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Study of Sewage Sludge Use for the Cultivation of Plants and its Effects on Soil Properties in Al Ahsa

دراسة استخدام الحماة المعالجة في الزراعة وتأثيرها على بعض النباتات وخصائص التربة في الأحساء

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ABSTRACT

Wastewater treatment plants produce a large amount of sludge, which negatively affects our environment. The agricultural application of sludge is an environmentally friendly disposal option. The current study investigated the use of sewage sludge in the fertilisation of arid land in Al Ahsa, KSA, to reduce the need for importing fertilisers and increase plant productivity. Sewage sludge was used as an organic fertiliser in the cultivation of cucumber (*Cucumis sativa*) and lettuce (*Lactuca sativa*) through its scalable addition to sandy soil at rates of 0 (control soil), 5, 15 and 45% in a pot experiment under greenhouse conditions. Chemical and microbiological analysis was carried out using a UV spectrophotometer, flame photometer and atomic absorption spectrum. The results indicated that the application of sewage sludge significantly altered soil properties. The total dissolved salts (TDS), soluble anions (Cl, HCO_3, NO_3 and SO_4), soluble cations (Na, K, Ca and Mg), nutrients (TKN, TP) and trace metals (Fe, Mn, Cu, Zn and Cr) increased in the sandy soil with the increasing sludge application rates. For example, the average TDS in the soil increased significantly ($p<0.01$) from 0.667 gm/l for the control to 1.73, 2.33 and 3.04 gm/l in soil mixed with sludge at 5, 15 and 45 %, respectively. The application of sewage sludge improved soil properties and increased organic matter from 1.72% in the control soil to 9.36% in the soil mixed with 45% sludge. In addition, the application of sewage sludge increased the growth yield of lettuce and cucumber plants. In conclusion, the current study revealed that using sewage sludge as organic manure at a low application rate of 5% can improve the soil's physical and chemical properties, provide plants with the required nutrients, and increase growth and yield.

الملخص

تعد الحمأة من مخلفات محطات الصرف الصحي غير المستفاد منها والتي تسبب تلوث البيئة، ولكن استخدمها في المجال الزراعي من الحلول التي تسهم في حماية البيئة. ركزت الدراسة الحالية على الاستفادة من الحمأة بعد معالجتها في مجال تخصيب التربة الصحراوية القاحلة والواسعة في المملكة العربية السعودية، وذلك من أجل تحسين إنتاجية النبات وتقليل الحاجة المتزايدة في استيراد الأسمدة. هدفت هذه الدراسة إلى تقييم هذا المنتج العضوي كيميائياً وحيوياً وذلك بإضافة الحمأة كمخصب إلى التربة بتركيزات متدرجة (0، 5، 15 و45%) ودراسة تأثيرها بطريقة علمية آمنة في زراعة بعض النباتات مثل الخيار والخس على المستوي المختبري. وتم إجراء التحاليل الكيميائية والحيوية لعينات الحمأة المخلوطة مع التربة وعينات النبات باستخدام الأجهزة الحديثة مثل جهاز الأشعة فوق البنفسجية، جهاز طيف اللهب، جهاز امتصاص الطيف الذري للعناصر. أشارت النتائج إلى أن إضافة الحمأة إلى التربة أدى إلى تغيير واضح في خصائص التربة؛ حيث ارتفع تركيز الأملاح الكلية الذائبة، الأنيونات (Cl, HCO3, NO3, SO4)، الكاتيونات (Na, K, Ca, Mg)، المغذيات (TKN, TP) والعناصر الصغرى (Fe, Mn, Cu, Zn, Cr) في التربة الرملية مع زيادة معدلات إضافة الحمأة. فمثلاً، متوسط تركيز الأملاح الكلية في التربة 0.667 جم/لتر، وارتفع إلى 1.73، 2.33 و3.04 جم/لتر في التربة عند خلطها بالحمأة بنسب 5، 15 و45% على التوالي، مع وجود فروقات معنوية إحصائياً. بالإضافة إلى تحسين خواص التربة وزيادة متوسط محتوى المادة العضوية من 1.72% في التربة وحتى 9.36% في التربة المخلوطة بالحمأة بنسبة 45%. كذلك أدى خلط الحمأة بالتربة الرملية إلى زيادة محصول النمو والإنتاجية لكل من نباتي الخس والخيار. وعليه تؤكد نتائج الدراسة أن استخدام الحمأة كسماد عضوي للتربة بمعدل إضافة منخفض 5 % يؤدي إلى تحسين خصائص التربة الفيزيائية والكيميائية، ويزود النبات بالعناصر المغذية المطلوبة، مما ينتج عنه زيادة في النمو والإنتاجية.

1. Introduction

Sewage sludge is a major product of biological wastewater treatment plants, and its disposal is a challenge (Waqas *et al.,* 2014; Leila *et al.,* 2017). Sludge treatment and disposal consume approximately half of the costs of operating sewage treatment plants in Europe (Brix, 2017). Traditional methods of sludge disposal, such as landfill, incineration and ocean disposal, have several disadvantages (Kidd *et al.,* 2007; Leila *et al.,* 2017). Although the landfilling of sludge is an inexpensive method of disposal, international restrictions and the EU Landfill Directive (Council of the European Communities, 1999) make it more difficult (Laturnus *et al.,* 2007). Sludge incineration is less economic because supplementary fuel is needed to burn the sludge into ash (Kelessidis and Stasinakis 2012). Both the landfilling and incineration of sludge negatively affect the environment through groundwater contamination and the production of global warming gases such as CH_4 and CO_2 (Scholz, 2016; Eid *et al.,* 2017). Hence, recent trends in waste management policy favour agricultural applications over traditional disposal methods (Zhao *et al.,* 2012).

