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Impact of Treated Wastewater on Soil and Crops Irrigated Using Drip and Sprinkler Systems

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ABSTRACT

The Jordanian standards (JS893/2006) governing the reuse of treated wastewater (TWW) in agricultural irrigation only permit the use of drip and/or surface irrigation, and ban Sprinkler irrigation usage except for golf fields, and only during the night. This research was conducted to investigate the impact of using drip and sprinkler irrigation systems using TWW on soil nutrients and crop quality. Three fields were irrigated with TWW (i) Alfalfa using sprinkler (AS), (ii) Barley using sprinkler (BS), and (iii) Barley using drip (BD). To give a comparison, another barley field received only rainwater (BR). Results showed that no E. coli was detected (< 3 MPN/gm) on the plants (alfalfa and barley) irrigated with TWW using either drip or sprinkler. The negligible presence of E. coli, if any, in the middle and lower parts of the alfalfa plant could be attributed to the sampling time and the dense leaf of alfalfa. Results revealed that irrigation systems have no significant effect on soil chemical properties. However, the effect of TWW on soil chemical properties was significant. The significant increase in soil chemical properties could be attributed to the TWW content and the amount of its usage.

Keywords: treated wastewater, alfalfa, barley, irrigation, sprinkler, drip, rainfed, E. coli, nutrients.

INTRODUCTION

Rapidly increasing population, climate change, urbanization, overexploitation of water resources for domestic, industrial, and agricultural use, water quality degradation, and global warming are all factors that serve to exacerbate the problem of water scarcity all around the world, especially in arid and semi-arid regions (Becerra-Castro *et al.,* 2015; Jasim *et al*., 2016; Flörke *et al*., 2018; Iglesias *et al*., 2010; FAO, 2013; Rodríguez-Liébana *et al.,* 2014).

Projections have shown that by 2025 over half of the world's population will live in places that are subject to severe water stress, and by 2040 demand is projected to exceed supply (Maimon *et al*., 2010; FAO, 2013). All these conditions increase the competition between domestic, agricultural, and industrial sectors for freshwater. Agriculture will be the most affected by water scarcity as it is considered the greatest water consumer, where about 70% of globally available freshwater is used in agriculture (FAO, 2017).

As the demand for freshwater is increasing, the best approach is to find alternatives such as using low-quality water for agricultural and industrial purposes. The most

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sustainable alternative that will be effective and conserve water resources in both the present and the future is the use of treated wastewater (TWW) (O'Connor *et al*., 2008; Gude, 2017).

The reuse of TWW has been recognized as a valuable source to reduce the utilization of freshwater for agricultural irrigation, increase food production, and save the environment (Bixio *et al*., 2006). The advantages of TWW reuse in agricultural irrigation are many (Jaramillo & Restrepo, 2017; Baghapour *et al*., 2013), as long as the process meets well-recognized biological quality criteria that leads to minimal health risks. TWW reuse saves water for first use and consequently decreases the overall water consumption, provides the most necessary nutrients used in chemical fertilization production, and allows the expansion of agricultural land in infertile areas. However, precautions should be considered since many hazardous consequences could result from reusing TWW such as soil salinization, and soil and groundwater pollution. Jordan, with its semi-arid, Mediterranean climate is considered among the driest countries in the world, suffering from water scarcity with a per capita freshwater share of 145 m3 per year, which is far below the international water poverty line of 500 m3 per year (Al Bakri, *et al*., 2013). Water scarcity and food insecurity are being exacerbated by climate change impacts on water resources. Frequent droughts, high population growth rate, political instability in the region, inefficient use of the available water resources in all sectors, the non-uniform spatial distribution of the population, and the lack of funds to develop new resources are among the challenges that add to the complexity of the water crisis in Jordan and increase the gap between supply and demands. The gab is being covered through the mining of groundwater resources at 130% of their safe yields and exploitation of non-renewable groundwater (Abu-Awwad, 2011).

