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Enhanced fodder production using treated wastewater from a pilot constructed wetland system

Riyad Abusamra[a], A. Rasem Hasan[b,c,*], Abdallah Alimari[d], Muhannad Alhajhussein[d], Mohammed Saleh[d], Rashed Al-Sa'ed[e], Raed Alary[d]

[a]*Faculty of Graduate Studies, Palestine Technical University Kadoorie, Tulkarem, Palestinian Authority, Tel. +970569569666; email: r.r.abusamra@students.ptuk.edu.ps*
[b]*Water and Environmental Studies Institute, An-Najah National University, P.O. Box 7, Nablus, Palestinian Authority, Tel. +970597511514; email: mallah@najah.edu*
[c]*Civil Engineering Department, An-Najah National University, P.O. Box 7, Nablus, Palestinian Authority*
[d]*National Agricultural Research Center (NARC), Ministry of Agriculture, Jenin, Palestinian Authority, Tel. +972599394855; email: omari_abd@yahoo.com (A. Alimari), Tel. +972598999768; email: alhajhussein@yahoo.com (M. Alhajhussein), Tel. +972599132786; email: muh.saleh89@gmail.com (M. Saleh), Tel. +972597033110; email: raedalary@yahoo.com (R. Alary)*
[e]*Institute of Environmental and Water Studies, Birzeit University, Birzeit, Palestinian Authority, Tel. +972599999820; email: rsaed@birzeit.edu (R. Al-Sa'ed)*

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ABSTRACT

Constructed wetlands (CWs) are nature-based systems used to treat and reuse recycled water in beneficial applications. This study investigated a pilot system of horizontal and vertical surface flow constructed wetlands and monitored its efficacy in treating domestic wastewater and the effluent quality for reuse in fodder crops irrigation. Treated wastewater was used to irrigate three fodder crops: barley (*Hordeum vulgare*), vetch (*Vicia sativa*), and clover (*Trifolium*). Each crop was planted in 18 pots, 9 irrigated with treated wastewater and 9 irrigated with freshwater. The results showed that CWs achieved more than 75% organic material removal and 18% nitrogen removal, with treated effluent complying with the legal requirements for effluent reuse in fodders irrigation. In addition, irrigation with treated wastewater can produce a fresh weight of fodders with protein content (9%–14%) almost similar to those irrigated with freshwater (8%–16%). Crops irrigated with treated wastewater showed an enhanced water use efficiency (WUE) compared to those irrigated with freshwater. WUE (kg/m^3) increased from 10.2 to 14.3 for barley, 9.9 to 22.8 for vetch, and 31.5 to 49.8 for clover. CWs as low-cost treatment solutions contribute positively to the economy and enhance food production's value chain in Palestinian rural communities.

Keywords: Constructed wetlands; Rural wastewater; Food security; Fodder production

1. Introduction

Water is crucial for life and an essential condition for civilization's existence. Nowadays, the water demand is increasing severely as the world population grows exponentially. The world's population is expected to increase by 2 billion in the next three decades, from 7.7 billion in 2019 to 9.7 billion in 2050 [1]. Such population growth is creating a continuous and growing pressure not only on water but also on other natural resources, including food and energy sources.

* Corresponding author.

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Palestine, as one of the MENA regions, has more than 75% arid to semiarid area. The domestic consumption of water in Palestine in the years 2012 to 2018 increased from 77 to 87.3 L/cap/d [2]. The population growth, change in living standards, climate changes, and the development of industry and tourism sectors have increased the demand for freshwater [3]. Besides, the political issue (the Palestinian-Israeli conflict) complicated the situation. According to the Oslo II agreement (Article 40) entitled "Water and Sewage" there are provisions regarding the water allocation between the Palestinian and Israeli sides [4]. The allocated share to the Palestinians was about one-fourth of the Israeli allocated share (Oslo II, 1995). In this article, the Palestinian needs are growing by 70–80 MCM yearly. Due to the aforementioned reasons, the water supply today cannot meet the demand from Palestinians. Because they receive only 75% of the amount of the agreed water [5].

Currently, the agricultural sector is the main water consumer, as it is estimated to consume around 70% on average of freshwater resources [2]. Accordingly, the agriculture activities share reached 45% of the total water in Palestine in 2015 [6]. Currently, the annual agricultural usage of water is estimated to be 150 MCM (60 MCM in West Bank), which is equivalent to 38.6% of the total available water [2].

Livestock production is an essential constituent of food security. Most feed and coarse fodder (high-cellulose feed, such as hay, straw, and grass) to feed dairy cattle are imported [7]. In Palestine, 12.8% of total agricultural holdings are livestock, estimated to be equivalent to 14,241 families [7], with around 70% of the cost for animal feeding [8]. Globally, over 33% of croplands are dedicated to growing fodders, with 26% of the earth's ice-free land is dedicated to grazing [9]. Around 29% of water used in agriculture is utilized for livestock production [10].

