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RESEARCH

Impact of Using Treated Wastewater on Alfalfa (*Medicago sativa* L.) Crop

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ABSTRACT

Purpose: *Water is an important natural resource in Palestine; needs appropriate practices by various departments. Treated wastewater (TWW) is very important as an additional water source for irrigation. The objectives of this research were to detect the impact of using TWW on Alfalfa (Medicago sativa L.) crop characteristics, productivity, and economic feasibility at different seasons.*

Research Method: *The Alfalfa (Medicago Sativa L.) crop was seeded in the field, and TWW was used as an irrigation source from Anzah Wastewater Treatment Plant (WWTP). The water and crop samples were taken during October, 2021 end of September, 2022 to perform the necessary analyses.*

Findings and Values: *The researcher found that the use of TWW improves the productivity, quality, and profit of the crop. The profit per hectare when using TWW is more than three times the profit when using freshwater (FW). The findings confirm that TWW is safe to use for irrigation of fodder crops. The research recommended to encouraging the reuse of TWW in the agricultural system after the full treatment for fodder crops and crops, consumed freshly.*

Keywords: *Dry weight, Fresh weight, Fodder, Plant extract*

INTRODUCTION

Water is the lifeblood of the biosphere (Casper 2007). The available water resources in the Middle East are scarce, limited, fragile, and threatened (Shevah 2015); they are already exploited, especially in Palestine (Zahra 2001). The supply of freshwater (FW) is likely to decrease while demand is likely to increase (Hall *et al.* 2008). The increase in demand in the use of water resources can have remarkable effects on the environment, socio-economics, and agricultural production, as well as on sustainable development (Hoffmann 2015). Water is an important natural resource in Palestine and requires adequate management practice aimed at efficient use and distribution. Water shortage and quality degradation are constraining the economy and development of most countries (Hamdy *et al.* 2004). The agriculture sector contributes significantly to the economy in Palestine; it consumes more than 65% of the available water (Isaac *et al.* 1996).

As reliance on water continues to grow, the cost per cubic meter of irrigation water is increasing dramatically over time. It is now generally accepted that wastewater reuse in agriculture is justified on agronomic and economic grounds provided that care is taken to minimize its adverse impacts on the health and the environment (Qadir *et al.* 2007).

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The reuse of treated wastewater (TWW) for crop irrigation could contribute to reducing water shortage, support the agricultural sector, and protect groundwater resources (Libutti *et al.* 2018). TWW reuse with acceptable quality plays a crucial role as an additional water source. The reuse of TWW for agricultural irrigation can reduce the problems associated with water scarcity and shortage.

The growing demand of Palestinian communities for food and FW requires encouraging the reuse of recycled wastewater in agriculture to protect the FW. Research, development, education, awareness, and dissemination of results from other experiences have become one of the major elements in Palestine to motivate the stakeholders and communities to use TWW to improve food security. Plant testing is important to meet the plant health, to ensure safety of plant inputs, enhancing economic return to farmers, and the suitability or quality of waters for irrigation purpose (Malezieux *et al.* 2009).

Alfalfa (*Medicago sativa* L.) is the most important forage crop (El-Ramady *et al.* 2020), and it is used for pasture, silage and fertility etc. (Zarczynski *et al.* 2021). Alfalfa needs a well-drained soil (Undersander 2011), and it grows well within an annual rainfall of between 500 mm and 1200 mm (De Kock 1980). The soil pH should be within the range of 6.5 to 7.5 (Islam *et al.* 1980).

Application of fertilizers should be based on soil test results (McNeill *et al.* 2009). Primary land preparation includes ripping, ploughing and cultivation (Peigne 2007). A sowing depth of 5–10 mm for clay soils is recommended (Salo 1999). Yield is sustained for 3 to 4 years (Myint 2020).

This research is a case study on Alfalfa (*Medicago sativa* L.) crop and water management under using TWW conditions. This study involves the use of scientific research to illustrate the impact of TWW reuse on agriculture, and Alfalfa productivity during October 2021 to end of September 2022. In this study, the impact of TWW reuse on the Alfalfa (*Medicago sativa* L.) crop characteristics, quality, and productivity will be studied over one year and compared with the results of irrigation by FW. Also, an economic study will be done to determine the productivity of the crop when irrigated with TWW and compared with irrigation by FW, and to prove that the TWW is valid for agricultural usage by testable experiments.

