}	0.61^{cab}	2.16^{c}	0.83^{c}
S_{75}	0.58^{a}	0.62^{ab}	2.14^{c}	0.81^{c}
S_{100}	0.60^{a}	0.63^{a}	2.11^{c}	0.78^{c}

Values followed by different superscript letters in the same column are significantly different at $P \leq 0.05$ level

S_1: control, S_2: 25, S_3: 50, S_4: 75 and S_5: 100 t/ha sewage sludge

Bulk density, particle density and the total porosity of the soil

The bulk density and particle density of soil: Table 4 indicates that application of sewage sludge resulted in a significant reduction in the bulk and particle density. Comparison of means in *Table 5* also shows that the addition of sewage sludge significantly decreased these two parameters across all of the treatments when compared with the control treatment (at $P \leq 0.05$). The most considerable reduction in the bulk and particle density

(0.78 and 2.11) respectively observed in the 100 t/ha treatment. In this study, the bulk density of the sludge was 0.44 g/cm^3 (*Table 1*). This bulk density is far lower than the initial bulk density of the soil (1.3 g/cm3). Therefore, it expects that the addition of sewage sludge would result in a diminished bulk density of soil. This trend may be ascribed to the addition of the bulk quantity of organic matter of low bulk density leads to better soil aggregation which in turn increased the soil porosity. Other studies *Mondals, S.et al.* (2015), have also recorded that the addition of organic material to soil reduces bulk density.

Sewage sludge will have a low bulk density due to containing high organic carbon content. Accordingly, adding it to soil resulted in diminished particle density by increasing the ratio of organic particles about minerals in the solid phase (*Angin, I. and Yaganoglu, V.* 2011). The growth of biotic secretions of microbes and the plant's root in response to the addition of sewage sludge may be another reason for the reduction in the particle and bulk density of soil. Overall, in this research addition of sewage sludge had a considerable effect on the alleviation of the soil's bulk and particle density. These results are in line with the research by *Ahmad Abadi, Z. and Ghajar Sepanlou, M.* (2012). *Song, U. and Lee, E.J.* (2010), *Angin, I. and Yaganoglu, V.* (2011) who showed that with an application of sewage sludge, the bulk and particle density of soil diminishes.

The total porosity of soil: The results of the analysis of variance (*Table 4*) demonstrated that the application of sewage sludge resulted in increased porosity. Comparison of means in *Table 5* also suggests that addition of sewage sludge has significantly increased the total porosity of soil across all of the treatments when compared with the control treatment. Although this ascending trend has been significant only in the 75 and 100 t/ha (in comparison with the control), porosity has increased from 0.59% in the control treatment to 0.63% in the 100 t/ha of sludge treatment (*Table 5*). The values of consumed sludge have caused increased total porosity due to the further reduction in the bulk density in comparison with the particle density of soil. The results of this research were by the findings of *Angin, I. and Yaganoglu, V.* (2011) who reported that with the addition of sewage sludge, the total porosity of soil has increased.

The mean weight diameter (MWD) of aggregates

Comparison of the means in *Table 5* suggests that with the increase in the level of sewage sludge, the content of stable aggregates in water has grown. The maximum and minimum stability of aggregates observed in the 100 t/ha and control treatment, respectively. The pots that received the highest amount of sewage sludge exhibited about 1.36 times higher value of MWD than control which may be related to increasing in water stable aggregate resulted from better soil aggregation.

Various studies have shown that addition of organic fertilizers to soil results in increased stability of the soil structure. Addition of sewage-sludge increased the organic matter content that modifies the aggregation status and structure of the soil (*Mondals, S. et al.* (2015). On the other hand, the increase in the organic secretions of the plant root as well as the microbial activity of soil in response to the addition of sludge can also be other reasons in aggregation. *Miller, J.J. et al.* (2002) have also reported that growth of fungal networks on the soil in response to an addition of sludge can result in increased stability of aggregates. These results were congruent with the findings of our study.

The effect of the application of sewage sludge on some of the chemical properties of soil

The sewage sludge treatments had significant results on some of the chemical properties of soil (*Tables 6 and 7*).

Table 6: Analysis of variance (F-statistics) of sewage sludge effect on some of soil chemical characteristics

Changing sources	**df**	**EC**	**pH**	**Organic Carbon**
Treatment	4	184.84*	58.07*	71.85*
Repetition	3	0.76ns	0.76ns	0.75ns
Experimental error	12	-	-	-
Coefficient of variation	-	8.46	0.15	7.54

ns and * are insignificant and significant at $P \leq 0.05$, respectively.