Treated wastewater is an opportunity to reduce the stress on freshwater and its high content of nutrients that can be a substitute for mineral fertilizers. The use of treated wastewater in irrigation is a worldwide practice, and many studies have been published on it [11–18]. The reuse of treated wastewater reduces the amount of freshwater used for irrigation. Climate change and pollution caused by anthropogenic activities have considerably reduced the available quantity of water [19]. As a solution to such stress on freshwater, reuse of treated wastewater in irrigation was proposed [20–22], and specifically claimed to be safe when used for fodder irrigation with risk parameters are under those recommended by WHO [22]. However, farm measures and management [20] could reduce the risk. For this, it is preferred to use non-conventional water resources as treated wastewater in arid and semiarid countries. A review of 73 published studies 1989 up to 2020 on the reuse of treated wastewater for animal feeding growing crops, found that the most investigated crop is rice, followed by maize [23]. The public and social acceptance of using the treated wastewater in agricultural activities were also investigated [24], and revealed that 75% of the householders were willing to use treated wastewater to irrigate the crops. However, the study found that the main obstacle is the availability of freshwater resources for irrigation and the limited sources of treated wastewater at the same site [24]. Though, traditions and human psychology negatively affected the acceptance of wastewater reuse [25], but women accepted more than men the use of treated wastewater in irrigation to achieve their goals of more economic and social values [26]. Also, the main accepted uses of treated wastewater are in agriculture and landscaping and that education level and knowledge of wastewater reuse are the main factors affecting the respondents' choices [27]. In the MENA region, Jordan has established a freshwater reallocation policy for domestic use and allocating of treated wastewater to agricultural use [28].

Moreover, the regulations in Palestine prohibit the unrestricted reuse of treated wastewater. Treated wastewater reuse can significantly alleviate the water scarcity in Palestine and fit the complexity of the geopolitical context [29]. The reuse of TWW have high potential due to different perspective; among these is the absence of other alternatives and the fact that raw wastewater is an environmental problem [30,31].

Constructed wetlands (CWs) are well known and practiced worldwide as a treatment process. CWs are recommended alternatives for wastewater treatment in developing countries, especially for those with warm climates [32]. Constructed wetlands can save energy by half [33]. Such systems have started in Germany in 1950s [34]. CWs could be classified according to the flow direction (horizontal and vertical) [35]. These two common systems are the most spread, but vertical flow (VF CWs) systems are getting more popular at present [35]. CWs have many advantages: water purification, water storage, carbon, and macro micronutrient recycling [36]. Moreover, different types of CWs could be attached to increase treatment efficiency, especially for nitrogen [34]. Hybrid systems comprise most frequently vertical (VF) and horizontal (HF) systems arranged in a staged manner. The most common kind of plants used in CWs in Europeis *Phragmites australis* [37]. In Palestine, the constructed wetland technology is considered a new technology. Yet, it is not widespread even though it started in 2003–2004 and is used successfully in a few small villages [38], and installed in variable treatment capacities, from pilot to large-scale treatment units [39]. Rural communities lack financial and human resources to install and sustain mechanized sanitation facilities, CWs offer the best alternative nature-based solutions, consuming less energy, with low maintenance and repair, and minimal biosolids production [39]. In addition to those CWs implemented at Birzeit University campus [40,41] near Birzeit town and National Agriculture Research Center (NARC) in Jenin governorate. The performance of different direction flow constructed wetlands in Palestine was studied with a concentration on the treatment efficiency utilizing the removal of the biochemical oxygen demand (BOD), and total suspended solids (TSS) [38,40] in addition nitrogen and phosphorous [42]. In general, the performance of existing wetlands in Palestine is medium to good, according to Palestinian and WHO regulations of treated wastewater. Removal of organic content, as represented by BOD and chemical oxygen demand (COD), was acceptable according to the guidelines, while nitrogen and phosphorus removals were medium. The establishment of CWs in other rural communities in Palestine was recommended providing the low operational and preventive maintenance requirements of such technology.

The main purpose of this research study is to evaluate the efficiency of CWs for the treatment of domestic wastewater and to assess the impacts of treated wastewater from the CWs on the production of three fodder crops.