MATERIALS AND METHODS

The water and plant samples were taken from *Anza* village in *Jenin* governorate. It is located 18 km southwest of *Jenin* City and 410 meters above sea level. FW samples were taken from an irrigation well that is fed by the *Jaba*' village well. TWW samples (secondary treatment) were collected from the *Anzah* Wastewater Treatment Plant (WWTP), located in *Anzah* village, *Jenin* governorate. FW and TWW samples were collected to represent all seasons of the year.

Five blocks were established in the field using a zig-zag pattern, each with an area of 1 m^2. Plant samples were collected from the same blocks as representative samples of the field to perform the required analyses. The study was conducted under open field conditions on a 0.1 ha plot, where Alfalfa (*Medicago sativa* L.) was cultivated. A sub-surface irrigation system (25 cm below ground level) was used.

Water samples were analyzed throughout the year to assess the quality of the TWW. Parameters included pH, electrical conductivity EC, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), water hardness, turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD_5), total carbon (TC), total organic carbon (TOC), inorganic carbon (IC), and concentrations of ions such as nitrate (NO_3^-), potassium (K^+), phosphate (PO_4^{3-}), sodium (Na^+), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), ferrous (Fe^{2+}), and others. Heavy metals (Cr^{3+}, Pb^{2+}, Al^{3+}, Cd^{2+}) were also analyzed.

Plant parameters such as chlorophyll content (using a SPAD meter), moisture content, organic matter, plant height, fresh weight, dry weight, ash content, crude protein (using a Kjeldahl apparatus), and crude fiber were measured. Plant samples were dried, ground using a mortar and pestle, and ashed in a muffle furnace at 550 °C for 5 hours. The ash was dissolved in HCl and diluted for spectrophotometric analysis of key nutrients.

Study elements (measurements)

Water analysis: pH, EC, turbidity, TDS, TSS, TS, BOD_5, COD, TC, IC, TOC, hardness, NO_3^-, PO_4^-, K^+, Na^+, Mg^{2+}, CO_3^{2+}, Cl^-, Zn^{2+}, Mn^{2+}, Fe^{2+}, and SO_4^{2-}.

Heavy metals in water: Cr^{3+}, Pb^{2+}, Al^{3+}, and Cd^{2+}.

Alfalfa (*Medicago sativa* L.) plant analysis: moisture, O.M, chlorophyll, height, fresh weight, dry weight, ash, crude protein, crude fiber, NO_3^-, PO_4^-, and K^+.

Water sampling

Water sampling and testing were conducted to observe the chemical and physical changes of the water during seasons of the year (October 2021 to end of September 2022), and to compare them with the established standards. Samples of water were collected six times during the year.

Plant sampling and extracts

Plant sampling and testing were conducted to observe the changes that occur in the plant over the year during the different seasons. A zig-zag pattern was used to ensure homogeneity in plant samples by determining five test plots in the field; the area of each plot was 1 m^2. Five samples with a weight of 1 kg were taken randomly from one point in each plot. The plant sample included shoot and leaves.

Plant samples were dried and ground using a mortar and pestle, and then placed into a muffle furnace at 550 °C for 5 hours for drying. The cooled ash of each sample was dissolved in 25 mL of 2 N HCl. After 20 minutes, the volume was increased to 250 mL with distilled water. After 30 minutes, the solution of each sample was filtered through Whatman No. 42 filter paper.

RESULTS AND DISCUSSION

The results of water analysis for FW and TWW samples from WWTP across different seasons from October 2021 to the end of September 2022 are shown in Table 1.

Based on the physical and chemical analyses conducted on FW and TWW samples, the water characteristics showed good agreement with the standards set by the Palestinian Standards Institution (PSI) and demonstrated acceptable quality for irrigating fodder crops. The results for plants irrigated with freshwater (PIFW) and those irrigated with treated wastewater (PITWW) are presented in Table 2.

Results of plant testable parameters show a positive impact on the PITWW compared to the PIFW. Plant O.M, chlorophyll, height, fresh weight, dry weight, ash, crude protein, crude fiber, NO_3^-, PO_4^-, and K^+ for Alfalfa were higher in TWW than those of FW.

Plant O.M, chlorophyll, fresh weight, dry weight, and crude protein were illustrated in Figure 1–5 respectively. Statistical analysis was done using the SPSS program, and all analysis results show significant differences (p-value $<$ 0.05).

