

Impacts of Wastewater Irrigation on Soil and Alfalfa Crop: Case Study from Gaza Strip

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This study was conducted between 2008 and 2009 to investigate the impacts of treated wastewater irrigation on soil and alfalfa crop after 7 years of wastewater irrigation. Beit-Lahia Pilot Project (BLPP) was initiated in 2003 where alfalfa crop was irrigated with partially treated wastewater from Beit-Lahia wastewater treatment plant. A control unit irrigated with well water was initiated in parallel for comparison. Soil and alfalfa samples were collected and analyzed for the main physiochemical, fecal coliform (FC), and heavy metals level through the field trial and the applied wastewater quality was also tested. These results were compared with the available data from 2003 to 2007. Results revealed that there is a concern in using treated wastewater under current quality as it negatively impacted the soil physico-chemical properties. Sodium adsorption ratio and electrical conductivity increased significantly by about 160% and 130%, respectively, due to wastewater irrigation (WWI) in both soil layers compared with well water irrigation. WWI caused slight decrease in soil pH in both surface and subsurface soil layers while it increased the soil organic matter content which varied seasonally due to climatic conditions and alfalfa uptake. Slight metal built up was noticed due to wastewater irrigation while metals level remained in the allowable range for soil by the time of this study. Alfalfa metals uptake was within the permissible range. Occasional high FC (900 and 2100 CFU/ml) level was noticed in the applied wastewater did not cause soil biological contamination as the FC level in the soil at BLPP due to wastewater irrigation was almost 260 CFU/g. © 2014 American Institute of Chemical Engineers Environ Prog, 00: 000–000, 2014

Keywords: Alfalfa, Beit-Lahia pilot project, introduction, irrigation, soil, wastewater

INTRODUCTION

Agricultural irrigation is the dominant water use sector accounting for more than two thirds of the global water resources [1]. The reuse of wastewater for agriculture irrigation has become a global practice due to its generated benefits [2]. Wastewater irrigation (WWI) not only can save the high quality water for potable use but also can provide plants' main nutrients and improves the wastewater disposal scheme [3]. The water scarcity in the Gaza Strip, Palestine, is well known where groundwater represents the only water source for all water uses. Low average annual rainfall

(330 mm/yr), rapid population growth rate (3.2%), and the willing of farmers to cultivate the poor land as a strategy of improving their income have contributed to the water scarcity in the Gaza Strip [4]. The quality of the groundwater has been deteriorated due to the sea water intrusion and the leaching of partially treated wastewater into the aquifer [5]. Moreover, the projection of annual water demand in the Gaza strip is expected to increase to 260 MCM by the year 2020 of which 100 MCM will be used for agricultural irrigation [6]. Currently, about 25% (30,000 CM per day) of the generated wastewater is infiltrated into the aquifer while the remaining 75% (90,000 CM per day) is disposed to the Mediterranean Sea and to the open areas causing severe environmental pollution [6]. According to the Palestinian water authority (PWA), utilization of wastewater is planned to provide about 78% of the total agriculture demand in the Gaza Strip with the remaining to be supplied by the freshwater to maintain the balance of salts in the soil and to provide the desired quality for certain crops [7]. Estimates showed that about 92 MCM of wastewater will be available for irrigation in the Gaza Strip by year 2020 [8]. Wastewater irrigation is an environmental friendly option for disposing the wastewater and a useful source of plant main nutrients (N, P, and K) [9]. It can improve the soil fertility by providing organic matter [10, 11] and hence increasing the crop yield as the case in the forage crop [12]. This increase in crop yield is aimed to reduce the use of fertilizers addition. However, continuous wastewater irrigation may lead to unfavorable impacts on both soil and crops depending on the crop and the soil type [13]. In some cases, long-term wastewater irrigation changed soil physical and chemical properties and caused heavy metals leaching [10, 14]. Wastewater irrigation may also contaminate the crops when it comes in contact with the irrigated water depending on the used irrigation system [9]. This study aims at investigating the potential impacts of using partially treated wastewater in irrigating alfalfa crop in a real field study at Beit-Lahia area to the north of Gaza Strip since 2003. For this purpose, crop and soil physiochemical properties were investigated by collecting site samples in 2008–2009. The results were analyzed and compared with the historical data from the site since 2003.