2. Material and methods

2.1. Wastewater treatment and samples analysis

This experiment was carried out inside the research station at the NARC in Qabatya – Jenin, north of the West Bank. A pilot CW was constructed in 2018 with a septic tank (2 m^3) followed by two treatment trains CWs. Each train has a horizontal subsurface flow tank followed by a vertical surface flow tank. Each tank is 0.5 m^3. The CW tanks were filled with natural stones of varied sizes and planted with common reed plants (*Phragmites australis*). The plant density was 100 plants/m^2. The plant is used to treat an average of 5 m^3/d of wastewater collected from the research station. During the experiment, the CW treatment pilot was monitored, samples were collected for all treatment stages, and weekly analysed for BOD, COD, and faecal coliform, all according to [43].

2.2. Crops production and monitoring

Seeds of local varieties of *Hordeum vulgare* (commonly known as barley), *Vicia sativa* (vetch), and *Trifolium* (clover) crops were obtained from NARC. The common names for these crops will be used in the rest of the paper. The local varieties of these crops were chosen to have similarities with the farmers' practices in the local community. The weight of 1,000 seeds was measured for the three crops by weighing 100 seeds for three samples and taking the average of this weight for each crop, and calculated as:

- (50 g/1,000 seeds) for barley
- (2 g/1,000 seeds) for clover
- (15 g/1,000 seeds) for vetch

The seeds were planted inside 8 litters' plastic pots, with (0.09 m^2) surface area, filled with a mixture of 1:1 v/v peat moss to silty clay soil (*Terra Rossa*), which is heavy, rich soil, neutral pH, with electrical conductivity (EC_e) as 0.8 dS/m. The planting density inside the plots is calculated on the bases of field plant density according to the farmers' practices as

- Barley at 13 g/m^2 (1.17 g/pot).
- Clover at 4 g/m^2 (0.36 g/pot). The seeds amount was mixed with fine sand to guarantee good distribution of seeds in the pots.
- Vetch at 15 g/m^2 (1.35 g/pot).

The experimental design was completely randomized with two treatments for each crop replicated nine times and placed inside the protected greenhouse.

The pots were irrigated for 11 d with freshwater from the planting until the germination of 90% of the seeds. Then, the drip irrigation system for each treatment is placed, the irrigation is started for each treatment, and the growing season was from late December 2020 up to mid-April 2021.

The plant growth was monitored during the growing period, and samples of the following plant parameters were collected: plant growth rate (plant height) (weekly), fresh weight at cutting date, roots length, leaves and flowers number/plant, and total protein content.

Statistical analysis of the characteristics of grown crops was carried out using GenStat statistical software [44]. Student *t*-test was used to determine the significance level between results obtained due to irrigation by the fresh and treated wastewater [45].

2.3. Climatic data and irrigation requirements

The crop water requirements (CWR) Is a term that refers to the depth of water required to be applied to meet the consumption via evapotranspiration [46]. Allen et al. [47] reported a guideline for CWR calculation. Accordingly, the procedure starts with the energy forces affecting the evaporation, in other words, the reference evapotranspiration (ET_o) (the climatic demand). The reference evapotranspiration is the depth of water lost from a field planted with an alfalfa crop of 12–15 cm in height when it is well covered by a disease-free crop [47].

The irrigation requirements during the experiment were calculated according to FAO modified Penman–Montieth formula [Eq. (1)] [48]. No fertilizers and no pesticides were added to eliminate any effect of factors affecting growth.

$$ET_c = K_c \times ET_o \quad (1)$$

where ET_c: crop water requirement (mm/d); K_c: crop coefficient; ET_o: reference evapotranspiration

Reference evapotranspiration (ET_o) in the study area is needed to calculate the crop water requirements (ET_c). Table 1 depicts the long-term averages of the climatic parameters collected for Jenin District from the Palestinian Ministry of Agriculture (MoA) and averaged from 1968 to 2018 [49]. Reference evapotranspiration was computed using the FAO procedure (Fig. 1).

The reference evapotranspiration ranged from 1.55 mm/d in January to reach a maximum of 6.21 mm/d in July, with an annual average of 3.78 mm/d.

2.4. Water use efficiency

The water use efficiency (WUE) is the ratio of the produced biomass to the volume of consumed water. The effect of water quality would be better understood when comparing the water use efficiency for the crops and the connection with crop utilization of water.

The water use efficiency for the three crops under the different water qualities was calculated based on the water consumption and the fresh and dry weight measurements.