Regarding the plant moisture, the moisture when irrigated with TWW was 75.7% compared to 77% for irrigation with FW. For Alfalfa, the moisture percentage decreased due to the increase in O.M content and nutritional value in the plant.

The crop productivity when using FW and TWW for irrigation in each month of the year is shown in Table 3 and Figure 6. From the data, the productivity in PITWW was almost twice as high as the productivity of PIFW. The plant average productivity (kg/ha) under different irrigation types during October 2021 – end of September 2022 is presented in Figure 7. The results show that using TWW increased production parameters; the highest annual production (74630 kg/ha)

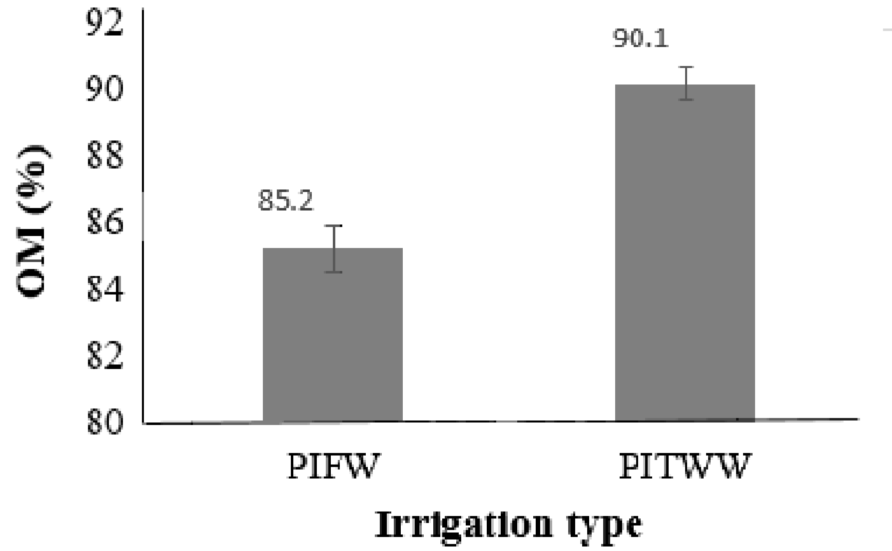

Figure 1. Average plant organic matter of plant irrigated freshwater (PIFW) and treated wastewater (PITWW) at different irrigation types during different seasons.

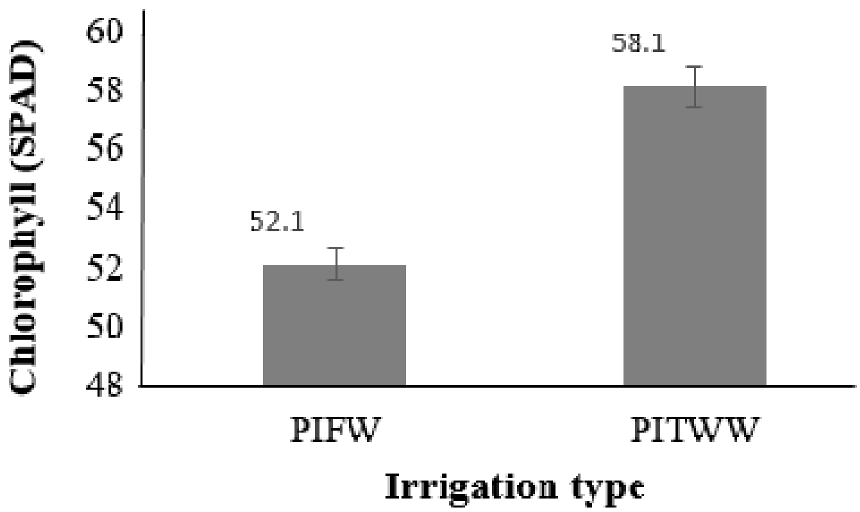

Figure 2. Plant chlorophyll average (SPAD) of plant irrigated freshwater (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

Table 1. Results of the analysis of fresh water (FW) and treated wastewater (TWW) samples from Anzah Wastewater Treatment Plant (WWTP) during different seasons.