STUDY AREA

Beit-Lahia pilot project (BLPP) as shown in Figure 1 was initiated in 2003 at Om Al Naser village, 9 km to the north of Gaza city through the French program "Water Management and Water Savings in the Near-East." The program aimed at

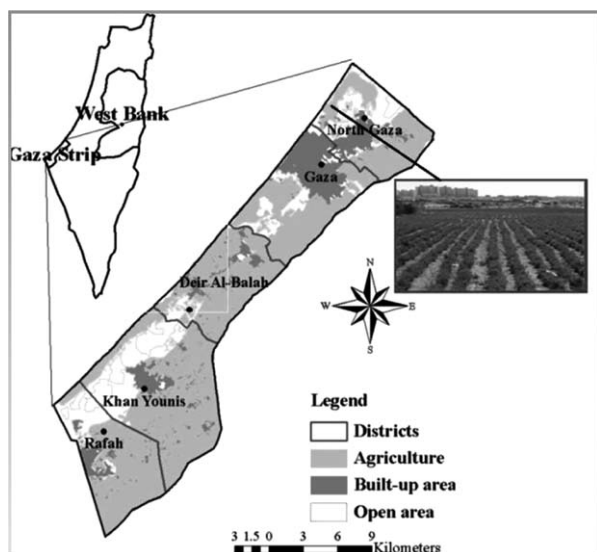


Figure 1. Approximate location of BLPP project with base map of the Gaza Strip (After Al-juaidi *et al.* [1]).

minimizing the water scarcity in the Gaza Strip using partially treated wastewater from Beit-Lahia wastewater treatment plant (BLWWTP) to irrigate 2 ha of Higazy alfalfa forage crop. A control unit with an area of 0.2 ha irrigated with well water was also initiated in parallel to the BLPP for comparison. In 2006, alfalfa crop at the control unit was replaced by citrus crops due to technical reasons. Drip irrigation system was installed in both BLPP and the control unit due to its high safety and to reduce contacts with the alfalfa crop.

No commercial fertilizers were added to either unit during the project. Partially treated wastewater effluent from BLWWTP was used to supply the BLPP with the irrigated water. BLWWTP effluent was collected in a lake with an area of about 30 ha generated from spreading the wastewater effluent into an open area. The lake was used to supply BLPP with water through a main feeding pipe. A sand filter was installed on the main feeding pipe reducing the total suspended (TSS) solids which could easily clog the drippers. TSS was reduced by almost 48% and the down to 700–800 mg/L.

MATERIALS AND METHODS

Wastewater sample for this study was collected between March 2008 and October 2009 to investigate the quality of the irrigated wastewater and to compare with previous records since 2003. For this purpose, four discrete composite wastewater samples were collected from the main supplying pipe in 2 L clean acid-washed polyethylene glass bottles at constant time interval of 10 min at each occasion. pH and electrical conductivity (EC) were measured on site using HI-8424 pH meter and El-Hanna-TH-2400 meter, respectively. The display was showed that pH value automatically compensated for temperature. The bottles were preserved in cold boxes and then moved to the soil and water laboratories at ministry of agriculture (MOA) where it stored at 4°. Wastewater quality analysis was performed according to the American Public Health Agency (APHA) [15]. The main wastewater characteristics are presented in Table 1. Heavy metals (Pb, Zn, and Cu) concentration in wastewater was tested using Atomic Absorption Spectrophotometer (ECL-AAS-4141) after samples being filtered using 0.45 µm filter and acidified using 0.1 M nitric acid. Sodium was determined by