3. Results and discussion

3.1. Quality of treated water from the CWs pilot system

Over the research period, the results of the wastewater analysis from the different stages of the CW pilot system installed at NARC are shown in Table 2. The raw wastewater

Table 1
The long-term average climatic parameters for Jenin and over the period 1968–2018 [49]

Month	Min. Temp.	Max. Temp.	Humidity	Wind	Sun	Radiation
	°C	°C	%	km/d	h	MJ/m²/d
January	9.1	17.5	72	104	5.6	10.5
February	10	18	74	118	5.3	12.1
March	12.2	21.9	67	112	7.5	17.4
April	15.1	26.3	62	119	8.5	21.2
May	18.6	28.9	60	131	9.7	24.2
June	22.7	31.7	62	136	11.6	27.3
July	25.4	33.4	64	139	11.5	26.9
August	26.5	33.8	66	135	10.8	24.8
September	24.7	32.4	65	107	9.4	20.7
October	21.2	30.1	62	86	8	16
November	14.8	24.1	66	82	6.7	12
December	11.2	19.2	70	90	5.7	9.9
Average	17.6	26.4	66	113	8.4	18.6

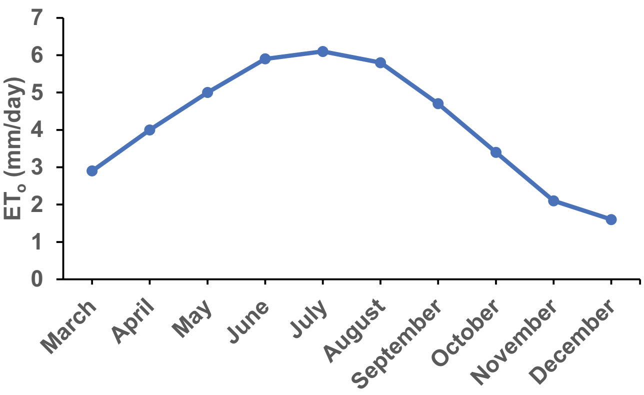

Fig. 1. The averaged long-term reference evapotranspiration in Jenin, and for the period 1968–2018 [49].

Table 2
Water quality at the different stages of the CW pilot at NARC

Sampling stage	BOD (mg/L)	COD (mg/L)	Total nitrogen (mg/L)
Untreated wastewater	230	520	40
After septic tank	91	375	40
After CWL Tank 1	35	160	30
After CWL Tank 2	23	119	32
Treated water tank	20	81	25
Freshwater [control]	5	60	18

is similar to the domestic wastewater in Palestine, and the treated wastewater is within the limits accepted for fodders irrigation considering the Technical Regulation TR34 issued by Palestine Standards Institution [50]. The average temperature was 13.3°C in January and February 2021, so the bacterial activity is expected to be minimum [51]. Organic contents such as BOD and COD after treatment were less than or equal to the limits of Type A of Palestinian guidelines; 20 and 100 mg/L, respectively. However, the total nitrogen was within the highest limits for the guidelines, close to 30 mg/L, but removed by18.6% which is low compared to the published data as 58% [52]. This reduction supports the explanation that the treatment unit efficiency is reduced due to the low temperature in winter that led to a lower microorganisms' activity, and providing that soluble nitrogen contents will be removed biologically only and hardly with any physical action. Freshwater analysis indicated a high content of total nitrogen (18 mg/L) where the maximum accepted limit of total nitrogen is 10 mg/L (equivalent to 50 mg/L as nitrate) [53].

3.2. Crop water requirement

The CWR was calculated based on the modified FAO – Penman Montieth formula. The climatic parameters (Temperature, Wind speed, humidity, and Solar radiation) for the last 40 y were obtained from the Palestinian Meteorological Department database (Table 1). The ET_o was computed using FAO – CROPWAT software, which utilizes Eq. (1). For this study, the reference evapotranspiration (ET_o) was 1.55 mm/d in January and 4 mm/d in April. Regarding the CWR calculations, the ET_o was multiplied by the crop growth stage factor [47]. In this study, the CWR value was 207.5 mm, which is almost 50% of previously published data as 557 [54], and 503 mm [55].

The crop water requirements were calculated by dividing each month of the growing period for specific three periods (1, 2, and 3, on average, 10 d for each period) (Table 3). Also, in the FAO method, growth stages (Ini, Dev, Mid, and Late) were determined based on monitoring, and corresponding crop coefficients (K_c) were introduced for each stage. During the experiment period, the higher irrigation requirements of the vetch were considered and used to avoid any water stress coming from irrigation shortage and to limit the effect of the water quality, not the quantity.