Parameter	Unit	Avg. FW	Oct. TWW	Dec. TWW	Jan. TWW	Feb. TWW	Apr. TWW	Jun. TWW	Sept. TWW	Avg. TWW	PSI*
pH	—	7.2	7.8	7.2	7.6	7.6	7.2	6.9	7.9	7.5	6–9
EC	mS/cm	1.00	1.37	1.40	1.35	1.15	1.44	1.56	2.11	1.48	<3.1
Turbidity	NTU	1.11	20.56	7.34	8.88	13.57	33.2	83.0	41.9	29.77	NA*
TDS	mg/L	7.4	869.6	888.2	855.3	729.3	909.2	980.3	1348.2	747.4	<2000
TSS	mg/L	2.8	195.6	185.9	187.0	170.9	159.8	169.8	192.1	180	<250
TS	mg/L	10.2	1065.2	1074.1	1042.3	900.2	1069.2	1150.1	1540.3	1120.2	<2250
BOD_5	mg/L	19.2	42.2	44.8	46.1	77.6	94.2	143.4	115.4	80.53	<250
COD	mg/L	32.5	85.2	90.7	91.3	160.1	173.5	264.2	210.1	153.6	<700
TC	mg/L	0.33	102.2	104.4	97.0	148.0	177.2	258.6	227.9	159.3	NA
IC	mg/L	0.17	90.3	91.8	83.7	115.9	136.4	185.2	171.6	125	NA
TOC	mg/L	0.16	11.9	12.6	13.3	32.1	40.8	73.4	56.3	34.3	NA
Hardness	mg/L	1.0	340.8	332.9	250.9	242.1	290.4	320.4	347.3	303.5	<350
NO_3^-	mg/L	0.01	0.3	1.0	1.5	0.45	1.2	1.8	0.5	0.96	<50
PO_4^-	mg/L	0.3	15.1	16.8	17.0	24.7	27.1	32.0	23.3	22.3	NA
K^+	mg/L	0.5	95.0	59.0	54.0	45.0	120.0	280.0	53.0	100.9	NA
Na^+	mg/L	1.2	122.3	118.3	116.5	114.6	115.2	118.3	58.4	109.1	<230
Mg^{2+}	mg/L	0.02	30.5	28.2	19.3	16.8	23.8	30.8	38.0	26.8	<60
CO_3^{2+}	mg/L	4.1	250.0	255.0	337.0	126.0	350.0	515.5	490.0	331.9	<520
Cl^-	mg/L	2.1	220.0	210.0	202.0	196.0	302.0	318.0	296.0	249.1	<350
Zn^{2+}	mg/L	n.d*	0.10	0.08	0.03	0.01	0.01	0.10	0.01	0.05	<2
Mn^{2+}	mg/L	n.d	0.15	0.30	0.10	0.15	0.15	0.15	0.19	0.17	<0.2
SO_4^{2-}	mg/L	n.d	35.0	50.0	50.0	69.0	45.0	30.0	76.0	50.7	<1000
Fe^{2+}	mg/L	n.d	0.05	0.04	0.02	0.03	0.02	0.02	0.10	0.04	<5
Heavy metals											
Cr^{3+}	mg/L	n.d	0.012	0.013	0.015	0.014	0.018	0.027	0.021	0.017	<0.1
Pb^{2+}	mg/L	n.d	0.061	0.072	0.134	0.111	0.121	0.162	0.176	0.120	<5
Al^{3+}	mg/L	n.d	0.001	0.001	0.008	0.002	0.010	0.019	0.031	0.010	<5
Cd^{2+}	mg/L	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	<0.01

*PSI: Palestinian Standards Institution for Fodder Crop;
NA: Not Applicable;
n.d: Not Detected.

was obtained with TWW compared to FW production (51370 kg/ha). This is because the TWW contains essential nutrients for the plant without the need to add fertilizer, thereby increasing the nutritional value and productivity of the plant. Statistical analysis was done using the SPSS program, and the analysis results of the figure below show significant differences in the parameters (p-value < 0.05).

Economic study

Crop production when irrigated with FW:

The production cost for 1 ha (10,000 m^2):

Productivity/year = 52,530 kg/ha/year

Table 2. The analysis results of Alfalfa (*Medicago sativa* L.) plant samples collected from the study area at different seasons.