Thus, TWW reuse is the most effective solution, proving less expensive and more sustainable compared with desalination or other alternatives. TWW is and will continue to be, a major component of the national water budget. It is therefore vital that the anticipated increase of TWW reuse should be managed carefully to provide, safely and economically, a viable resource that meets the current and future demand for irrigation water, and to maximize the returns per cubic meter of TWW (Ammary, 2007).

Many studies were conducted to show the advantages and benefits of utilizing TWW using drip system compared to other types of irrigation systems (Hidri, *et al*., 2013; Capra & Scicolon, 2001; Song, *et al*., 2006). These studies recommended the use of drip irrigation, as it showed a low level of contamination, but at the same time, it needs careful and good management and maintenance. Martijn & Redwood (2005) reported that local irrigation methods like surface and subsurface drip irrigation methods minimize pathogen dispersion to crops and workers. In the study by Gideon et al., (1991) it was shown that applying TWW via subsurface trickle irrigation resulted in the minimal soil surface and plant contamination, while maximum contamination was reached when sprinkler irrigation was used. EI Hamouri, *et al*., (1996) in their study, using raw and TWW showed that drip irrigation resulted in the highest irrigation performances and crop yields as compared with sprinkler and surface irrigation. Many studies have reported that using TWW with good quality, as applied by the WHO, will have no significant effect of increasing the microbial activities on crops using drip irrigation (Cirelli, et al., 2012; Lonigro, *et al*., 2016; Orlofsky, *et al*., 2016; Urbano, *et al*., 2017; Farhadkhani, et al., 2018).

Tabatabaei and Najafi, (2009) reported that using drip irrigation soil will act as another filter that decreases physical, chemical, and biological pollutants such as total suspended solids, total coliform, and fecal coliform in treated wastewater. Also, they conclude that there is no significant difference in soil surface pollution between surface drip irrigation with treated wastewater and/or any irrigation system with traditional water quality.

On the other hand, Mostafazadeh-Fard, *et al*., (2006) reported that sprinkler systems did not have significant effects on the accumulation of diethylenetriaminepentaacetic acid (DTPA)-extractable heavy metals in soil. Li, *et al.,* (2019) reported that micro-sprinkler irrigation worked well in combination with different levels of TWW when applied to tall fescue in sea reclamation land.

In Jordan, TWW is mainly used to irrigate fodder crops. According to Jordan standards (JS893/2006), agricultural reuse of TWW may only be carried out using drip and/or surface irrigation. It is prohibited to use sprinkler irrigation as an application system, except for land which is used for golf courses, and then only during the night. Despite the prohibition, some farmers are using sprinklers as an application system for TWW reuse to irrigate fodder crops, such as alfalfa and barley. Due to the high initial cost, maintenance, and labor needed for drip irrigation, farmers are switching to the use of sprinkler irrigation for more efficient and lower-cost fodder irrigation.

Studies related to sprinkler irrigation using TWW are very limited. Khaskhoussy, *et al*., (2015 & 2019) compared the effect of surface, drip, and sprinkler irrigation methods using TWW on soil trace elements. The results indicated that drip and subsurface drip irrigation could reduce soil contamination with trace elements in comparison with surface and sprinkler irrigation.

The main objective of this research is to investigate the impact of using sprinkler irrigation as an application system using for TWW on soil macronutrients and the quality of the resultant crops compared to the drip irrigation system and rainfed agriculture.

Methodology

This research was conducted at a farm that uses TWW for fodder production, located in Al Jizah/Um Rummaneh village (Latitude 31o44’44’’, Longitude 35o52’40’’), 35 km south the capital Amman. The farm is situated in an area characterized as having a semi-arid climate (desert). The main rainfall season is from October to May. The average rainfall ranges from 0 mm in summer months to its maximum (82.2 mm) in January, with an annual average of 329 mm for the last 39 years from 1988 to 2017 (Queen Ali Airport weather station). No rainfall during the period of sample collection (June and July 2019). The farms are comprised of alfalfa and barley fields irrigated with TWW effluent from South Amman Wastewater Treatment Plant (WWTP). The WWTP activated sludge was put into operation in 2012. Most of the area (10 hectares) was planted with alfalfa in 2017 and a limited area (2 hectares) was planted with barley. The farmer used to add 50 kg/ha diammonium phosphate (DAP) before planting and 50 kg/ha urea every two months. For this research, four fields were studied: (i) Alfalfa irrigated with TWW effluent using sprinkler system (AS), (ii) Barley irrigated with TWW effluent using sprinkler system (BS), (iii) Barley irrigated with TWW using drip system (BD), and (iv) Control field of rainfed barley (BR) as a control field. Plants and soil samples were collected during the period from April to July 2019. TWW effluent characteristics from South Amman WWTP were obtained from the Ministry of Water and Irrigation, 2019.