Table 3
Irrigation requirements for clover, vetch and barley

Month	Period	Clover				Vetch				Barley			
		Stage	K_c	ET_c		Stage	K_c	ET_c		Stage	K_c	ET_c	
				mm/d	mm/period			mm/d	mm/period			mm/d	mm/period
Dec.	2									Init	0.3	0.47	1.9
Dec.	3	Init	0.4	0.62	5.6	Init	0.85	1.32	11.9	Init	0.3	0.47	5.1
Jan.	1	Init	0.4	0.62	6.2	Init	0.85	1.32	13.2	Dev	0.47	0.74	7.4
Jan.	2	Dev	0.46	0.72	7.2	Dev	0.85	1.32	13.2	Dev	0.79	1.23	12.3
Jan.	3	Dev	0.58	0.96	10.6	Dev	0.87	1.44	15.8	Mid	1.07	1.76	19.4
Feb.	1	Dev	0.7	1.23	12.3	Dev	0.89	1.56	15.6	Mid	1.09	1.93	19.3
Feb.	2	Dev	0.81	1.52	15.2	Dev	0.91	1.69	16.9	Mid	1.09	2.05	20.5
Feb.	3	Mid	0.9	2	16	Mid	0.92	2.04	16.3	Mid	1.09	2.43	19.4
Mar.	1	Mid	0.91	2.33	23.3	Mid	0.92	2.36	23.6	Mid	1.09	2.8	28
Mar.	2	Mid	0.91	2.65	26.5	Mid	0.92	2.68	26.8	Late	1.07	3.1	31
Mar.	3	Mid	0.91	3	33	Mid	0.92	3.04	33.5	Late	0.81	2.68	29.5
Apr.	1	Mid	0.91	3.36	33.6	Mid	0.92	3.4	34	Late	0.52	1.91	19.1
Apr.	2	Late	0.89	3.61	18.1	Late	0.88	3.57	21.4	Late	0.31	1.25	6.2
Total (mm/growing season)					207.5				242.5				219.1

3.3. Crops physical characteristics

3.3.1. Barley

The results in Table 4 indicate significant differences between plants irrigated with treated wastewater and those irrigated with freshwater at a confidence level of 95%, and for all characterized physical parameters except for roots length. Fresh weight is higher by 50% for plants irrigated with treated wastewater (81.5–166.7 g/plant) than those irrigated with freshwater (70.3–105.2 g/plant) (Fig. 2). Also, plants irrigated with treated wastewater were longer at an average of 67.4 cm, than those irrigated with freshwater with an average of 52.2 cm (Fig. 3).

The average fresh weight for plants irrigated with treated wastewater was 122.3 g/plant, and 85.9 g/plant for freshwater irrigated plants. Providing the experimental conditions of seeds weight as 50 g/1,000 seeds, pots surface area of 0.09 m^2/pot, and sowing rate of 23 seed/pot, this will result in a planting density as 13 kg/dunam (1 dunam = 0.1 ha). Assuming a germination rate of 90%, fresh weights of barley will result in biomass of 31,275 and 21,957 kg/dunam for irrigation with treated wastewater and freshwater, respectively. Water content of produced barley was 88%, and so dry weight of barley will be 3,751 and 2,635 kg/dunam for irrigation with treated wastewater and freshwater, respectively. When all produced barley is baled, providing a standard bale of 25 kg with a current selling price at farm gate about 8.57$, irrigation with treated wastewater will produce 150 Bale/dunam with total revenue of 1,286$/dunam, while for under freshwater irrigation, the produced barley will be 105 Bale/dunam with total revenue of 903.4$/dunam. These results are in agreement with previously published data [56], where very high yield for barley irrigated with treated wastewater compared with freshwater was noticed [57]. Also, a significant increase in barley biomass yield (grain and straw yield) was documented when plants were irrigated with treated wastewater [58]. Barley when used to produce both grains and straw, more profits will be expected than the calculation above.

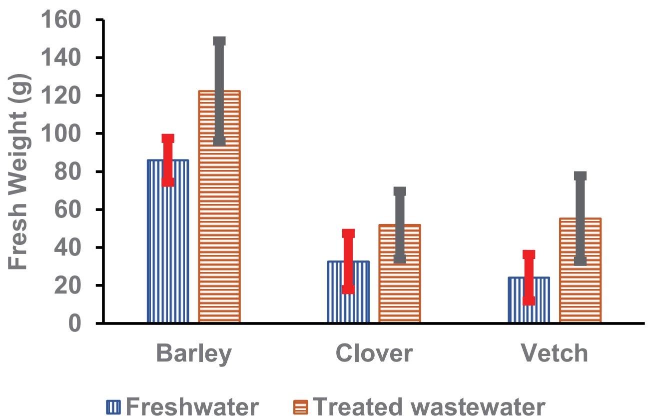

Fig. 2. Fresh weight of grown crops and according to the type of irrigation.

3.3.2. Clover

Clover fresh weight when irrigated with treated wastewater is higher than plants irrigated with freshwater, with a significant difference under a confidence level of 95% (Table 5). The average weight ranges from 20.0 to 65.9 g/plant with an average of 51.8 g/plant in the plants irrigated with treated wastewater compared to 15.71–55.16 g/plant with an average of 32.6 g/plant for those irrigated with freshwater. Differences in leaves and root lengths were not significant.