The agricultural application of treated sludge can significantly reduce the cost associated with its disposal, protect the environment, reduce costs compared to commercial fertilisers, provide essential plant nutrients and improve soil fertility (Dolgen *et al.,* 2007; Ahmed *et al.,* 2010; Nogueira *et al.,* 2013; Tejada *et al.,* 2016). Sewage sludge is used worldwide as a fertiliser to reclaim degraded soils and replace chemical fertilisers in agriculture (Zhao *et al.,* 2012). Where sludge contains the main nutrients (N, P, K) and organic matter it can be used to improve soil properties, benefit microbial growth and subsequently increase plant production (Abd-Alla *et al.,* 1999; Eid *et al.,* 2017). It is reported that about 50% of the sludge produced in the EU is consumed by agricultural uses (Schowanek *et al.,* 2004). For instance, agricultural use is the prevalent practice for sludge disposal in countries such as France, Spain, Italy and the UK (Mininni *et al.,* 2015).

Arid land has low organic matter content, and hence organic amendments are needed to improve soil fertility and productivity (Hussein, 2009; Eid *et al.,* 2017). Abd-Alla *et al.* (1999) investigated the effect of the application of sewage sludge to arid soil on nitrogen fixation and legume growth. The results revealed that the agricultural application of sewage sludge at low rates (20%) may significantly improve legume growth and soil fertility, whereas sludge application at high rates (50%) may significantly limit microbial activity due to the toxic effect of heavy metals and, consequently, inhibit legume growth (Abd-Alla *et al.,* 1999). A study was conducted to evaluate the utilisation of treated sewage water in the irrigation of sorghum fodder and its effect on some soil properties (Aljunied, 2007). The study revealed that the use of treated sewage water did not result in a

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significant concentration of potentially toxic heavy metals. Sewage sludge could be applied as a foliar fertiliser for improving agricultural maize yields instead of applying it to soil (Tejada *et al.,* 2016). Hussein (2009) reported that the application of sewage sludge to sandy and calcareous soils in Al Ahsa significantly increased soil electrical conductivity (EC), soluble anions and cations, available P, micronutrients and heavy metals and increased the growth yield of cucumber plants.

The excessive agricultural application of sewage sludge may lead to the accumulation of unwanted products in soils, such as trace organic pollutants and heavy metals (Nogueira *et al.,* 2013; Eid *et al.,* 2017; Gattullo *et al.,* 2017). The most commonly found heavy metals in sewage sludge include arsenic, cadmium, chromium, copper, zinc, lead and nickel (Nogueira *et al.,* 2013). Recently, new techniques for pre-treating sewage sludge, such as aerobic digestion, anaerobic bioreactors or chemical conditioning, have been introduced to achieve the efficient decontamination of sewage sludge before its release into the environment (Laturnus *et al.,* 2007; Kelessidis and Stasinakis, 2012). It is reported that the conversion of sewage sludge to biochar would significantly decrease toxic metal and polycyclic aromatic hydrocarbon (PAH) concentrations in soil and plants (Waqas *et al.,* 2014). Moreover, the long-term accumulation of trace metals and organic pollutants in soil should be monitored and evaluated regularly (Laturnus *et al.,* 2007). The aim of this study is to investigate using sewage sludge in the fertilisation of arid land in Al Ahsa, KSA, through the cultivation of cucumber (*Cucumis sativa*) and lettuce (*Lactuca sativa*), by its scalable addition to sandy soil in a pot experiment and to investigate its effects on some soil properties. Cucumber and lettuce were chosen because they are among the most widely cultivated and consumed vegetables in the area.

2. Materials and Methods

2.1. Experimental Design:

Air-dried sewage sludge was collected from three sewage treatment plants (STP) in Al Ahsa, Saudi Arabia, namely the Hofuf STP (**SH**), Umran STP (**UM**) and Oyun STP (**OU**), as shown in Table 1. The collected sludge samples were ground to pass through a 2 mm sieve. The ground sludge was mixed with sandy soil in proportions of 0 (control), 5, 15, and 45% using pot culture, as illustrated in the experimental layout shown in Figure 1. Sandy soil was used as it is the main soil type in Saudi Arabia. The pot experiment was conducted in a completely randomised block design with three replicates for each treatment (0, 5, 15 and 45% of added sludge). Cucumbers and lettuce were cultivated under greenhouse conditions at the Agricultural and Veterinary Training and Research Station at KFU.

Table 1: Sewage Treatment Plant Details, Al Ahsa, Saudi Arabia.

STP Name	Hofuf STP (SH)	Umran STP (UM)	Oyun STP (OU)
Location	Al-Hofuf	Al-Omran	Al-Oyun
Sewage treatment method	Aerobic Activated Sludge		
Production Capacity (m3/day)	110x103	28x103	20x103
Sludge treatment methods	Thickening and Belt Filtration	Thickening and Drying beds	

The pre-testing of the characteristics of the three sludge stations revealed no significant differences between the characteristics of the sludge. Thus, the collected data were statistically analysed using one-way analysis of variance (ANOVA) at a significant level of $P<0.05$ to assess the significant variance between treatments. Moreover, each of the two plants used (lettuce and cucumber) was considered to be a stand-alone experiment. Bivariate correlations (Pearson's) were used to identify any statistically significant relationships ($p<0.05$) between soil characteristic parameters. Statistical tests were conducted using the SPSS software package (version 26.0).