Plant Samples

Plant samples (alfalfa and barley) were collected from each field, in three replicates. Random samples were collected from three parts 1/3rd upper, 1/3rd middle, and 1/3rd lower parts of the plant. Samples were collected immediately after irrigation had ceased in two stages. In the first stage, fresh plant samples were collected from barley at the mature stage and alfalfa at the bud stage and analyzed for Escherichia coli (E. coli). In the second stage, another set of fresh samples was collected from alfalfa for three successive weeks and analyzed for total fecal coliform, fecal coliform, and E. coli. No special procedure has been taken during the sampling period that could affect the irrigation schedule. Plant samples were collected with high precautions and a high level of hygiene to prevent any disturbance and/or contamination. Collected samples were delivered to the laboratory on the same day in the icebox to prevent any damage and/or contamination. Total coliforms and E. coli were analyzed and reported as Most Probable Number (MPN) per gram weight of the plant sample according to Alexander, (1965).

Soil Samples

Soil samples were collected from three depths (0-20, 20-50, and 50-90 cm), from each field, in three replicates. Soil samples were air-dried and crushed to pass through a 2 mm sieve, then analyzed for some physical and chemical parameters. Soil texture was determined using the hydrometer method (Gee & Bauder, 1979). Soil paste extracts electrical conductivity (ECe) and pH was determined using the conductivity and pH meters, respectively. Sodium and potassium were determined in the extract of the saturated paste using flame photometry (Berry *et al*, 2002). Soil microelements were determined using Atomic Absorption Spectrophotometer (Liang & Karamanos, 1993). The presence of phosphorus was determined using a Spectrometer (Fontaine, 1942). EDTA Titration method was used for calcium and magnesium determination (Barrows & Simpson, 1962). Total nitrogen was determined using the Kjeldahl method (Bremmer & Mulvaney, 1982).

Statistical Analysis

The data were transformed logarithmically for analyses using the GLM procedure of SAS (2009) for comparing the treatments of AS, BS, BD, and BR. SAS (2009). Means of significant effects ($P < 0.05$) were compared using the Duncan Multiple Range Test.

Results and Discussion

Treated Wastewater Characteristics

Table 1. presents South Amman TWW effluent characteristics. Effluent quality was in line with the Jordanian standards (JS893/2006) for agricultural irrigation using TWW. However, oil and grease (16 mg/l), and molybdenum (0.02 mg/l), which were analyzed once yearly, exceeded permissible values (8 mg/l) and (0.01 mg/l), respectively, in the JS893/2006. TWW is slightly alkaline (pH values varied between 8.14 and 8.52).

Table 1: Treated wastewater characteristics, South Amman WWTP (2019) (*).

Sampling date	BOD (mg/l)	COD (mg/l)	pH	TDS (mg/l)	TN (mg/l)	TSS (mg/)	NH4 (mg/l)	NO3 (mg/l)	PO4 (mg/l)	Total Coliforms (MPN/100ml)	E. coli (MPN/100ml)
10-Jan	17	174*	8.18	1,176	88.7	64	61	<0.3	18.9	2,300	200
13-Feb	12	134	8.22	1,048	81.3	8	63.6	1.6	18.1	16,000	9,200
3-Mar	81*	143	8.14	1,014	79.1	17	69.3	4.6	19.9	5,400	3,500
4-Apr	24	161*	8.18	846	75.3	71	49.6	0.3	12.8	35,000	230
6-May	22	180*	8.17	1,104	42.9	49	21.8	4.6	12.3	1,600	920
16-Jun	13	260*	8.29	1,194	42.7	140	26.4		18	790	330
10-Jul	15	234*	8.45	1,169	22.3	89	4.1	2.5	3.6	490	140
22-Aug	23	230*	8.3	2,308*	34.7	198	17.5	0.7	3.6	49,000	33,000
17-Sep	12	98	8.52	1,202	27	28	18.6	0.9	<0.6	4,600	4,600
8-Oct	36	108	8.31	1,105	37.6	79	31.7	0.5	4.7	7,000	7,000

