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# Evaluation of Soil Properties and Production of *Cucumis sativus* Irrigated with Treated Wastewater in Gaza Strip

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors JMS and MMY designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MMY and MJS managed the analyses of the study. Author MJS managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

This research aimed to evaluate the impact of treated wastewater (TWW) irrigation on soil properties and production of cucumber. The field experiment was set up in the North zone of the Gaza Strip in the season period from April to July 2015. The Cucumber was planted in a design of one block with randomised treatments plots scattered within. The experiment comprised six treatments: four treatments were above surface drip irrigated; two treatments irrigated with potable water (PW) and two treatments irrigated with TWW, with and without plastic ground cover. The remaining two treatments were sub-surface drip irrigated with TWW, also with and without the cover at a depth of 20 cm below ground. Each treatment was replicated in 5 plots. Samples of PW, TWW and soil were analysed. The weight of harvested cucumber and the plant biomass were determined, SPSS analysed data. Both biological oxygen demand (BOD) and chemical oxygen demand (COD) of TWW were higher than the acceptable World Health Organization (WHO) limit.

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The pH, total alkalinity, phosphorus and potassium levels were significantly increased in TWW compared to PW. Conversely, electrical conductivity (EC), total dissolved salts (TDS), nitrate, sulfur, chloride, sodium, calcium, magnesium and total hardness were significantly decreased in TWW. However, EC and TDS of both PW and TWW were higher than the WHO permissible limit. Heavy metals were below the detected limit. Total and faecal coliforms in TWW exceeds that of the WHO standards. Irrigation with PW and TWW increased soil EC, TDS, nitrate, sulfur, chloride, phosphorus, potassium, sodium, calcium and magnesium, particularly with TWW. The weight of harvested cucumber and the plant biomass were higher in plots irrigated with TWW than those irrigated with PW. In conclusion, TWW is a promising candidate to substitute PW irrigation for crops in Gaza Strip in having to low a level of heavy metals and proven to enhance soil fertility and cucumber productivity.

*Keywords: Cucumber productivity; biomass; soil properties; treated wastewater; potable water; Gaza Strip.*

## 1. INTRODUCTION

Wastewater is an inevitable by-product of human activity, and its recycling is vital to alleviate PW scarcity. Such diminishing of PW sources is further aggravated by the rise in human population which leads to high demand for food production mostly felt in arid and semi-arid regions such as the Middle East region. In Gaza Strip, groundwater is the only source of potable water and its pumping to meet the need of fast-growing population as well as the agricultural sector far exceeds the aquifers recharge capacity [1]. It is worth mentioning that the agriculture alone consumes around two-thirds of the available groundwater in Gaza Strip [2]. In such conditions, the groundwater level is seriously falling, and the salinity is increasing making the water unsuitable either for human consumption or irrigation purpose. Hence, using of TWW for agricultural irrigation would be a potential alternative strategy of conserving potable water. However, care must be taken as municipal wastewater contain numerous types of pollutants [3].

The collected wastewater through the old sewage network system is pumped to four wastewater treatment plants (WWTPs) established in Gaza Strip: Beit Lahia, Gaza, Khan Younis and Rafah. These plants are massively overloaded, and the actual flow far exceeds the design flow as a result of rapid population growth [4]. Most of the wastewater effluent is disposed into the nearby Mediterranean sea [5,6]. This necessitates the utilisation of the wasted effluent in agriculture to solve the water shortage problem in the Gaza Strip in the National Water Policy. Despite that, TWW reuse in agriculture is still not officially adopted in the Gaza Strip. Such practice is restricted to some irrigation sites beside the treatment plants as well as some field trials funded through international cooperation projects.

To implement a successful strategy of TWW reuse scheme in Gaza Strip, multi-disciplinary research is urgently needed concerning TWW impact on soil and crops and most importantly on human health. Acceptance of farmers to use TWW for irrigation is also crucial. To our best knowledge, only three recent studies assessed the effect of TWW irrigation on Chinese cabbage, white corn and melon plants growth as well as on some soil properties in Gaza Strip were published [7-9]. The present research was carried out at a large field scale to compare two types of water quality and to provide an applicable knowledge for the first time in the effect of TWW irrigation on soil properties and production of cucumber which is consumed in large quantities in the Gaza Strip.