Table 4
Physical characteristics of grown barley with statistical analysis (2-tailed *t*-test)

Criteria	Irrigation water	*N*	Range	Std. dev.	Std. error mean	*t*-test	df	*p*-value
No. of spikes	Fresh	9	1–4	1.093	0.364	–6.904	16	0.000*
	Treated	9	4–8	1.225	0.408			
No. of tillers	Fresh	9	2–5	0.882	0.294	–2.966	16	0.009*
	Treated	9	3–6	0.866	0.289			
Plant length (cm)	Fresh	9	46.4–52.6	2.974	0.991	–4.299	16	0.001*
	Treated	9	55.0–84.7	10.180	3.393			
Root length (cm)	Fresh	9	6.3–13.0	2.376	0.792	–0.004	16	0.997
	Treated	9	6.3–13.0	2.373	0.791			
Fresh weight (g)	Fresh	9	70.3–105.2	11.554	3.851	–3.779	16	0.002*
	Treated	9	81.5–166.7	26.475	8.825			

Table 5
Physical characteristics of grown clover with statistical analysis (2-tailed *t*-test)

Criteria	Irrigation water	*N*	Range	Std. dev.	Std. error mean	*t*-test	df	*p*-value
No. of leaves	Fresh	6	2–5	1.05	0.43	–2.45	10	0.035*
	Treated	6	4–5	0.52	0.21			
Leaves length (cm)	Fresh	6	30.1–67.3	11.84	4.84	–1.30	10	0.22
	Treated	6	49.0–59.6	3.59	1.46			
No. of flowers	Fresh	6	1–3	0.63	0.26	–2.08	10	0.05*
	Treated	6	2–4	0.75	0.31			
Root length (cm)	Fresh	6	7.6–16.1	3.67	1.50	1.96	10	0.08
	Treated	6	7.1–11.1	1.44	0.59			
Fresh weight (g)	Fresh	6	15.7–55.2	14.81	6.05	–2.02	10	0.049*
	Treated	6	20.0–65.9	17.87	7.29			

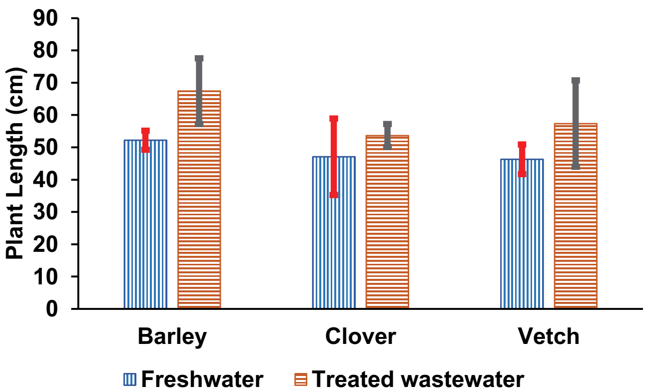

Fig. 3. Plant length of grown crops and according to type of irrigation.

As shown in Figs. 2 and 3, the length and fresh weight for plants irrigated with treated wastewater are higher, and this is due to the nutrients existing in the treated wastewater, as stated by [23,59].

Providing the same analysis for barley and under the experimental conditions of clover seeds weight as 2 g/1,000 seeds, pots surface area of 0.09 m^2/pot, and sowing rate of 180 seed/pot, this will result in clover planting density as 4 kg/dunam. Assuming a germination rate of 90%, fresh weights of clover will result in biomass of 103,640 and 65,280 kg/dunam for irrigation with treated wastewater and freshwater, respectively. At a water content of 88%, the dry weight of clover will be 12,425 and 7,833 kg/dunam for irrigation with treated wastewater and freshwater, respectively. When all produced clover is Baled, providing a standard bale of 25 kg with a current selling price at farm gate about $6.86 irrigation with treated with wastewater will produce 497 Bale/dunam with total revenue of 3,408$/dunam, while for freshwater irrigation, the produced clover will be 313 Bale/dunam with total revenue of 2,149$/dunam. These results agree with data in literature [56,60] for the production rates of clover under similar conditions using treated wastewater for agricultural irrigation.