flame photometer. Potassium, calcium, and magnesium were determined after wet digestion of subsamples in H₂SO₄ salicylic acid mixed with three addition of H₂O₂. All results were compared with the available data since 2003 to examine the development in water quality. Since 2003, soil samples from both the BLPP and the control unit were collected twice a year before and after the rainfall season, October and March, respectively. For this study, soil samples were collected in October 2008 and March 2009 to study the impact of wastewater irrigation in line with the available data since 2003. Soil samples were subdivided into horizons of surface layer 0–30 cm and subsurface layer 30–60 cm. Three soil samples from each layer were randomly collected from the control unit soil layer down to 30 cm depth using manual auger to represent the total area. Samples from each layer were mixed to form one composite sample. For the BLPP, 24 soil samples from each layer were collected using manual auger during this study. Although the site soil was uniform, it was intended to collect soil samples from similar locations used in the last for consistency. Samples from the same layer were mixed to form three composite samples. Soil samples were collected in plastic bags and labelled. Samples were then air dried at room temperature and grounded using porcelain mortar and pestle to pass through 2 mm sieve. Soil profile of the top 30 cm soil layer in both BLPP and the control unit was similar and contained 76% sand, 16% clay, and 2% silt with (loamy sand soil) while the soil profile of the subsurface soil layer showed sandy soil with 98% sand and 2% clay. Soil samples analysis were performed according to the standard method APHA [15]. Moisture content was determined by oven drying whilst pH and EC were determined in 1:1 (w/v) soil water extracts. Soil organic matter (OM) content was determined by adding 10 ml of 1 N potassium dichromate and 20 ml sulfuric acid reagents to 1 g of soil, swirled, and allowed the solution to cool down [16]. For the heavy metal analysis, soil samples were (1 g) was digested by adding 10 ml of (3:1 HCL/HNO₃) in a digesting Erlenmeyer flask. The mix was left overnight to react and then heated up for 2 h under reflux before it was cold. The mix was rinsed in distilled water before it was centrifuged with 2000 rpm speed for 3 min and then the solution was extracted in 20 ml. The extract was then diluted using concentrated HCL with 1:10 ratio and the supernatant was then analyzed using Atomic Absorption Spectrophotometer (ECL-AAS-4141) [17]. For the fecal coliform analysis, soil samples were diluted in 1:1 ratio and were placed on a rotating shaker for 5 min at 180 rpm. Samples were then left to settle for 30 min before 1 ml of the solution was extracted and centrifuged at 3000 rpm for 5 min. The samples were then incubated and tested according to APHA [18]. Three alfalfa samples were randomly collected from BLPP (0.5 kg/sample) while it was not possible to collect alfalfa samples from the control unit by the time of this study 2008–2009 as alfalfa plant was replaced by citrus crops. Alfalfa samples from BLPP were collected using clean knife at 5–7 cm above the ground level with yellow and old plants were discarded. Samples were collected in paper bags to allow transpiration. Metals in alfalfa sample were tested as described by Zarcinas *et al.* [19]. Briefly, alfalfa samples were washed using 10% HCL-HNO₃ (3:1) solution and distilled water to remove any impurities. Samples were then air dried at room temperature before being oven dried at 60 ± 5°C for 72 h. Alfalfa samples were then mechanically grounded until passing 1 mm sieve. 1.0 g of the grounded alfalfa sample powder was weighed using the electronic balance and 10 ml of 10% concentrated HCL-HNO₃ (3:1) was added for wet digestion. The mix was kept at room temperature for 12 h before it was heated up to 140°C. The remaining milliliters of the acid residue was then analyzed for the metals content. Quality assurance protocols were applied to all sample preparation and testing

Table 1. Main applied wastewater quality parameter at BLPP.