### 1.1 Study Area

The Gaza Strip is a part of the Palestinian coastal plain located in an arid to semi-arid region. It is bordered by Egypt from the South, the Negev desert from the East, and the Mediterranean sea from the West (Fig. 1). The total surface area of the Gaza Strip is only 365 $km^2$, where about two million people live and work, making it the most densely populated area in the world [10]. The Gaza Strip is divided geographically into five Governorates: Northern, Gaza, Mid-Zone, Khan Younis and Rafah. The annual average rainfall varies from 400 mm in the north to about 200 mm in the south of the Strip and most of the rainfall occurs in the period from October to March, the rest of the year being dry [11]. In this regard, the only water resource in the Gaza Strip is the groundwater aquifer which is continuously being over-exploited, making a substantial deficit in potable water supply. Hence, reconciliation relies in the use of TWW generated from the four existing WWTPs in agriculture.

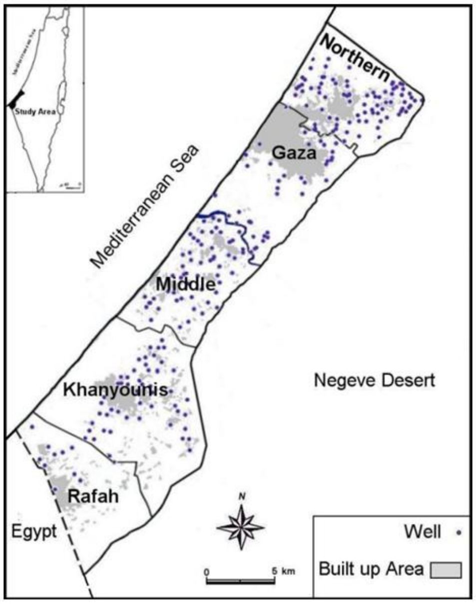


**Fig. 1. Gaza Strip map**

## 2. MATERIALS AND METHODS

### 2.1 Experimental Field Design

The field experiment was set up in the Environmental Protection Research Institute (EPRI) agricultural station located in the Northern Governorate of the Gaza Strip where the sandy soil prevail. Drip irrigation system was employed. The experimental design comprised six treatments: four treatments were above surface drip irrigated; two treatments irrigated with PW, with and without plastic ground cover and two treatments irrigated with secondary TWW, also with and without the cover. The remaining two treatments were sub-surface irrigated with secondary TWW, with and without the cover at the depth of 20 cm below ground. Each treatment was replicated in 5 plots. Therefore, the experimental field was consisted of 30 plots for the cultivation season (5 replicate plots x 6 treatments). Plot dimensions were 5 × 2 meters. Each plot was planted with 10 cucumber plants per the running 5 meters at 40 cm apart. The experiment was conducted in a design of one block with randomized treatments plots scattered within. Cucumber seedlings were planted in the season period from 10 April, 2015 to 9 July, 2015.

### 2.2 Water Collection, Irrigation and Analysis

The secondary TWW was brought about by a specialized tank vehicle from Beit Lahia WWTP located in the Northern Governorate of the Gaza Strip, after a permission issued by Beit Lahia municipality. In the experimental field station, the transported TWW was pumped into a 5 L plastic tank. Before used in the field irrigation, TWW was filtered through a screen filter with 80-mesh sieve to avoid introducing particles to the system that might have otherwise clogged the drippers [12]. The PW was obtained from a local well near the experimental station. Both water types were applied to the field by a drip irrigation system with discharge of 4 L/plant/h according to the standard water requirements [13]. Irrigation of cucumber plant as a summer crop was performed twice/day; at early morning and at evening. Chemical and biological analyses of both PW and TWW were performed at three weeks intervals during the growing season according to standard analytical methods [14].