The plants were irrigated daily with groundwater or whenever needed. The resulting physio-chemical characteristics of the irrigation water, analysed using a standard method (APHA 2005), are shown in Table 2. It is obvious that the values of the physio-chemical characteristics of this groundwater are within the normal range adequate for irrigation (Al-Gossaibi *et al.,* 2000).

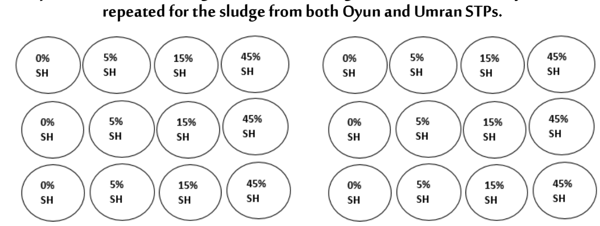
Table 2: Physio-Chemical properties of irrigation water used in the experiment.

Parameter	Concen.	Cations	Concen. (mg/l)	Anions	Concen. (mg/l)
pH	7.86	Na+	156.9	Cl-	221.4
EC (μS/cm)	1350	K+	15.10	HCO3-	163.0
TDS (mg/l)	809	Ca+2	82.21	SO4-2	289.1
Turbidity (NTU)	0.50	Mg+2	42.34	NO3-	0.262
Free Cl2 (mg/l)	0.07	Hardness	379.7	PO4-2	0.087

2.2. Soil Mixture Analysis:

At the end of the experiment, soil samples were taken from each pot and air-dried, ground and passed through a 2 mm sieve for further analysis. The pH and TDS were measured in soil-water extracts (Jackson, 1958). Soluble anions (Cl, HCO_3 and SO_4) and cations (Na, K, Ca and Mg) were also measured in the soil extracts (Carter and Gregorich, 2008). Organic matter was measured in the soil mixture following the wet oxidation method, the total Kjeldahl nitrogen (TKN) was determined using the micro-Kjeldahl method while sodium and potassium were determined by flame photometry (Jackson, 1967). Total phosphorus was measured using the method described by Carter and Gregorich (2008). Samples for trace metals (Fe, Mn, Cu, Zn and Cr) were digested using a nitric acid mixture and measured using an Atomic Absorption Spectrophotometry (Carter and Gregorich, 2008).

Figure 1: Experimental layout of mixed sludge (Hofuf STP) with sandy soil in proportions of 0, 5, 15 and 45% for the cultivation of cucumbers and lettuce *(Table represents the actual weight used for the sludge and soil)*. The same layout was repeated for the sludge from both Oyun and Umran STPs.



% sludge /soil	Hofuf STP (SH) and Lettuce			
	0%	5%	15%	45%
Sludge	0	100	300	900
Soil	2000	1900	1700	1100
Total*3	6000 gm sludge/soil mixtures			

% sludge /soil	Hofuf STP (SH) and Cucumbers			
	0%	5%	15%	45%
Sludge	0	250	750	2250
Soil	5000	4750	4250	2750
Total*3	15000 gm sludge/soil mixtures			

2.3. Plant Material Analysis:

At the end of the experimental period, plant samples were collected and air-dried to determine their fresh and dry weights and prepare them for further chemical analysis. The harvesting weights and dry matter percentage of the lettuce were recorded. Total phosphorus, TKN and protein were measured in the lettuce using well-established methods (Mazen *et al.,* 2010). The number of cucumber fruits was recorded, and their weight, length and circumference were measured. A microbial analysis of coliforms, aerobic mesophilic bacteria, yeasts and moulds in the lettuce and cucumber plants was conducted following the methods described in the American Bacteriological Analytical Manual (USFDA, 2001).

3. Results and Discussion

3.1. Soil/Sludge Mixture Physio-Chemical Properties:

Generally, the results of the current study revealed that the application of sewage sludge altered sandy soil properties. Increasing the sludge application rates significantly increased the values of the soil chemical properties. The observed changes in the soil chemical properties after the addition of the sludge are related to the composition and nature of the added sludge, including the organic matter and soil physio-chemical characteristics (Kidd *et al.,* 2007; Tejada *et al.,* 2016; Eid *et al.,* 2017). Table 3 presents the physio-chemical analysis, including the moisture, pH, TDS, soluble anions and soluble cations of the soil samples composed of the sandy soil/sludge mixture of various percentages. The results include the characteristics of the sandy soil (control), the sludge from the three sewage treatment plants in Al Ahsa and the soil mixed with 5%, 15% and 45% sludge.

The average percentage of moisture in the sandy soil mixed with the sludge ranged from 6.19% for 5% sludge application to 7.10% for 45% sludge application, whereas the percentage of moisture in the sandy soil was 0.178% (Table 3). The sandy soil mixed with the sludge from the Umran STP had higher values of soil moisture.

Table 3: Effects of sewage sludge application on sandy soil properties (Physio-chemical parameters), including an ANOVA F ratio of statistically significant variance.