3.3.3. Vetch

Vetch plants irrigated with treated wastewater also have higher results than those irrigated with freshwater (Figs. 2–4); however, this difference is not significant, at a confidence level of 95%, except for the fresh weight and root lengths (Table 6). Fresh weight averaged at 55.2 g/plant (25.6–86.6) for irrigated plants with treated wastewater, while for those irrigated with freshwater, the fresh weight averaged at 24.1 g/plant (6.1–40.9). Roots were mostly longer

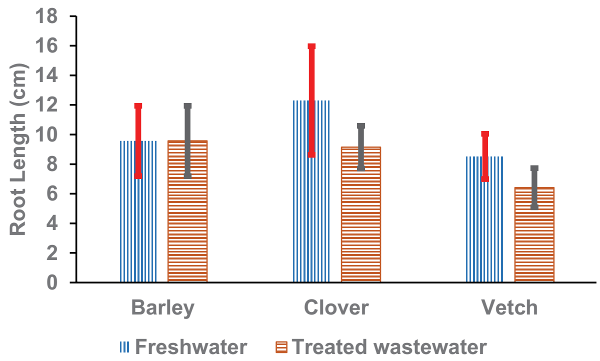

Fig. 4. Root length of grown crops and according to type of irrigation.

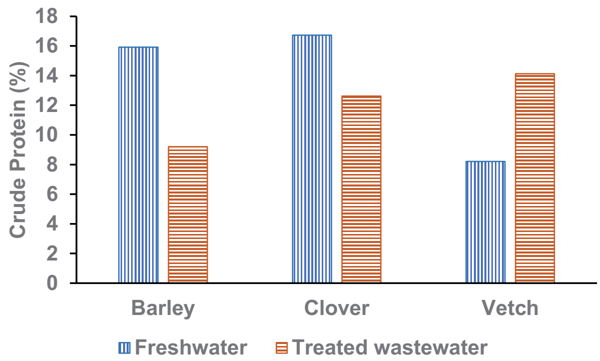

Fig. 5. Crude protein content for the different crops grown on treated wastewater and freshwater (control).

for plants irrigated with freshwater than those irrigated with treated wastewater.

The results indicate that the plants would have higher fresh weight and length when irrigated with treated (Table 6), similar to published results [61]. Regarding the dry weight, irrigation with treated wastewater produced 33.83 g/plant compared to 22 g/plant for plants irrigated with freshwater.

Providing the same analysis for barley and clover, but with seeds weight as 15 g/1,000 seeds, and sowing rate of 90 seed/pot, the planting density for vetch will be 15 kg/dunam. The fresh weight of vetch will result in a biomass of 55,240 and 24,090 kg/dunam, and the dry weight will be 6,629 and 2,891 kg/dunam for irrigation with recycled water and freshwater (control), respectively. Balling all produced vetch, assuming a standard bale (25 kg) with a selling price of 6.86$ at farm gate, irrigation with recycled water will produce 265 Bale/dunam and a total revenue of 1,818$/dunam compared with freshwater irrigated clover (116 Bale/dunam) with a total revenue of 793$/dunam.

3.3.4. Crude protein

The results of crude protein analysis for the three crops indicate the effect of changing the water quality (i.e., the irrigation with treated wastewater) on the nutritional value of the forage crops. These results show a different pattern, where the crude protein content of plants irrigated with treated wastewater was less than plants irrigated with freshwater (Fig. 5). The protein content was higher for vetch in the plants irrigated with treated wastewater.

The results of clover, in general, agree with the published data, where the protein content of clover was 15%–25% [62], however, the results in the experiment are lower for clover. It could be justified that the high increase in fresh weight reduced the protein in the plant tissues. This is supported by the results of vetch, where the protein content in plants irrigated with treated wastewater is higher than those irrigated with freshwater. Moreover, the protein content in barley was higher than the content published by [63], where the protein content is 9.21% in the results compared to 3.8% for barley straw. The suggested content is for straw separately, while the content for grain is 11%. The sampling method affects the protein content; the samples are composite samples of the whole plant parts in the experiment. The protein content is lower in the results and higher than the straw alone. This justification agrees with the published data [64] where the protein content of vetch plants is 23%, while [65] presented a value exceeding 6%.

3.3.5. Water use efficiency

Water use efficiency for the three crops planted in the experiment are presented in Fig. 6 as an average of all irrigated plants. The results ranged from 12 kg/m^3 for both vetch and barley to 37.7 kg/m^3 for clover under freshwater irrigation. While for plants irrigated with treated wastewater, WUE in kg/m^3 averaged at 17.1 for barley, 27.3 for vetch, and 59.7 for clover.

The results of WUE for biomass in barley as 17.1 are lower than the published data as 11.3–22.3 kg/mm [66], but for the plants irrigated with treated effluent, the results agree with the published values. While for clover, the WUE is higher than [55] as 15–20 kg/m^3, but it agrees with other literature [67]. The increase is caused by the enhanced conditions of availability of nutrients in the treated wastewater as explained by [54], therefore the production was higher as shown in the fresh weight results as well.