Parameter	Unit	Avg. PIFW	Oct. PITWW	Dec. PITWW	Jan. PITWW	Feb. PITWW	Apr. PITWW	Jun. PITWW	Sep. PITWW	Avg. PITWW
Moisture	%	77.0	77.0	77.8	76.1	79.2	74.1	71.8	73.6	75.7
O.M	%	85.2	90.5	90.1	90.4	88.6	89.1	91.1	90.7	90.1
Chlorophyll	SPAD*	52.1	56.9	47.4	49.8	59.1	85.3	57.5	50.9	58.1
Height	cm	40.1	56.3	46.9	42.6	60.1	65.2	67.0	63.1	57.3
Fresh weight	kg/m^2	0.43	0.68	0.65	0.60	0.65	0.63	0.63	0.56	0.63
Dry weight	kg/m^2	0.14	0.15	0.14	0.14	0.15	0.16	0.18	0.24	0.16
Ash	%	14.8	9.5	9.9	9.6	11.4	10.9	8.9	9.3	9.9
Crude protein	%	12.0	15.6	17.0	19.0	17.0	16.0	12.5	15.0	16.0
Crude fiber	%	11.0	29.0	22.0	14.0	17.0	25.0	27.0	27.0	23.0
NO_3^-	g/kg	0.005	0.025	0.020	0.010	0.050	0.025	0.010	0.015	0.022
PO_4^-	g/kg	0.020	0.220	0.230	0.220	0.220	0.220	0.210	0.230	0.220
K^+	g/kg	10.25	15.6	18.0	15.0	13.0	11.5	11.0	11.8	13.7

*SPAD: Soil and Plant Analysis Development.

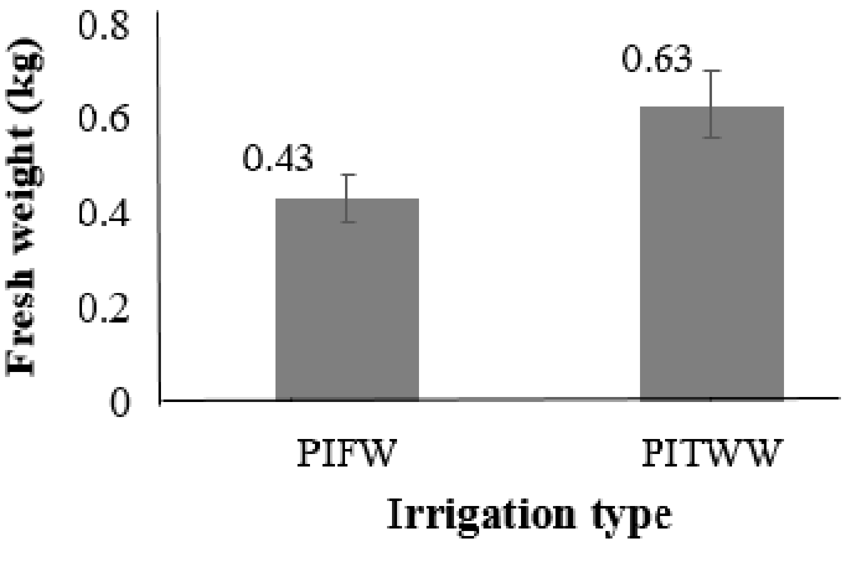

Figure 3. Average fresh weight (kg) of plant irrigated freshwater (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

Table 3. The Alfalfa (*Medicago sativa* L.) productivity when using FW and TWW during October 2021 – end of September 2022.

Crop Productivity	Unit	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Total
PIFW	kg/ha	4760	4420	4590	4080	4590	4250	4250	4590	4250	3910	4080	3600	51370
PITWW	kg/ha	6800	6460	6460	5950	6460	5950	5950	6460	6290	5610	6630	5610	74630

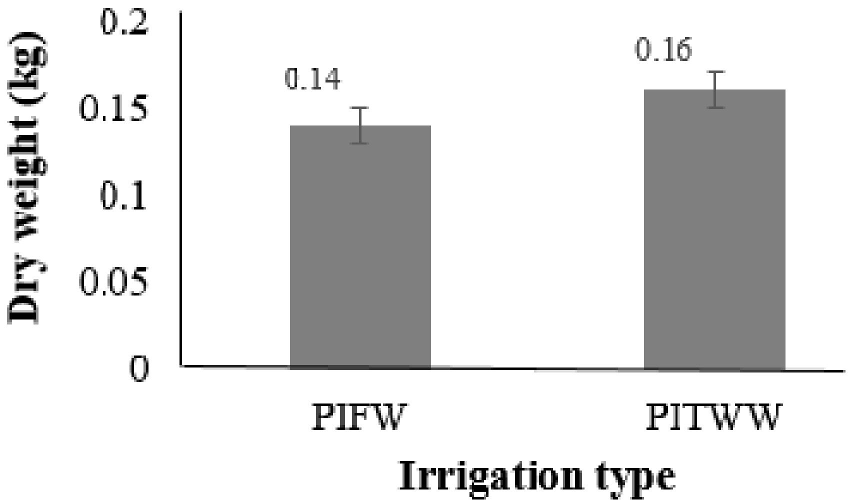

Figure 4. Average dry weight (kg) of plant irrigated freshwater (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