Parameter	2003	2004	2005	2006	2008	2009	Fresh water	FAO 1985
pH	8.19	7.89	7.64	7.38	7.55	7.66	7.9	6.5–8.5
EC (dS/m)	1.83	1.82	1.85	1.85	1.95	2.51	1.62	0.8–3
TDS (mg/L)	1245	1272	1212.7	1268	1230	1230	878.7	500–2000
Chloride (mg/L)	292.3	268	277	252	265	294	156.6	0–100
Nitrate (mg/L)	13.12	12.5	25.2	22.26	21.6	21.6	96.5	0–50
NH ⁺ ₄ (mg/L)	31.08	50	48.72	54.92	77.13	77.13	—	0–50
Ca ⁺ ₂ (mg/L)	82.32	82.73	73.59	69.26	83.21	83.21	98.4	0–200
Na ⁺ (mg/L)	246.5	216.88	226.82	223.38	250.19	290.19	87.9	0–900
K ⁺ (mg/L)	32	25	31.25	28.75	15	45	35.5	0–100
Sulfate (mg/L)	59.36	25.44	50.88	44.1	37.31	37.31	17.87	0–100
COD	100	65	90	110	118	118	—	—
BOD ₅	75.5	29	25	50	53.1	53.6	—	10–30
SAR	4.2	5.32	5.11	5.47	5.92	6.95	3.52	3–9
F.C (CFU/100 ml)	10	900	2100	150	220	130	—	0–1000

Table 2. Heavy metals in applied wastewater.

Parameter	2004	2005	2006	2008	2009	Fresh water	Allowable FAO, 1985
Cd (mg/L)	0.05	—	—	0.05	—	—	0.03
Pb (mg/L)	1.1	2.8	1.9	3.8	2.3	0.8	5
Zn (mg/L)	0.3	—	—	0.5	3.2	—	2
Cu (mg/L)	—	—	0.9	—	0.8	—	0.2

—: Below detection limit.

procedures to ensure the accuracy and precision of the analyses and all samples were analyzed in duplicates and the mean value was recorded.

STATISTICAL ANALYSIS

The mean values of both surface and subsurface soil layers parameters was compared using *T* test calculated at $P < 0.05$. Influence of using wastewater irrigation compared with well water at the control unit was also investigated and the comparison was performed whenever possible due to the limited available data from the control unit. Analysis was performed using MS Excel software, 2010.

RESULTS AND DISCUSSION

The applied wastewater quality parameters varied slightly over time due to the quality of the irrigated wastewater as shown in Table 1. On average, wastewater was alkaline with pH value ranged between 7.38 and 8.19 as presented in Table 1. Salinity and sodium adsorption ratio (SAR) level in the irrigated wastewater increased since 2003 by 0.68 dS/m and 2.75, respectively. The EC increase and salinity built up due to wastewater irrigation is a common practice and has been reported by Qian and Mecham [10]. The applied wastewater had a considerable amount of plant main nutrients as nitrate, phosphate, and potassium (NPK). According to Ayers and Westcott [20], the applied wastewater at BLPP had a moderate level of total dissolved solids TDS (1224) mg/L (450–2000) and the irrigated water at BLPP was typically suitable for irrigation [21].

BOD was slightly higher than the recommended level by US EPA [22]. The Palestinian standards Institute for treated wastewater states a BOD concentration of 60 in the case of the fodder crops as low to moderate concentrations could be beneficial [23]. It can be seen a higher ammonia concentration in the irrigated wastewater. However, ammonium can be converted either to either NO₃[−] or NO₂ depending on pH