Table 7: Effect of different sewage sludge treatments on Electrical conductivity, pH, Organic Carbon

Treatment	Electrical Conductivity	pH	Organic Carbon
S_0	0.88^d	7.58^a	0.57^d
S_{25}	1.05^d	7.56^b	0.59^d
S_{50}	1.99^c	7.52^c	0.70^c
S_{75}	3.09^b	7.50^c	0.88^b
S_{100}	3.69^a	7.47^b	1.18^a

Values followed by different superscript letters in the same column are significantly different at P≤0.05 level

S_1: control, S_2: 25, S_3: 50, S_4: 75 and S_5: 100 t/ha sewage sludge

The soil organic carbon content

The table of analysis of variance (Table 6) indicated that the application of sewage sludge resulted in a significant increase in the soil organic carbon content (at the probability level of 5%). Comparison of means also indicated that with the addition of sewage sludge to the soil, organic carbon content significantly increased across all of the treatments (except for 25 t/ha treatment), when compared with the control treatment (*Table 7*). The sludge used in this research contains 15.60% organic carbon (*Table 1*). Therefore, concerning the considerable level of organic carbon, application of various amounts of it has resulted in a significant increase in the soil organic carbon content, such that the soil organic carbon content increased from 0.57% in the control treatment to 1.18% in 100 t/ha of sludge. These results showed congruence with the reports of *Urbaniak, M. et al.* (2017); who indicated that application of sewage sludge increases the soil organic carbon content.

The soil pH

The effect of the application of sewage sludge on the reduction of soil pH became significant at the probability level of 5% (*Table 6*). Comparison of means (*Table 7*) also reveals that with the addition of sewage sludge to the soil, the soil pH decreased in all of the treatments when compared with the control treatment. This reduction more appeared at a high rate of sewage sludge can be attributed to organic acids produced during the mineralization (*Angin, I. et al.* 2012), the process of biodegradation of the organic fraction [45] and nitrification processes of NH_4 in the sludge (*Cytryn, E. et al.* 2012), thereby is the cause of soil acidification. The minimum and maximum values of pH observed in the

100 t/ha of sludge and control treatments (7.47 and 7.58, respectively). However, no significant difference detected between the 50 and 75 t/ha. As sewage sludge contains large amounts of organic matter, it can have a considerable effect on the biological activity and the reduction of soil pH. *Elloumi, N. et al.* (2016) have also introduced the reason for the decrease in pH as the presence of the organic acids present in organic fertilizer, the degradation of organic matter, and the acids produced from microbial activity. Many researchers have also reported that with the addition of sewage sludge to the soil, the soil pH declines (*Elloumi, N. et al.* 2016).

The soil electrical conductivity

The results of the analysis of variance of electrical conductivity suggest a significant difference (at $P \leq 0.05$) of this characteristic across various levels of the sewage sludge (*Table 6*). Comparison of means (*Table 7*) also showed that with the addition of sewage sludge to the soil, the soil's electrical conductivity has increased across all of the treatments when compared with the control treatment. The 100 t/ha has had the highest impact on increasing the soil salinity. In this treatment, the EC value was 3.69 $dS.m^{-1}$, while in the control sample it was 0.88 $dS.m^{-1}$. With the rising sewage sludge doses, electrical conductivity increased which may be related to the high salt content of sewage sludge. Our results are consistent with *Belhaj, D. et al.* (2016) and *Bourioug, M. et al.* (2018), and *Shirani, H. et al.* (2010). However, Kumar and Chopra [4], found that sewage sludge increases both electrical conductivity and soil pH.

CONCLUSIONS

Based on the findings obtained from this research, it found that sewage sludge has a considerable fertilizer potential. Application of this compound not only increased the soil organic carbon content, but it also elevated the concentration of macronutrients (K, P, and N) in the soil, playing a role in its fertility. Furthermore, usage of sludge led to a significant increase in the total porosity and electrical conductivity along with the concentration of heavy metals and a reduction in pH together with the bulk and particle density of soil. Nevertheless, it should be noted that given the production stages, sewage sludge may bring about the potential risks of biologic and microbial contamination as well as heavy metals or toxic elements, where addition of high amounts of them to soil can cause pollution of the environment and the food cycle of human beings, resulting in critical and irrecoverable damages. Accordingly, considering the positive effects of this compound, it is recommended that environmental studies and investigation of the potential of contamination of these compounds performed separately, and any recommendation regarding the usage of these compounds should give with caution. On the other hand, utilization of sewage sludge can increase the soil electrical conductivity and using it in large amounts may be problematic in the soil. Therefore, to use it in agricultural lands, every year soils should be tested regarding chemical, biological, and physical aspects so that in case of illogical observation of some characteristics, its usage would offer with greater accuracy and management.

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