Sample (Sludge/ Soil mixture, %)	Moisture (%)	pH	TDS (gm/l)	Soluble cations (mg/l)			
				Na+	K+	Ca+2	Mg+2
Sandy soil_0%	0.178	7.37	0.667	85.5	39.6	67.7	64.7
SH-Hofuf_5%	5.82	7.83	1.68	198	78.9	192	118
SH-Hofuf_15%	6.2	7.97	2.98	289	120	323	286
SH-Hofuf_45%	6.97	8.03	3.72	349	145	369	337
SH-Sludge_100%	5.27	7.46	9.04	1467	557	523	584
OU-Oyun_5%	5.93	7.81	1.59	200	66.3	167	104
OU-Oyun_15%	5.61	7.84	1.84	248	93.4	117	147
OU-Oyun_45%	6.47	7.96	2.46	307	102	244	192
OU-Sludge_100%	6.3	8.02	8.25	1394	435	643	467
UM-Umran_5%	6.83	8.29	1.92	203	94	197	112
UM-Umran_15%	6.93	7.67	2.18	245	95.2	231	152
UM-Umran_45%	7.85	7.85	2.95	367	149	254	186
UM-Sludge_100%	5.54	7.34	12.1	2054	665	770	587
ANOVA F Ratio	76.8	4.14	40.0	46.4	46.2	23.1	29.1

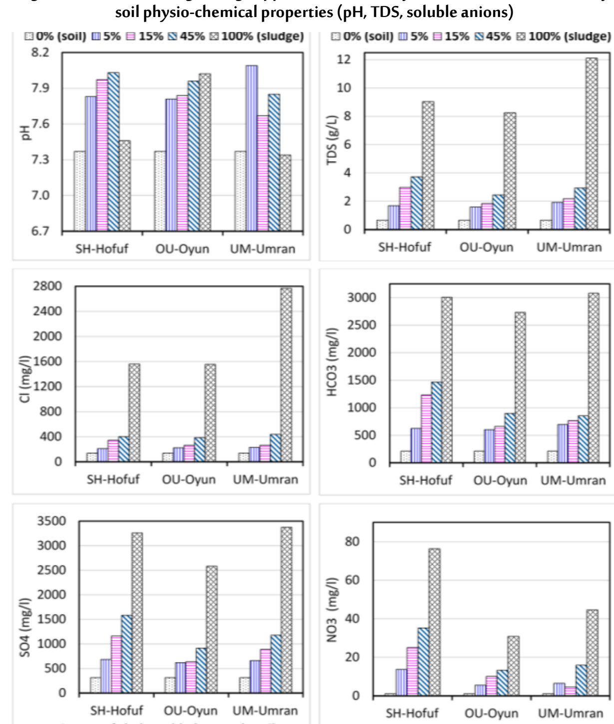
Sample (Sludge/ Soil mixture, %)	Soluble anions (mg/l)				
	Cl-	HCO3-	SO4-2	NO3-	PO4-2
Sandy soil_0%	137	212	314	1.13	0.98
SH-Hofuf_5%	213	624	685	13.7	3.98
SH-Hofuf_15%	345	1232	1162	25.0	6.00
SH-Hofuf_45%	403	1467	1582	35.2	18.2
SH-Sludge_100%	1560	3008	3261	76.3	75.8
OU-Oyun_5%	226	603	619	5.54	7.24
OU-Oyun_15%	266	661	636	10.0	16.0
OU-Oyun_45%	386	898	914	13.4	11.1
OU-Sludge_100%	1553	2734	2583	30.9	42.6
UM-Umran_5%	230	696	662	6.54	17.5
UM-Umran_15%	266	764	889	4.58	35.7
UM-Umran_45%	439	856	1179	15.9	47.3
UM-Sludge_100%	2769	3080	3373	44.6	81.2
ANOVA F Ratio	17.8	67.7	47.9	6.74	8.90

The bold F ratio is significant at p < 0.01 (Critical F-value = 5.99), the italic and underlined F ratio is significant at p < 0.05 (Critical F-value = 4.10)

The average pH value for the sandy soil was 7.37 with relatively higher values of pH in sandy soil mixed with sludge, as shown in Figure 2. The TDS values reflect soil salinity and higher values that can affect plant growth. The TDS value measured in the sandy soil was 0.667 g/l with average higher values of 9.80 g/l in the sludge samples. The highest TDS value (12.1 g/l) was measured in the sludge from the Umran STP. It is obvious from Figure 2 that increasing sludge application rates increases sandy soil salinity. Increased soil salinity as a result of the increasing sludge application rates may be due to the high salt content in the sludge, which has been observed in previous studies (Hussein 2009; Ahmed *et al.,* 2010; Eid *et al.,* 2017). Hence, a lower sludge application rate of 5% is recommended to minimise sandy soil salinity, which is adequate for plant growth.