and biological conditions. Ammonium can be a source of nitrogen to the crops which is one of the basic nutrients. It was also noticed that the nitrate NO₃[−] has higher concentration in the fresh water than the in the partially treated wastewater. NO₃[−] concentration was within the permissible range by the FAO for irrigation. The high concentration of the TSS is of lower importance in the case of the agricultural reuse, the main problems associated to the high TSS content are operational and technical ones. High TSS may cover the leaf surfaces or obstruct some types of sprinkler nozzles. It may be necessary to reduce the concentration of solids to avoid such operational problems which depends on the irrigation scheme [24]. For this purpose and to reduce the TSS level, a sand filter was installed on the main feeding pipe. Heavy metals level conversely is shown in Table 2. Lead (Pb) maximum concentration was 3.8 mg/L in 2008 while Cu and Zn increased the FAO (1985) allowable range as its maximum level was 0.8 and 3.2 mg/L in 2009, respectively. This increase in metals level might be attributed due to the existence of small scale workshops nearby BLWWTP, such as painting and battery industries where it disposes its sewage to the main collection system and thus to the treatment plant. Moreover, BLWWTP was originally designed with four primary aerated lagoons followed by two secondary settlement/maturation lagoons and tertiary maturation/storage lagoon. It was planned to produce an effluent of suitable quality to allow for agriculture irrigation. However, due to the rapid population growth, BLWWTP was processing almost three times its design capacity by the time of this study which could be a main reason of the quality deterioration. BLWWTP has only up to 60% metals removal capacity [25].

Previous work by other researchers indicated that long-term wastewater irrigation has inconsistent impact on soil pH. Schipper *et al.* showed that continuous wastewater irrigation increased pH due to the high content of basic cations in the applied wastewater [26]. Others reported pH decrease

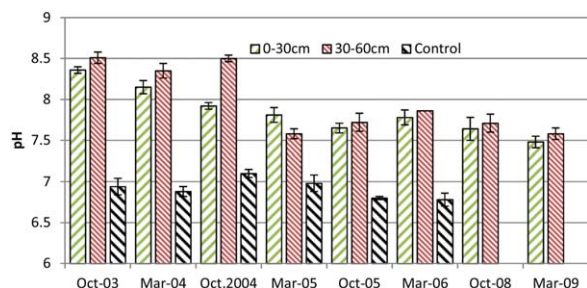


Figure 2. Development of pH in BLPP both soil layers and the average control unit. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

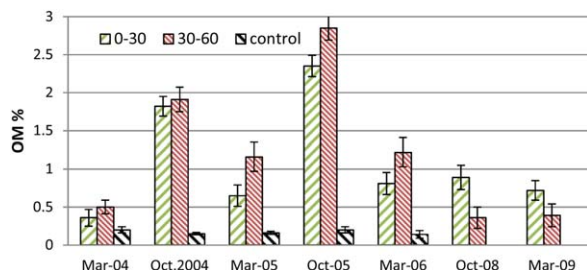


Figure 3. Development of OM in BLPP both soil layers and the average control unit. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

due to the formation of organic acids and high ammonia content [14]. This study showed that long-term wastewater irrigation at PLBB reduced the pH after 2 years of irrigation (2005) in both soil layers as shown in Figure 2.

This decrease resulted from cations leaching and displacement of cations which accounts for higher pH in the subsurface layer compared with the top 30 cm [9, 14, 27] and pH decreased by 0.88 and 0.93 in both surface and subsurface soil layers at BLPP, respectively, in the period between 2003 and 2009. However, soil pH was significantly higher at the BLPP due to wastewater irrigation ($P < 0.05$). Similar pH reduction was noticed by many other researchers and this pH decrease could be due to the fact that long-term wastewater application can add some organic acids and displace cations which results in lowering the pH with time [27–29]. Meanwhile, pH ranged from 7 to 8.5 pH unit over the 7 years of WW application. This pH range is very suitable for agriculture soil, hence, WW application improved the soil pH compared with the control unit. These results are in agreement with the ones obtained by Aghtape *et al.* [12] and Albulbasher Shahalam *et al.* [11, 13]. pH may vary over soil profile due to wastewater irrigation which was insignificant. Average pH was 7.7 and 7.9 in surface and subsurface layer, respectively. Soil OM may vary due to the microbial activity, plant uptake, and soil type. It highly influences metals mobility in soil and increasing their solubility and leaching [27]. OM increased significantly due to wastewater irrigation compared with the control unit ($P < 0.05$) except October 2008 and March 2009, with no significant changes were noticed through the soil profile within the soil layers at BLPP. This increase in OM may be due to the fact that wastewater contains some organic compounds [30]. Wastewater irrigation enhanced the soil properties by implying excess organic matter as was also reported by Mohammad and Ayadi [11]. OM level varied seasonally with high correlation in both soil layers at BLPP as shown in Figure 3. Lower OM level was noticed at the beginning of the alfalfa growing season