### 2.3 Soil Sampling and Analysis

Ten pre-sowing soil samples were taken randomly from the field at 2 depths; five samples from 0-10 and five samples from 10-20 cm. Then samples were transferred to EPRI laboratory to be tested for chemical properties. Pre-sowing soil analysis will serve as a base line to follow possible changes in soil chemical properties inflicted by PW and most importantly by TWW irrigation. During and at the end of growing season, soil samples were collected from each replicated plot by randomly selecting 5 sampling points within the 5 meters long designed sampling zone in each replicated plot. Soil was sampled within the row, 20 cm from the dripper. Each soil sample was collected into a plastic bag (Whirl-Pak, USA) by removing about 200 g of soil from 2 depths; from 0-10 and 10-20 cm, thus covering top soil and major root growing layer. Therefore, at each sampling event 60 soil samples were collected corresponding to 5 plots x 6 treatments x 2 depth. Then samples were transported to EPRI laboratory to be air dried and sieved through 2 mm mesh [15]. Soil distilled water suspensions were made at a ratio of 1:2.5 (w/w) and shaken overnight for direct measurement of pH (with a pH meter, pH 330i/SET, Germany), EC (with a conductivity meter, Cond 315i/SET, Germany) and TDS (with a TDS meter, Pro30, Germany). Then, suspensions were filtered using Whatman filter paper and the filtrate was used for determination of nitrate, sulfur, chloride, phosphorus, potassium, sodium, calcium and magnesium, using the standard methods [14].

## 2.4 Fruit and Plant Harvesting

Cucumber fruits were harvested four times at three weeks intervals throughout the growing season. After each harvest time, cucumber fruits were counted and weighed using an electronic balance (TORREY, L-PCR-40, USA), and used as an indicator for yield of each experimental treatment. Cucumber plants were also gathered and weighed at the end of the experiment for determination of plant biomass which is used as an indicator for plant growth of each experimental treatment.

## 2.5 Statistical Analysis

Data were computer analyzed using SPSS/ PC (Statistical Package for the Social Science Inc. Chicago, Illinois USA, version 21.0) statistical package. Mean and standard error means were calculated. The independent sample t-test procedure was used to compare means of quantitative variables by the separated cases into two qualitative groups such as the relationship between PW and TWW chemical properties. The results were accepted as statistically significant when the *P*-value was less than 5%. The percentage difference was calculated according to the formula [16]: Percentage difference equals the absolute value of the change in value, divided by the average of the 2 numbers, all multiplied by 100.

Percent difference =

$$(| (V1 - V2) | / ((V1 + V2)/2)) \times 100.$$

The mean fruit weight was calculated as mean total fruit weight/mean total fruit quantity. The mean plant biomass was also calculated as mean total plant biomass/mean total plant quantity for each treatment.

## 3. RESULTS AND DISCUSSION

### 3.1 Chemical and Biological Properties of PW and TWW

Table 1 compared chemical and biological properties of PW with TWW used for cucumber irrigation throughout its growing cycle. The BOD and COD were nil in PW while they registered mean values of 112.5±6.3 and 274.8±15.1 mg $L^{-1}$, respectively in TWW. These values did not meet the WHO Standards of BOD<100 mg $L^{-1}$ and COD<150 mg $L^{-1}$, respectively [17]. High values of BOD and COD were previously reported for TWW in developing countries [7,18]. Chemical properties showed a significant increase in the pH mean value of TWW compared to PW ($P$ = .018). Such increase in the pH of TWW could be attributed to increase production of ammonia under aerobic conditions. The significant elevation of total alkalinity recorded for TWW with respect to PW ($P$ = .007) do support this view. Conversely, EC and TDS displayed significant decreases in TWW than PW ($P$ = .013 and $P$ = .015, respectively). The pH of PW and TWW (7.28±0.05 and 7.91±0.07, respectively) was within the WHO acceptable range (6.5-9.5) whereas EC (4148±72.0 and 3120±81.4 $\mu$S $cm^{-1}$) and TDS (2595±49.3 and 1978±56.6 ppm) values were higher than the WHO permissible limit of <2500 $\mu$S $cm^{-1}$ for EC and <1600 ppm for TDS [17], indicating the salinity of both water qualities. Such findings are in agreement with that found by other authors [9,19].