(*) As sourced from the Ministry of Water and Irrigation

Plant Microbial Content

E. coli was considered as the ideal indicator organism for testing fecal contamination. Since fecal coliforms can arise from environmental factors, not only from wastewater, all these factors confirm the necessity to count the population of E. coli as an indicator of fecal contamination. E. coli can survive longer time and reproduce rapidly than other bacteria (Winfield & Groisman, 2003). Moreover, some E. coli strains are known to cause gastrointestinal tract infections (Tauxe *et al*., 1997; Brandl, 2006; and Lynch *et al*., 2009).

Tables 2 and 3 present E. coli and total fecal coliform content for the plants irrigated with TWW using sprinkler and drip irrigation systems and compared to rain-fed values, for the first and second stage of sampling, respectively. In the first stage of plant sampling, TWW E. coli content was 230 MPN/100 ml. Results indicate that E. coli plant contents were not detected (less than 3 MPN/gm) in the first stage (April 2019), regardless of sampling location and/or type of irrigation system used. Also, there is no difference in E. coli content between plants irrigated with TWW and/or rainfed. In the second stage of plant sampling, TWW E. coli content varied from 330 MPN/100ml (June 2019) to 140 MPN/l00ml (July 2019).

Results showed the absence of E. coli from the upper 1/3rd of the alfalfa plant for three successive weeks. However, in the middle and the bottom parts of the alfalfa plant, E. coli content was detected in 2 out of 9 replicates, albeit in negligible concentration (400 to 2300 MPN/gm), knowing that permissible E. coli values are not specified for field and forage crops in JS893/2006. Considering the environmental factors that could affect the presence of bacteria such as ambient temperature and humidity, rate of ultraviolet radiation, soil moisture and pH, antagonism with indigenous soil microorganisms, method of irrigation, and finally, the type of plant could impact the fate and population of microorganisms in soil and on crop surfaces (Becerra-Castro *et al*., 2015; WHO, 2006). The absence of E. coli from the plant irrigated with TWW could be attributed to its good quality (E. coli was 230 in April, 330 in June, and 140 MPN/l00ml in July). Ultraviolet (UV) radiation from the sun is one of the inactivation factors of microorganisms, which can be seen as a benefit of being in the semi-arid region (Bichai *et al*., 2012). The UV light destroys the genetic material of the microorganisms which prevents them from reproducing and functioning.

The negligible presence of E. coli, if any, in the middle and lower parts of the plant could be attributed to the sampling time and the dense canopy (80 to 90%) for alfalfa. Plant samples were collected immediately at the cessation of irrigation in the afternoon which reduces the limited solar radiation from penetration and the exposure of the lower parts of the plant to solar radiation which will enhance the favorable environment for E. coli to live. Bogosian *et al*., (1996) and Sampson *et al*., (2006) found that E. coli has an increased ability to survive in cooler water temperatures. Many studies have also shown that there is no link between water pathogen and microbial presence in soil or crops irrigated with such water (Cirelli *et al*., 2012; Forslund *et al*., 2010 and 2012; Libutti *et al*., 2018; Lonigro *et al*., 2016; Orlofsky *et al*., 2016; Urbano *et al*., 2017). Tripathi et al., (2019) reported that the presence of pathogens could be due to the spread from soil surface through aerosol. In addition, JS893/2006 requires that harvested alfalfa should be air-dried for two weeks before its end-use, to ensure that there is no presence of E. coli.