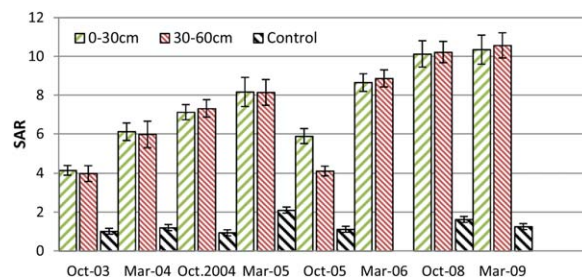


Figure 4. Development of SAR in BLPP both soil layers and the average control unit. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

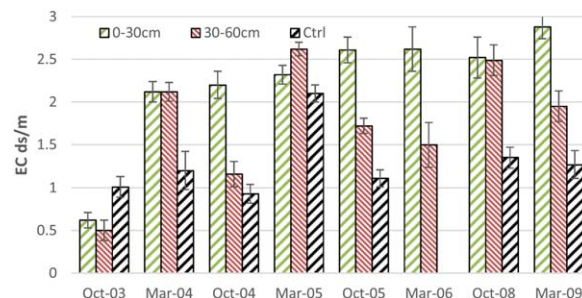


Figure 5. EC level in BLPP and control unit soil layers. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

(March to May) due to the high OM uptake by alfalfa. OM can benefit the soil as it buffers the possible negative impacts associated from overloading the soil with nutrients due to wastewater irrigation [14]. High OM in was noticed in the summer seasons due to the decrease in soil water content and the microbial activities leading as shown in Figure 3. OM level varied slightly over the soil layers where low OM was noticed in the subsurface layer with average value of 1.41% compared with 1.73% in the surface layer. Conversely, soil organic matter at the control unit was constant with almost no change over time with an average of 0.3% which was significantly lower ($P < 0.5$) than the soil OM content at the BLPP. The low OM at the control unit was due to the soil texture as loamy sandy has low OM content in general. This confirms that wastewater irrigation increased the soil OM compared with the control unit and this is in line with the findings by Qian and Follett [31]. Remarkable drop in soil OM level was noticed at BLPP in 2008–2009 as OM decreased in both soil layers by 0.9 and 0.4%, respectively. This drop is believed to be due to the soil tillage took place at the end of the 2008 which resulted in excess of oxygen and sun light to penetrate the soil.

SAR is the relative concentration of Na^+ to Ca^{++} and Mg^{++} . SAR impact on soil can be viewed in combination with the EC values to study the influence of wastewater irrigation on soil properties like permeability. Wastewater irrigation increased the SAR level as shown in Figure 4 and caused sodium built up in soil layers. SAR values increased by 6.2 and 6.3 units in both surface and subsurface soil layer at BLPP due to wastewater irrigation. This increase was significantly higher than the SAR value at the control unit ($P < 0.05$) and continued to increase with time due to the sodium build up which was increasing in irrigated water leading [10]. The concern of sodicity of the soil due to the wastewater application and the increase in SAR was reported by many studies [10, 13]. Increase in SAR level was also reported by Qian and Mecham (2000) where the SAR value

increased by 400% due to wastewater irrigation and hence negatively impacted the soil infiltration and permeability and increased the soil sodicity.