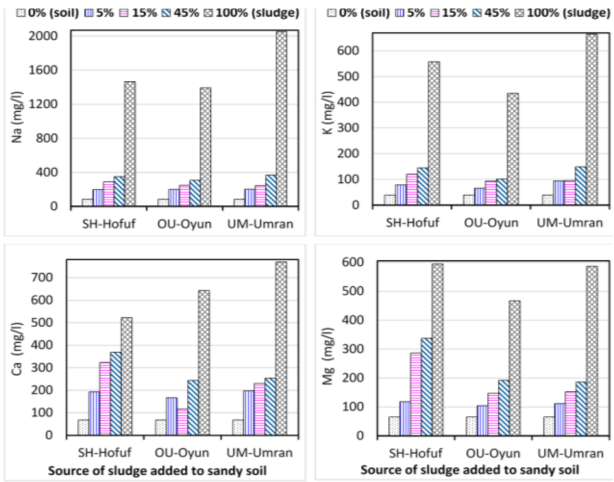
Soluble Anions: The anion (Cl, HCO_3, NO_3, SO_4 and PO_4) results measured in the sandy soil/sludge mixtures are presented in Table 3 and Figure 2. The average concentrations of chloride and bicarbonate in the sandy soil are 137.4 mg/l and 212 mg/l, respectively, and they increased to their highest values of 2769 mg/l (Cl) and 3080 mg/l (HCO_3), respectively, in the sludge from the Umran STP. Cl and HCO_3 values increased with increasing sewage application rates. SO_4 concentrations in the sandy soil averaged 314 mg/l and increased with increasing sludge application rates with higher values (3373 mg/l) for the soil mixed with the sludge from the Umran STP (Figure 2). The average concentrations of nitrate and phosphate in the sandy soil were 1.13 mg/l and 0.98 mg/l, respectively, and they increased with the increasing sludge application rates. Figure 2 illustrates that higher nitrate values were measured in the soil mixed with the sludge from the Hofuf STP.

Figure 2: Effects of sewage sludge application (Hofuf, Oyun and Umran) on the sandy soil physio-chemical properties (pH, TDS, soluble anions)



Soluble Cations: The values of Na, K, Ca and Mg measured in the soil/sludge mixtures are outlined in Table 3 and Figure 3. Na and K concentrations in the soil were 85.5 mg/l and 39.6 mg/l, respectively, with the highest values of 2054 mg/l (Na) and 665 mg/l (K) recorded in the sludge from the Umran STP. However, Ca and Mg ranged, respectively, from 67.7 mg/l and 64.6 mg/l in the soil to 770 mg/l and 587 mg/l in the sludge from the Umran STP. Figures 2, 3 and Table 3 indicate statistically significant increased values of soluble ions with increasing sludge application rates. Therefore, it can be concluded that TDS, soluble anions (Cl, HCO_3, NO_3, SO_4 and PO_4) and soluble cations (Na, K, Ca, Mg) increase in soil mixtures with increasing sewage sludge application rates. These findings are in close agreement with those reported in similar studies (Antolin *et al.,* 2005; Gasco and Lobo 2007; Kidd *et al.,* 2007; Hussein, 2009; Ahmed *et al.,* 2010).

Figure 3: Effects of sewage sludge application (Hofuf, Oyun, Umran) on the sandy soil chemical properties (soluble cations)



3.2. Organic Matter and Nutrients:

Table 4 and Figure 4 represent the values of organic matter and nutrients (N, P) measured in the sandy-soil mixed sludge in various proportions. The concentrations of total organic carbon (TOC%) and total organic matter (TOM%) in the sandy soil were 0.998% and 1.72%, respectively, whereas their average concentrations in the sludge were 15.35% and 26.47 %, respectively (Table 4). The average TOC and TOM values in the sandy soil mixed with sludge varied significantly from 1.88% and 3.25% for the sludge application rate of 5% to the higher values of 5.43% and 9.36% for the sludge application rate of 45%. Higher values of organic matter were reported in the sandy soil mixed with the sludge from the Hofuf STP (Figure 4). Increasing sludge application rates significantly increased the organic matter content in the sandy soil because of the high content of organic matter (25.1–27.8%) in the studied sewage sludge.

Table 4: Effects of sewage sludge application on sandy soil properties (organic matter, nutrients, trace metals), including an ANOVA F ratio of statistically significant variance.

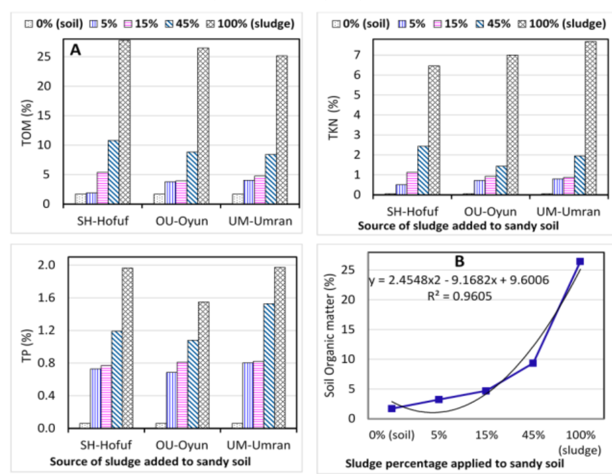
Sample (Sludge /Soil mixture, %)	Organic matter (%)		Nutrients (%)		Trace metals (mg/kg)				
	TOC	TOM	TP	TKN	Fe	Mn	Cu	Zn	Cr
Sandy soil_0%	0.998	1.72	0.060	0.055	2388	67.6	6.0	35.7	28.4
SH-Hofuf_5%	1.10	1.90	0.728	0.507	2415	70.1	26.0	57.5	38.0
SH-Hofuf_15%	3.13	5.40	0.770	1.13	3139	74.1	51.7	163	60.8
SH-Hofuf_45%	6.27	10.81	1.19	2.43	3557	92.1	88.5	342	74.8
SH-Sludge_100%	16.12	27.79	1.96	6.47	4227	104	162	668	60.7
OU-Oyun_5%	2.20	3.80	0.686	0.721	2516	61.3	33.9	148	49.3
OU-Oyun_15%	2.29	3.95	0.811	0.924	2610	69.3	36.9	513	59.0
OU-Oyun_45%	5.13	8.84	1.08	1.44	2846	109	54.4	321	72.1
OU-Sludge_100%	15.35	26.47	1.55	7.01	3556	154	112	696	42.2
UM-Umran_5%	2.34	4.04	0.803	0.793	2776	73.3	42.4	124	55.4
UM-Umran_15%	2.77	4.77	0.821	0.874	2444	65.0	35.4	113	56.0
UM-Umran_45%	4.88	8.42	1.53	1.95	2966	84.1	52.0	229	63.1
UM-Sludge_100%	14.58	25.14	1.97	7.69	4081	98.8	96.1	613	38.0
ANOVA F Ratio	290	291	55.5	182	13.3	6.76	16.7	15.8	13.4