Table 2. E. coli content for barley and alfalfa plants irrigated with TWW using the different irrigation systems, April 2019.

***E. coli* (MPN/gm)**										
Plant		**Drip**			**Sprinkler**			**Rainfed**		
	Sample location/ Replicates	**Upper 1/3rd**	**Middle 1/3rd**	**Bottom 1/3rd**	**Upper 1/3rd**	**Middle 1/3rd**	**Bottom 1/3rd**	**Upper 1/3rd**	**Middle 1/3rd**	**Bottom 1/3rd**
Barley	1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
	2	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
	3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Alfalfa	1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
	2	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
	3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3

Table 3. Total coliform, fecal coliform, and E. coli presence in alfalfa irrigated with TWW via sprinkler (*).

One week from cutting alfalfa, immediately after irrigation ceased, 30 June 2019									
Replicates	**Total coliform (MPN/gm)**			**Fecal coliform (MPN/gm)**			***E. coli* (MPN/gm)**		
	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd
1	23×10²	23×10²	23×10²	< 3	23×10²	4×10²	< 3	23×10²	< 3
2	< 3	< 3	23*10²	< 3	<3	9×10²	< 3	< 3	4×10²
3	23×10²	23×10²	23×10²	< 3	23×10²	< 3	< 3	23×10²	< 3
Two weeks from cutting alfalfa, immediately after irrigation ceased, 8 July 2019									
Replicates	**Total coliform (MPN/gm)**			**Fecal coliform (MPN/gm)**			***E. coli* (MPN/gm)**		
	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd
1	23×10²	4×10²	9×10²	< 3	<3	< 3	< 3	< 3	< 3
2	< 3	< 3	< 3	< 3	<3	< 3	< 3	< 3	< 3
3	4×10²	23×10²	23×10²	< 3	9×10²	< 3	< 3	< 3	< 3
Three weeks from cutting alfalfa, immediately after irrigation ceased, 15 July 2019									
Replicates	**Total coliform (MPN/gm)**			**Fecal coliform (MPN/gm)**			***E. coli* (MPN/gm)**		
	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd	Upper 1/3rd	Middle 1/3rd	Bottom 1/3rd
1	23×10²	< 3	4×10²	23×10²	<3	< 3	< 3	< 3	< 3
2	23×10²	< 3	23×10²	4×10²	<3	23×10²	< 3	< 3	9×10²
3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3

(*) Shaded cells mean *E. coli* was detected.

Results revealed that there were no significant differences in E. coli content for plants irrigated with TWW using sprinkler and/or drip irrigation systems and there was no E. coli accumulation on the plants irrigated using sprinklers as compared with drip irrigation systems. Ibekwe *et al*., (2018); Elifantz et al., (2011); Frenk *et al*., (2013); and Broszat *et al*., (2014) have shown that the population and presence of bacteria have no significant relation with the TWW irrigation if good quality TWW is applied. Farhadkhani *et al*., (2018) reported that the high concentration of indicator bacteria reflects low treatment plant efficiency in terms of removing such bacteria and is probably attributed to the inefficient disinfection process.

The findings of this study, coupled with the fact that JS893/2006 demands that fodder crops (alfalfa and barley) should be dried for two weeks before being fed to animals indicate that using sprinkler irrigation could be as safe as drip irrigation when good quality TWW is applied in arid and semi-arid regions.

Soil Properties

Table 4 presents soil separates, texture, pH, and saturated paste extract electrical conductivity (ECe) for the different fields. In general, the dominant soil texture is clay with clay particles concentrated in the deep layers. Soil texture varies from silty clay loam in the barley/sprinkler (BS) field to clay in the barley/rainfed (BR) and alfalfa/sprinkler (AS) fields. Soil pH varies from 8.1 to 8.5 (slightly alkaline) for the four fields.