Continuous wastewater irrigation usually increases soil salinity causing salts build up [14]. EC increased significantly ($P < 0.05$) by 2.26 dS/m and 1.45 dS/m in the surface soil and subsurface soil layers at BLPP due to wastewater irrigation compared with 0.26 dS/m in the control unit as shown in Figure 5. This increase might be due to the high water absorption by the alfalfa roots that minimized the free water and therefore concentrated the salts in the top soil layer. EC increased may also have resulted from the limited leaching efficiency of the drip irrigation which allows the salts to remain in the root zone. However, the leaching efficiency increased during rain seasons (December to February) and salts leached down to the subsurface layer. EC level at the control unit was not changed with the average EC value was about 1.28 dS/m. The increase of EC at BLPP soil may be

due to the cations accumulation (mainly Na^+ and K^{++}) which increase the soil salt content [21]. This can be noticed from the increase in SAR level at the soil in BLPP. The impact of irrigated water on soil can be associated by both of salinity and SAR values as illustrated in Table 3.

Current projection of salinity EC (2.8 dS/m) and SAR value (12–20) indicated that there is a potential of soil sodicity and slight to moderate negative impacts on soil fertility and permeability may take place due to the current wastewater irrigation. This level of SAR and EC showed the need to take some measurements such as soil leaching by applying fresh water for certain time to flush the salts out and to provide a better water quality, thus avoid the development of possible negative impacts. Crops with high salt tolerance could be an option as well.

Lead, copper, and zinc were identified as the main heavy metals to be considered in wastewater reuse [30]. The level of heavy metals in soil and crop is of high concern due to the possible consequences on human health and safety [33]. Moreover, heavy metals in soils occur in complicated forms because of their association with a number of physicochemical forms that in turn influence their availability. Metals build up depends on soil type, OM, and other soil parameters [34]. This creates the need to understand the impact of wastewater irrigation at different conditions. Because of the wastewater irrigation Zn, Pb, and Cu levels increased in BLPP soil by 0.37, 2.76, 0.95 mg/kg, respectively, while there was no indication of soil contamination in the control unit as metals level was below the detection limit most of the time as shown in Table 4. This metals build-up resulted from the application of wastewater irrigation as wastewater enriched the metals concentration in soil [9, 33, 35]. However, the level of heavy metals in BLPP soil still at the permissible

Table 3. Guidelines for interpretation of water quality for irrigation (Pescod, 1992) [32].

SAR	EC (dS/m)		
	No Problem	Slight to moderate	Sever Problem
0–3	>0.9	0.2–0.9	<0.2
3–6	>1.3	1.3–0.25	<0.25
6–12	>2.0	2.0–0.35	<0.35
12–20	>3.1	3.1–0.9	<0.9
20+	>5.6	5.6–1.8	<1.8

Table 4. Heavy metals in BLPP and control unit soil layers.

	Mar-04	Oct-04	Oct-04	Oct-05	Mar-06	Oct-08	FAO, 2000
0–30 (cm)							
Zn (mg/kg)	0.03	0.34	0.01	0.02	0.2	0.4	150
Pb (mg/kg)	0.2	0.51	0.33	—	—	2.96	50
Cu (mg/kg)	1.5	0.53	0.62	—	0.75	2.45	50
30–60 cm							
Zn (mg/kg)	0.08	0.07	0.6	—	0.5	0.2	150
Pb (mg/kg)	0.01	0.4	0.25	—	—	0.5	50
Cu (mg/kg)	0.82	0.42	1.3	0.5	0.4	0.68	50
Control Unit 0–30							
Zn (mg/kg)	0.2*	BD*	BD*	0.11*	BD*	BD*	150
Pb (mg/kg)	0.2*	BD*	0.17*	BD*	BD*	BD*	50
Cu (mg/kg)	BD*	0.2*	BD*	0.2*	BD*	0.12	50

*BD = Below detection.

Table 5. Heavy metals content in Alfalfa crop.

	2003		2004		2005		2008	Allowable limit (SPEA, 2005)
	BLPP	Control	BLPP	Control	BLPP	Control	BLPP	
Pb (mg/kg)	1.86	BD*	1.99	0.2	2.77	1.77	8.28	9
Zn (mg/kg)	1.05	BD*	1.65	BD*	1.95	0.25	2.81	100
Cu (mg/kg)	0.2	BD*	BD*	BD*	0.2	BD*	0.5	20

*BD = below detection.

range according to the FAO [35] as shown in Figure 4. Alkaline pH may immobilize the metals and prohibit its leaching to the subsurface layers [33, 37]. In general, metals level at BLPP soil remained within the permissible range and was not hazardous.