The bold F ratio is significant at p < 0.01 (Critical F-value = 5.99)

This is in close agreement with similar previous studies (Hussein, 2009; Mazen *et al.,* 2010; Leila *et al.,* 2017; Eid *et al.,* 2017). The results indicate a positive significant correlation between sludge application rates and the organic matter content of sandy soil with a regression coefficient of 0.961 (Figure 4B).

The concentration of TKN in the sandy soil is very low (0.055%), and it increased with increasing sludge application rates to reach up to 2.43 % at a mixed ratio of 45% sludge (from the Hofuf STP) and soil mixture (Table 4). The average value of TKN in the sludge was 7.05% with a relatively higher value in the sludge from the Umran STP (Figure 4). Similarly, a very low value of TP was recorded in the sandy soil (0.060%) with higher TP values (1.53%) as the percentage of sludge increased, especially for the soil mixed with the sludge from the Umran STP. Moreover, there is a statistically significant variance of TP in the soil mixed with the sludge from various STPs (Hofuf, Oyun and Umran), with an ANOVA F ratio of 55.5, p<0.01. The increasing concentrations of nutrients (N and P) in the soil after the sludge application may be due to the high content of these elements in the sludge used and/or the releasing of nutrients through the bacterial decomposition of the organic matter in the sludge. Hence, the application of sewage sludge improved the soil chemical properties and increased nutrients and organic matter, as reported in the literature (Antolin *et al.,* 2005; Mendoza *et al.,* 2006; Hussein, 2009; Ahmed *et al.,* 2010; Leila *et al.,* 2017).

Figure 4: A) Effects of sewage sludge application (Hofuf, Oyun, Umran) on sandy soil chemical properties (organic matter and nutrients); B) Regression between sludge application to sandy soil and average organic matter content (%)



3.3. Trace Metals:

The results of the Fe, Mn, Cu, Zn and Cr trace metals measured in the sandy soil/sludge mixtures are presented in Table 4. Iron concentrations ranged from 2388 mg/kg in the sandy soil to 4227 mg/kg in the sludge from the Hofuf STP. However, the average value of Mn measured in the sandy soil was 67.6 mg/kg with higher values of up to 154 mg/kg in the sludge from the Oyun STP. Increasing sludge application rates did not significantly increase the Fe and Mn values in the soil/sludge mixtures. The highest values of Fe (4227 mg/kg) and Mn (154 mg/kg) measured in the sewage sludge were lower than the average values reported by Gattullo *et al.* (2017) and Eid *et al.* (2017) for Fe (15470, 25400 mg/kg) and Mn (520, 595 mg/kg), respectively.

Cu and Zn concentrations in the soil were 6.0 mg/kg and 35.7 mg/kg, respectively, with the highest values of 162 mg/kg (Cu) and 696 mg/kg (Zn) measured in the sludge from the Hofuf and Oyun STPs, respectively. Those high values of Cu and Zn are similar to those reported by Eid *et al.* (2017) but higher than the average values of 128 mg/kg (Cu) and 302 mg/kg (Zn) reported by Gattullo *et al.* (2017). Table 4 indicates that Cu and Zn significantly increase in soil mixtures as the sewage sludge application rates increase. The concentration of Cr in the sandy soil was 28.4 mg/kg, which increased with increasing sludge application rates to reach up to 74.8 mg/kg at the mixed ratio of 45% sludge (from the Hofuf STP). The measured values of these trace metals in the sludge are significantly lower than the KSA permissible limits, which are 4300, 7500 and 3000 mg/kg for Cu, Zn and Cr, respectively (Ministry of Agriculture 2000). Similar studies have indicated that the application of sewage sludge increases soil micronutrients and heavy metals (Antolin *et al.,* 2005; Mazen *et al.,* 2010; Nogueira *et al.,* 2013; Eid *et al.,* 2017).

Sludge application rates of 5% resulted in relatively lower concentrations of these trace metals in the sandy soil/sludge mixture compared to the higher rates of 15 and 45%. The main environmental concern of sewage sludge application to soil over long periods and/or at higher rates is the accumulation of trace metals in the soil that can affect plant growth (Kidd *et al.,* 2007; Waqas *et al.,* 2014). The bio-availability of trace metals in soil is influenced by soil characteristics and organic matter content (Hussein, 2009). The agricultural use of sewage sludge may result in the accumulation of trace metals in the soil and plants leading to the intake of these trace metals by livestock and, subsequently, humans through the food chain (Nogueira *et al.,* 2013; Leila *et al.,* 2017; Gattullo *et al.,* 2017).