The highest average soil ECe (3.14 dS/m) was in AS field followed by the BS field (1.54 dS/m) and the lowest average soil ECe (0.96 dS/m) was in the BD field followed by the BR field (0.96 dS/m). The increase in soil ECe in AS field could be attributed to TWW which was used to irrigate alfalfa in large quantities, estimated based on WWTP records (1132 mm/season) compared to (566 mm/season) for barley. In the BD field, the ECe distribution followed the drip bulb shape wetting pattern with the lowest ECe (1.24 dS/m) at the soil layer (20-50 cm) and the highest ECe (1.57 and

1.74 dS/m) at the surface (0-20 cm) and the deep (50-90 cm) soil layers. In general, since arid and semi-arid regions are characterized by high evaporation and low rainfall, then leaching is necessary to avoid salt accumulation in the root zone and its negative impact on soil productivity and crop yield (Francois & Maas, 1994; Munns, 2002).

Table 4: Soil separates and texture for the different fields and layers.

Treatment	Depth (cm)	Soil separates (%)			Texture	pH	ECe (dS/m)
		Sand	Silt	Clay			
BR	0-20	19.9	38.7	41.5	Clay	8.3	1.16
	20-50	19.9	34.7	45.5	Clay	8.3	0.86
	50-90	16.5	26.0	57.5	Clay	8.2	0.93
BD	0-20	25.2	40.0	34.8	clay loam	8.5	0.87
	20-50	27.2	28.0	44.8	Clay	8.4	0.84
	50-90	21.2	28.7	50.1	Clay	8.4	0.93
BS	0-20	18.5	51.3	30.1	silty clay loam	8.1	1.57
	20-50	17.2	43.3	39.5	silty clay loam	8.2	1.24
	50-90	16.5	34.7	48.8	Clay	8.2	1.74
AS	0-20	26.5	24.7	48.8	Clay	8.2	3.50
	20-50	22.5	27.3	50.1	Clay	8.1	3.08
	50-90	15.9	32.0	52.1	Clay	8.1	3.01

Soil Macro Nutrients (NPK)

Table 5 presents total soil nitrogen, phosphorus, and potassium (NPK) content for the different fields. Regardless of crop type and/or irrigation system, there was no significant difference in the soil N content (1.91, 2.1, and 2.1%) between BD, BS and AS fields, irrigated with TWW. Using TWW the soil total nitrogen was increased by more than four times as compared with the BR field. Results indicate that there was no significant difference in soil P content between BD (21.8 mg/l) and BS (16.9 mg/l) fields. However, soil P content in the BD field was significantly higher than that in BR and AS fields by 61% and 79%, respectively. Whilst the highest soil K content was in AS field (39.4 mg/l) followed by the BD field (32.0 mg/l); and soil K content in AS field was significantly higher than that in BR and BS fields by 40% and 67%, respectively. Results agree with many researchers (Arienzoa *et al*., 2009; Fuentes *et al*., 2002; Rusan *et al*., 2007; Mohammad & Mazahreh, 2003; Qian & Mecham, 2005) who found that TWW improved soil available NPK content.

Table 5: Soil nitrogen, phosphorous, and potassium content for the different fields (**).

Field	Nitrogen (%)	Phosphorous (mg/l)	Potassium (mg/l)
	Pr >F 0.0049	**Pr >F 0.0198**	**Pr >F 0.0353**
BR	0.51 b	12.14 b	23.67 B
BD	1.91 a	21.78 a	32.00 Ab
BS	2.10 a	16.95 ab	28.11 B
AS	2.10 a	13.56 b	39.44 A

(**) Means with the same letter in each column are not significantly different at $P < 0.05$.

Soil Chemical Properties

Soil chemical properties as affected by TWW and the different irrigation systems are given in Table 6. Results revealed that there is no significant difference in all measured soil properties Sodium (Na), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Lead (Pb), Cadmium (Cd), Copper (Cu) and Zinc (Zn) between BS, BD, and BR fields. Also, Ca, Mg, Pb, Cd, and Zn soil content reveals no significant difference for all fields (BS, BD, BD, and AS) irrigated with TWW. However, Na, Fe, Cu and Zn soil content in AS field is 9.9, 4.2, 1.3, and 2 times significantly higher than that in the BR field. Results indicate that even though Fe, Cu, and Zn soil content are relatively high in AS field compared to that in BD and BS fields, it is not significantly different. Thus, irrigation systems cannot be seen to have any significant effect on measured soil chemical properties. The significant increase in soil chemical properties could be attributed to TWW content and the amount of applied TWW. The estimated amount of TWW applied for alfalfa fields was 1132 mm/season and 566 mm/season for barley fields.