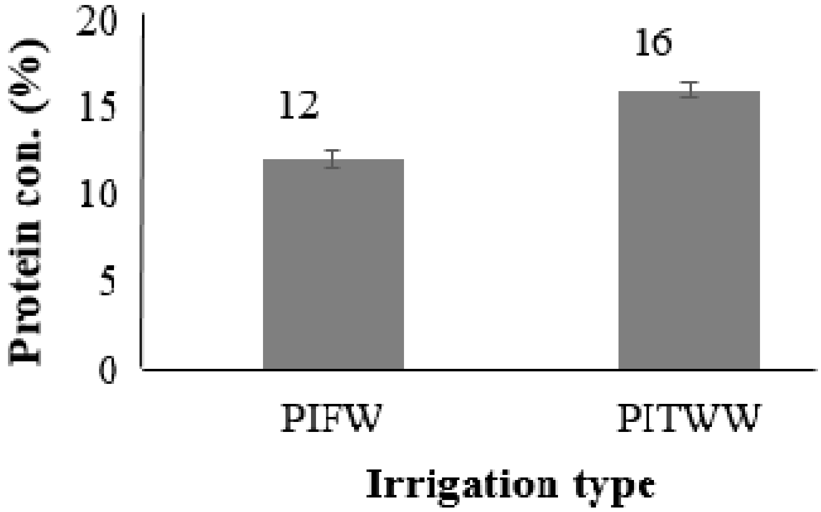

Figure 5. Average protein (%) of plant irrigated fresh water (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

Water requirement/cutting = 800 cubic meters × 1.39 $ = 1,112 $/cutting

Water requirement/year = 800 cubic meters × 1.39 $ × 12 cuttings = 13,344 $/year

Seed, labor, and fertilizer cost/year = 139 $ + 1,667 $ + 1,600 $ = 3,406 $/year

Profit/year = Output – Input

= (Productivity/year) – (Seed, labor, and fertilizer cost/year + water requirement cost/year)

= (52,530 kg × 0.5 $/kg) – (3,406 $ + 13,344 $) = 9,515 $/ha/year

Crop production when irrigated with TWW:

The production cost for 1 ha (10,000 m^2):

Productivity/year = 74,630 kg/ha/year

Water requirement/cutting = 800 cubic meters × 0.28 $ = 224 $/cutting

Water requirement/year = 800 cubic meters × 0.28 $ × 12 cuttings = 2,688 $/year

Seed and labor cost/year = 139 $ + 1,667 $ = 1,806 $/year

Profit/year = Output – Input

= (Productivity/year) – (Seed and labor cost/year + water requirement cost/year)

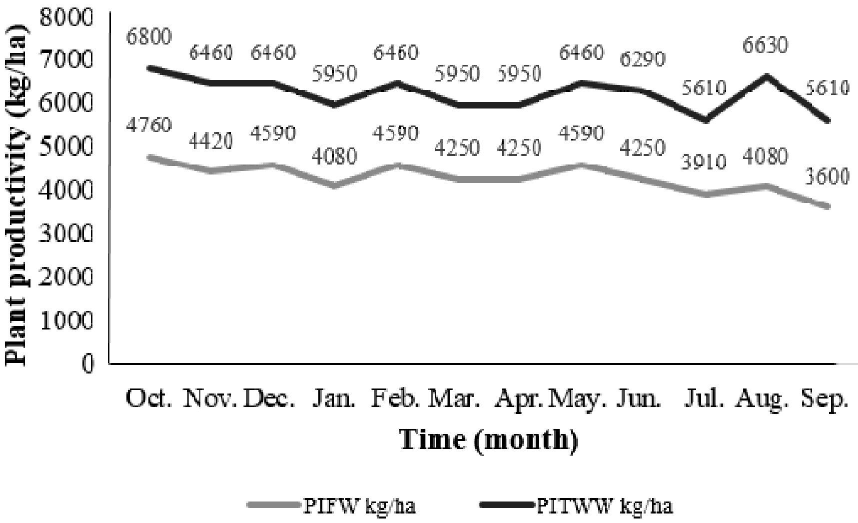

Figure 6. The Alfalfa (*Medicago sativa* L.) productivity (kg/ha) of plant irrigated freshwater (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