Pearson's correlations revealed positive significant relationships ($p<0.01$) between sludge application rates and all the measured soil characteristic parameters (except moisture, pH and Cr) with a correlation coefficient (r) ranging from 0.570 (between NO_3 and Mn) to 0.994 (between Na and K). This supports the finding that increasing sludge application rates increases the values of the soil chemical properties. Soil moisture is positively correlated ($p<0.01$) with pH (r=0.725), TP (r=0.682) and Cr (r=0.780).

As reported in Tables 3 and 4, an ANOVA analysis (F ratios) indicated significant variances ($P<0.01$) in all measured soil characteristic parameters (except pH, significance at $p<0.05$) based on the various sludge application rates (0, 5, 15 and 45 %). Hence, the differences in soil chemical properties with an increasing sludge application is statistically significant. However, an ANOVA analysis based on the source of the sludge added (Hofuf, Oyun and Umran) revealed no significant differences in soil mixture properties (except soil moisture, TP and Cr being significant at $p<0.05$). This might indicate that the characteristics of the sludge from the three STPs in Al Ahsa are relatively similar, as they used the same sewage treatment method.

3.4. Plant Growth and Productivity:

The harvesting measurements of the lettuce and cucumbers planted in the soil mixed with sewage sludge at a proportion of 0 (control), 5, 15 and 45% (three replicates for each) are presented in Table 5. The average harvesting weight of lettuce planted in the soil was 105.1 gm. The average harvesting weights of the lettuce planted in the soil mixed with 5%, 15 % and 45% sludge were 151.9, 126.5 and 96.4 gm, respectively. It is clear from Figure 5 that the sludge application rate of 5% (and 15% in the case of the Hofuf STP) resulted in the highest harvesting weight. The harvesting weight decreased with increasing sludge application rates. However, these differences were not statistically significant ($p<0.05$), as indicated in Table 5. Moreover, the sandy soil mixed with the sludge from the Hofuf STP produced higher plant production than the soil mixed with the sludge from the Oyun STP. The lowest in plant production was the soil mixed with the sludge from the Umran STP with no plant growth at the sludge application rate of 45%.

Figure 5: Effects of sewage sludge (Hofuf, Oyun, Umran) application rates (0, 5, 15 and 45%) on the harvesting weight (gm) of lettuce.

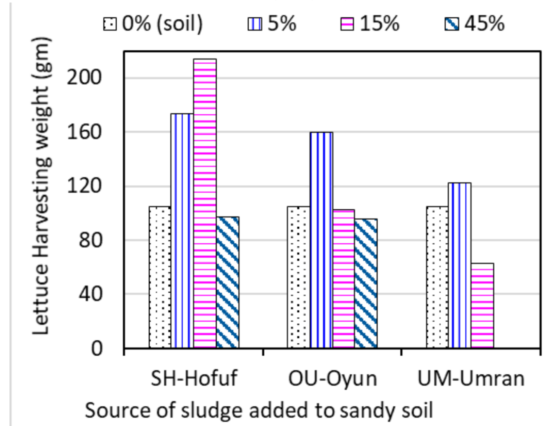


Table 5: Harvesting measurements of lettuce (A) and cucumbers (B) planted in sandy soil mixed with sludge (0, 5, 15 and 45%), including an ANOVA F ratio of statistically significant variance.

A - Lettuce (*Lactuca sativa*)						
Sample (Sludge/Soil mixture, %)	Harvesting weight (gm)			Average weight (gm)	SD	CV %
	Exp 1	Exp 2	Exp 3			
Sandy soil (0%)	45.62	91.52	178.2	105.1	67.30	64.04
SH-Hofuf (5%)	221.2	120.0	179.1	173.4	50.82	29.31
SH-Hofuf (15%)	222.6	214.8	205.0	214.1	8.82	4.12
SH-Hofuf (45%)	90.73	124.2	76.58	97.15	24.43	25.14
OU-Oyun (5%)	151.9	204.6	123.7	160.1	41.09	25.67
OU-Oyun (15%)	97.44	90.45	119.6	102.5	15.22	14.85
OU-Oyun (45%)	118.6	72.71	NA	95.66	32.45	33.92
UM-Umran (5%)	137.5	107.1	121.7	122.1	15.21	12.46
UM-Umran (15%)	63.02	no plant growth		63.02	NA	NA
UM-Umran (45%)	no plant growth					
ANOVA F Ratio*	3.05	0.579	1.89	0.835		
B - Cucumber (*Cucumis sativa*)						
Sample (Sludge/Soil mixture, %)	Number of fruits			Average measurements		
	Exp 1	Exp 2	Exp 3	Weight (gm)	Length (cm)	Circumference (cm)
Sandy soil (0%)	1	1	0	52.5	11.5	8.8
SH-Hofuf (5%)	1	1	1	93.8	12.5	12.7
SH-Hofuf (15%)	2	1	NA	81.2	13.3	10.3
SH-Hofuf (45%)	2	NA	NA	92.7	14.0	8.3
OU-Oyun (5%, 15% and 45%) no fruit, weak plant growth						
UM-Umran (5%, 15% and 45%) no fruit, weak plant growth						

***ANOVA F Ratio is not significant at $p < 0.05$**

However, cucumber fruit was produced only from the plants grown in soil and soil mixed with the sludge from the Hofuf STP. The average harvesting weight of a cucumber planted in soil was 52.5 gm, increasing to the highest value of 93.8 gm for soil mixed with 5% sludge from the Hofuf STP (Table 5). It is reported that the addition of sewage sludge significantly increases fruit numbers and the gross yield of cucumber plants (Dolgen *et al.,* 2007; Hussein, 2009). Increasing plant production due to sludge application might be due to the effects of the sludge on improving soil aggregation and the contribution of organic matter in improving soil chemical properties, increasing soil water retention and, consequently, providing essential nutrients for plant growth (Antolin *et al.,* 2005; Hussein, 2009).