Table 6: Soil chemical properties for rainfed field and fields irrigated with TWW using different irrigation systems (**)

Field	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Mn (mg/l)	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Zn (mg/l)
TWW	181.2	-	29.7	0.26	0.06	< 0.03	< 0.01	< 0.08	0.06
BS	53.36 b	4.80 a	4.00 a	71.12 ab	89.88 a	0.676 a	nd(***)	34.633 ab	4.8167 a
BD	54.09 b	2.67 a	2.00 A	102.14 ab	81.92 ab	0.706 a	Nd	31.189 ab	4.6933 a
BR	31.93 b	3.60 a	2.44 a	46.38 b	68.93 b	0.681 a	Nd	23.544 b	4.1656 a
AS	316.23 a	5.91 a	5.38 a	193.14 a	92.34 a	0.749 a	Nd	47.111 a	4.5278 a
	Pr >F <0.0001	Pr >F 0.2501	Pr>F 0.1655	Pr >F 0.1372	Pr >F 0.0693	Pr >F 0.6588		Pr >F <0.0001	Pr >F 0.4430

(**) Means with the same letter in each column are not significantly different at $P < 0.05$.
(***) nd means not detected.

Conclusion

The findings of this study, coupled with the fact that JS893/2006 demands that fodder crops (alfalfa and barley) should be dried for two weeks before being fed to animals indicate that using sprinkler irrigation could be as safe as drip irrigation when the good quality of TWW is applied in arid and semi-arid regions. Using TWW for agricultural irrigation requires that salinity should be controlled through leaching to avoid salt accumulation in the root zone and its negative impact on soil productivity. Further research into TWW reuse using sprinkler irrigation systems is needed to investigate its long-term impact on soil and crop quality.

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تاثير استخدام المياه العادمة المعالجة على التربة والمحاصيل المروية بنظامي التنقيط والرش

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الملخص

تسمح المعايير الأردنية (2006 / JS893) التي تحكم إعادة استخدام المياه العادمة المعالجة (TWW) في الري الزراعي فقط باستخدام الري بالتنقيط و/ أو بالري السطحي، وتحظر استخدام الري بالرش، باستثناء ملاعب الجولف، وأثناء الليل فقط، وتم إجراء هذا البحث لدراسة تأثير استخدام الرّي بالتنقيط والرش بالمياه العادمة المعالجة (TWW) ومياه الامطار على التربة وجودة المحاصيل. تم ري ثلاثة حقول باستخدام TWW: (1) البرسيم باستخدام الرش (AS)، (2) الشعير باستخدام الرش (BS)، و(3) الشعير باستخدام التنقيط (BD) وحقل شعير اخر يعتمد على مياه الأمطار فقط (BR). وأظهرت النتائج عدم وجود بكتيريا قولونية (<3 MPN / جم) على النباتات (البرسيم والشعير) المروية باستخدام TWW بطريقتي التنقيط أو الرش، وفي حال تواجدها يمكن أنْ يعزى الوجود الضئيل للبكتريا القولونية في الأجزاء الوسطى والسفلية من نبات البرسيم إلى وقت أخذ العينات وكثافة أوراق البرسيم. أوضحت النتائج أنّ أنظمة الرّي ليس لها تأثير كبير على الخصائص الكيميائية للتربة، ومع ذلك فان تأثير TWW على الخصائص الكيميائية كان كبيرا، ويمكن ان تعزى الزيادة الكبيرة في الخصائص الكيميائية للتربة الى ما تحتويه المياه العادمة المعالجة وكمياتها المستخدمة.

الكلمات الدالة: المياه العادمة المعالجة، البرسيم، الشعير، الرّي، الرش، التنقيط، مياه الامطار، بكتيريا قولونية، المغذيات.