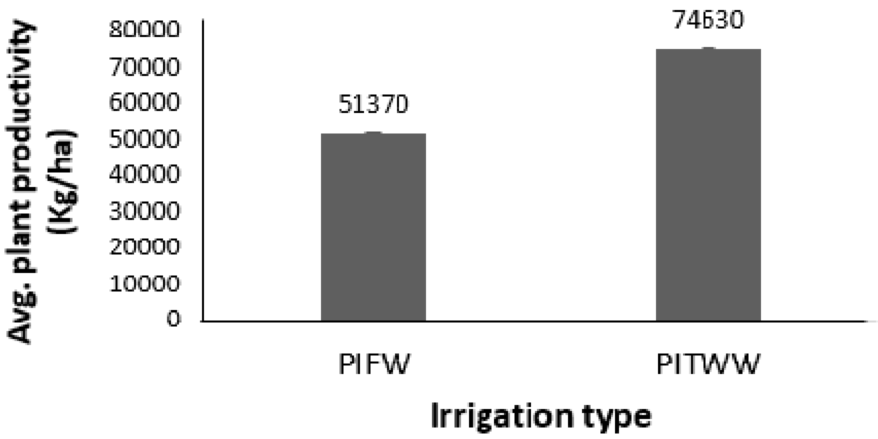

Figure 7. The Alfalfa (*Medicago sativa* L.) average productivity (kg/ha) of plant irrigated freshwater (PIFW) and plant irrigated treated wastewater (PITWW) at different irrigation types during different seasons.

= (74,630 kg × 0.5 $/kg) – (1,806 $ + 2,688 $) = 32,821 $/ha/year

Saving/ha = Profit (TWW) – Profit (FW)

= 32,821 $ – 9,515 $ = 23,306 $/ha/year

From the economic calculations, the profit when irrigating with FW equals 9,515 $/ha/year, while the profit when irrigating with TWW equals 32,821 $/ha/year. The profit saved when comparing the two treatments equals 23,306 $/ha/year. This indicates that the profit per hectare when using TWW is more than three times higher than when using FW. This is because TWW contains the essential nutrients required for plant growth, enhancing productivity and reducing fertilizer needs. Furthermore, the price of one cubic meter of TWW is approximately five times lower than that of FW.

CONCLUSION

Based on the physical and chemical analyses conducted on FW and TWW samples collected from the Anzah Wastewater Treatment Plant (WWTP) between October 2021 and the end of September 2022, TWW characteristics showed strong compliance with the guidelines and demonstrated acceptable quality for irrigating fodder crops, with all values falling within the threshold limits defined by the Palestinian Standards Institution (PSI).

The results of measured plant parameters showed a positive impact under TWW irrigation compared to FW. Levels of organic matter, chlorophyll, plant height, fresh weight, dry weight, ash, crude protein, crude fiber, NO_3^-, PO_4^{3-}, and K^+ in *Alfalfa (Medicago sativa* L.) were all higher under TWW treatment.

The plant moisture when irrigated with TWW was 75.7% compared to 77% when irrigated with FW. For Alfalfa, the moisture percentage decreased due to the increase in organic matter (O.M) content in the plant.

The results show that using TWW increased production parameters; the highest annual production (74,630 kg/ha) was obtained with TWW compared with FW production (51,370 kg/ha).

Because of the nature of the crop and the multiple harvests per year, the nutrient requirements of Alfalfa are relatively high; therefore, the use of TWW provides the plant with the necessary elements for growth and productivity.

Plant analysis revealed significant improvements in plant properties due to TWW irrigation. A notable outcome of the study is that TWW serves as a valuable nutrient source for crops. Its use not only improves yield and quality but also reduces the need for external fertilizers.

It is thus highly encouraging to reuse TWW in agricultural systems after full treatment. The study confirms that TWW is safe and effective for irrigating fodder crops. Collecting and treating wastewater contributes to making the best use of every drop of water, supporting sustainable agricultural practices.

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