Table 6 shows the effects of the sewage sludge (Hofuf, Oyun, Umran) application rates (0, 5, 15 and 45%) on some of the properties of the lettuce plants. The average percentage of dry matter in a lettuce planted in soil is 9.74% compared to the lower average values of 7.98, 7.95 and 6.76% for lettuce plants grown in soil mixed with sludge in the proportion of 5, 15 and 45%, respectively. This variance in dry matter is statistically significant (p<0.05). TP (%) values averaged 0.60% in the lettuce planted in soil and decreased to 0.50, 0.46 and 0.43% for lettuces planted in soil mixed with 5%, 15% and 45% sludge, respectively. Relatively higher values of dry matter (%) and TP (%) were measured in lettuces planted in soil mixed with the sludge from the Hofuf STP compared to those from the Oyun and Umran STPs. TP is positively correlated with dry matter (r= 0.857).

The average percentage of TKN and protein in lettuces planted in soil are 0.364 and 2.28 %, respectively. The values of TKN (%) and protein (%) decreased in lettuces planted in the soil mixed with 5% sludge and then increased in lettuces planted in the soil mixed with 15% and 45% sludge with a significant variance at P <0.01 (Table 6). A similar study has indicated that increasing sludge application rates results in an increase in the elemental contents of cucumber plants (Hussein, 2009). Moreover, Mendoza *et al.* (2006) found that the agricultural use of sewage sludge increased the metal content of sorghum leaves.

Table 6: Dry matter, TP, TKN and protein (%) of lettuces planted in sandy soil mixed with sludge (0, 5, 15 and 45%), including an ANOVA F ratio of statistically significant variance.

Sample (Sludge/Soil mixture, %)	Dry matter (%)	TP (%)	TKN (%)	Protein (%)
Sandy soil (0%)	9.74	0.600	0.364	2.28
SH-Hofuf (5%)	9.31	0.591	0.267	1.67
SH-Hofuf (15%)	8.77	0.559	0.333	2.08
SH-Hofuf (45%)	7.28	0.464	0.337	2.11
OU-Oyun (5%)	6.79	0.496	0.254	1.59
OU-Oyun (15%)	7.30	0.346	0.300	1.87
OU-Oyun (45%)	6.23	0.403	0.365	2.28
UM-Umran (5%)	7.84	0.419	0.218	1.36
UM-Umran (15%)	7.79	0.465	0.372	2.33
UM-Umran (45%)	no plant growth			
ANOVA F Ratio	*5.56*	2.62 (NS)	13.47	13.14

The bold F ratio is significant at p < 0.01 (Critical F-value = 8.45), the italic and underlined F ratio is significant at p < 0.05 (Critical F-value = 4.35); NS = not significant.

The results of the microbial analysis of the lettuce and cucumbers planted in the soil mixed with sludge (0, 5, 15 and 45%) indicate that no bacterial coliforms (0 cfu/g) were found in the plant samples. Aerobic mesophilic bacteria and yeast/moulds were found in small quantities of plant samples of both the lettuce and cucumbers. The aerobic mesophilic bacteria count ranged from 1.6 to 9.7 cfu/g in both the cucumbers and the lettuce, whereas the yeast and mould counts ranged from 0 to 7.3 cfu/g.

Therefore, the application of sewage sludge increased the growth yield of the lettuce and cucumber plants, especially at the application rates of 5 to 15%. This aligns with studies that have proved that the application of sewage sludge to soil promotes plant growth and productivity significantly more than the application of commercial fertilisers (Hussein, 2009; Gattullo *et al.,* 2017). Another study showed that sewage sludge application rates of 40 g/kg (4%) might maintain soil health and maximise cucumber growth yields (Eid *et al.,* 2017).

4. Conclusion

The valuable benefits of the agricultural application of sewage sludge are important, especially when added to arid soils that are poor in organic matter content, such as those of Saudi Arabia. The current study investigated the effects of different application rates of sewage sludge (0, 5, 15 and 45%) on some soil properties and the growth yield of lettuce and cucumber plants. The findings of the current study prove that the agricultural use of sewage sludge could significantly enhance soil properties/fertility, provide essential plant nutrients, and increase plant production. The application of sewage sludge to sandy soil in this study resulted in a considerable increase in the organic matter content of soil and, ultimately, plant production. The lower application rates of 5% sludge are effective in improving soil properties, soil fertility and plant production with a lower accumulation of metals.

The agricultural application of sewage sludge would be an environmentally friendly solution for traditional disposal problems, decrease the need for commercial fertiliser and, ultimately, protect our surrounding environment. The soil fertility benefits of sewage sludge application can be maintained by proper environmental management, focusing on the potential hazards of heavy metal contamination. Further studies are needed to monitor the long-term accumulation of heavy metals in soil and investigate aspects of pre-treating sewage sludge before agricultural application. Also, in future research, it is recommended that using lower rates (2%) of sludge application be investigated in order to sustain the improvement to soil fertility while reducing the risks of heavy metal accumulation. Moreover, careful monitoring of trace metals in fruit and vegetables is required.

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