3.3.6. Applicability of treated wastewater in the developing countries

Rainfed farming is the dominant agricultural activity in Palestine, covering approximately 77% of the total area. It covers approximately 02.2 million dunams of the pasture area, but the available does not exceed 621 thousand dunams. The shortage leads to a decrease in the pastoral load and overgrazing practices. The productivity of the pastures is low due to the low rainfall, which does not meet the demand of the livestock sector for forages [2]. The alternative will be the use of green forages produced under irrigation conditions, and in particular, the use of wastewater irrigation. This way, suitable green fodder production would be achieved under the prevailing water-scarcity conditions [68]. In this study, the effluent from CW was utilized in irrigation to enhance the production of some fodders. Thus, the limitation in the water

Table 6
Physical characteristics of grown vetch with statistical analysis (2-tailed *t*-test)

Criteria	Irrigation water	*N*	Range	Std. dev.	Std. error mean	*t*-test	df	*p*-value
Leaves length (cm)	Fresh	9	8.2–18.3	3.526	1.175	0.84	10	0.422
	Treated	9	10.8–19.0	3.262	1.087			
Plant length	Fresh	9	38.8–53.7	4.610	1.537	–1.57	16	0.136
	Treated	9	44.6–78.9	13.370	4.457			
No. of flowers	Fresh	7	1–6	1.574	0.595	–0.77	14	0.453
	Treated	9	1–7	1.944	0.648			
Root length (cm)	Fresh	9	6.2–10.8	1.534	0.511	3.13	16	0.006*
	Treated	9	4.8–8.9	1.322	0.441			
Fresh weight (g)	Fresh	9	6.1–40.9	12.255	4.085	–3.65	16	0.002*
	Treated	9	25.6–86.5	22.522	7.507			

resources was overcome. In addition, this practice contributes to food security in Palestine by improving the growth of produced crops, mainly barley and clover. Many studies have reported the importance of using wastewater in forage crop production. Irrigation using treated wastewater increased the yield of many forage crops such as barley, corn, and vetch [56]. Unfortunately, wastewater irrigation is an issue of concern to public agencies responsible for maintaining community health and environmental quality. Many developing countries still cannot implement comprehensive wastewater treatment programs for diverse reasons. Therefore, risk management and interim solutions are needed to prevent adverse impacts from wastewater irrigation [69]. In addition, the use of treated wastewater should be subjected to public awareness campaigns, which are highly needed to address the legal, social, economic, and institutional considerations. Farmer's participation in developing guidelines, standards, policies, and plans for this issue is very important for reuse sustainability. Wastewater treatment for reuse in agriculture can be subjected to classical benefit-cost analysis to show if the present value of future additional crop yields is more than the present value of wastewater treatment [70].

4. Conclusions

Properly operated and maintained CWs coupled with a reuse scheme for irrigation is a solution for rural wastewater treatment in Palestine, also enhances the country's food security and rural economy. Nitrogen levels in the treated wastewater by CWs improved the growth of produced crops, mainly barley and clover. Major conclusions of this research are that irrigation with treated wastewater will end up with higher yields of forage crops and higher efficiencies of water use compared to irrigation with freshwater, and so rainfed. Most of the physical characteristics of grown crops were larger when irrigated with treated wastewater, except for the root length; this mostly due to the availability of nutrients with irrigation water, and so plants were under less stress to extend their roots to access nutrients in the soil. When irrigated with treated wastewater, protein content increased for vetch among the three crops. However, clover generated higher yields and so revenues, but with much lower protein contents. The reflection of protein content data of clover produced with treated wastewater irrigation will reduce its price. Barley was the lowest in yield, protein content, and WUE when irrigated with treated wastewater. This study recommends scaling-up the irrigation and production of forage crops utilizing recycled water, especially in rural areas where this resource is available.

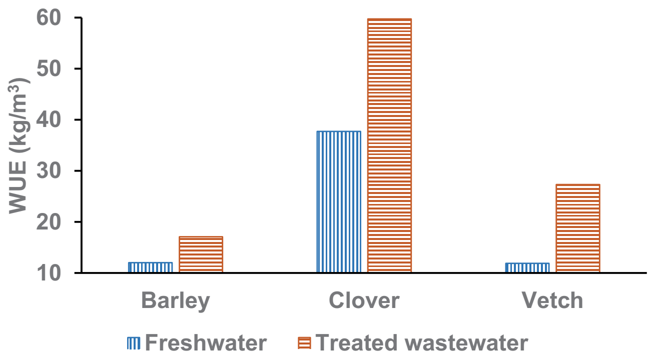

Fig. 6. Water use efficiency (WUE) for the different crops grown on treated wastewater and freshwater (control).

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