Wastewater application increases soil organic matter and hence increased the activity of soil microorganisms. The retention of the microorganisms depends mainly on different soil parameters such as moisture content, pH, and organic matter [38]. Results revealed that the highest soil Fecal Coliform in BLPP soil was 260 and 180 CFU/100 g in both surface and subsurface soil layer at BLPP, respectively. This was insignificant compared with soil samples from the control unit. This might be due to the leaching capacity of sandy soil and the OM level which played an important role in bacterial retention. It is believed that soil micro biota decomposed due to different factors mainly the OM content and moisture content. Low moisture content resulted from the semiarid climate could also be a reason of the low FC level observed in BLPP soil [38]. Moreover, due to the nature of the BLPP as shown in Figure 1 where it is an open field with sun radiation can cause natural disinfection [39].

Results of metals (Pb, Zn, and Cu) level in alfalfa crop at BLPP and the control unit are illustrated in Table 5. It shows an increase in alfalfa metals content with time due to wastewater irrigation in BLPP. Pb level was increased by 6.24 mg/kg in 2008 compared with 2003. Zn increased by about 1.75 mg/kg while Cu increased by 0.3 mg/kg until 2008. This increase in metals level may be attributed to the increase metals level in soil which provides sufficient metals for alfalfa. It may also be attributed due to the increase in metals concentration in the irrigated wastewater which is most likely had been in contact with alfalfa crop and hence increased the level of metals in the alfalfa crop. This result is in line with previous studies [33, 40]. Nevertheless, heavy metals (Cu, Pb, and Zn) concentration at alfalfa crop irrigated with wastewater was below the toxicity level assigned by Chaney *et al.* [41] (40 mg/kg, 40 mg/kg, and 500 mg/kg) for Cu, Pb, and Zn, respectively. It was also less than the permissible limit allowed by the SPEA [42] (20 mg/kg, 9 mg/kg, and 100 mg/kg) for Cu, Pb, and Zn, respectively. The metals increase due to wastewater was insignificant ($P > 0.05$) compared with the metals level in the control unit as shown in Table 5.

Historical records from the control unit showed no heavy metals contamination was observed in alfalfa samples at any time since 2003. The order of alfalfa metals content at BLPP due to wastewater irrigation was $Cu > Pb > Zn$ and was similar to the order of metals level in soil, which may confirm that long-term irrigation increased metals accumulation in soil and the alfalfa uptake [40]. Results showed that the concentration of metals in the alfalfa crop was within the permissible limit, International journal of water resources and environmental engineering [43].

CONCLUSION

The trend towards reusing recycled wastewater for irrigation is growing due to the water scarcity especially in arid and semi-arid areas. Wastewater contains a complex matrix of organic and inorganic materials that may impact the soil and plant physico-chemical properties. Wastewater irrigation supplied the necessary amount of irrigated water which can release the stress from the agricultural demand. Wastewater irrigation enhanced the soil organic matter and supplied the soil with the main nutrient. Conversely, BLWWTP effluent has high level of sodium and continuous wastewater irrigation resulted in high Na^+ accumulation in the soil which negatively affects the soil infiltration and plant nutrients uptake. Continuous build-up of salts was also noticed which may negatively affect the crop and even soil productivity.

This requires more leaching fraction and drainage using fresh water as well as crop rotation. The increase of metals level in the soil profile due to wastewater irrigation was not hazardous due to the soil texture and high leaching capacity of sandy soil. However, metals accumulation may pose some risk in the long term and it would be necessary to undertake risk assessment prior to any reuse project. Wastewater reuse is site specific and comprehensive evaluation of the potential wastewater reuse impacts may include the quality of the applied water, the irrigation system, the soil texture, and the crop.

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