Nitrate, Sulfur, Chloride and sodium concentrations were significantly lower in TWW than PW ($P$ = .003, $P$ = .030, $P$ = .021 and $P$ = .040, respectively). The low level of nitrate in TWW may be referred to the idea that nitrate is being reduced to ammonium hydroxide due to an aerobic condition. On the other hand, higher nitrate levels in the groundwater of the Gaza Strip were reported; 90% of the wells having nitrate concentrations that are several times higher than the WHO standards of 50 mg/L [20]. In addition, the lower level of sulfur in TWW may be attributed to possible transformation of sulfate to hydrogen sulfide under aerobic conditions. The overall high concentrations of chloride and sodium salts in PW may offer an explanation of its higher TDS and EC. Elevated chloride concentrations in PW could be explained by seawater intrusion into the costal aquifer in the Gaza Strip [21]. Calcium and magnesium levels were lower in TWW, with only calcium showed significant change ($P$ = .021). Such result coincides with the finding that the total hardness was also significantly lower in TWW ($P$ = .009). Phosphorus and potassium levels were significantly higher in TWW ($P$ < .001 and $P$ = .008, respectively). It is known that TWW is nitrogen phosphorus potassium (NPK) supplier [22].

Heavy metals were below detected level (<0.063 mg $L^{-1}$) in both PW and TWW. This is explained, in part, with limited industrial activities in Gaza Strip [23], giving an advantage of using TWW in agriculture. It is worth mentioning that Ag, As, Bi, Cd, Co, Hg, Mo, Pb, Se and Sn were not detected in both irrigation water used. Concerning bacterial contamination, TWW displayed total and fecal coliforms contents of $5x10^3$ and 204 CFU/100 ml, respectively which exceed WHO standards of $1x10^3$ CFU/100 ml for total coliform and < $2x10^2$ CFU/100 ml for fecal coliform [17]. However, PW was free of total and fecal coliforms. The presence of these bacteria indicates insufficient wastewater treatment and this could be a potential source of health risk [24]. Adding efficient disinfection units to WWTP, or/and by following the safety guidelines when using TWW in irrigation may contribute largely to resolve fecal coliform problem.

### 3.2 pH, EC and TDS of Pre-sowing Soil and after Irrigation with PW and TWW

The mean values of pH, EC and TDS of pre-sowing soil and after irrigation with PW and TWW during and at the end of cucumber growing cycle at two depths of 0-10 and 10-20 cm are presented in Table 2. The mean pH value of pre-sowing soil ranged between 7.97±0.05 to 8.19±0.07 which is in the normal range of a desirable agricultural soil. Application of PW and TWW lowered the pH registering mean values ranged between 7.51±0.05 to 7.81±0.05 and 7.49±0.06 to 7.85±0.08 during and at the end of the growing cycle, respectively. The pre-sowing soil as well as soil irrigated with PW and TWW of different treatments were less acidic at the top layer (0-10 cm) and more acidic at the deep layer (10-20 cm). These results were in the line with that obtained by other authors [9,25]. The mean values of EC and TDS were higher in soil irrigated with PW and TWW than that of pre-sowing soil in both layers, with the highest effect during the end of the growing cycle at the depth 20 cm. Increase of EC and TDS in response to PW and TWW irrigation may be explained by the accumulation of less soluble salts in the soil and possible production of organic acids due to decomposition of organic compounds. Castro and his colleagues concluded that there were no negative effects with respect to changes in soil pH but a significant increase in EC and sodium content was observed in wastewater irrigated soil [26]. In the present study, high salinity of the used irrigation water and high sodium content in the soil irrigated with TWW do support this conclusion. Hence, selecting more salt-tolerant crops would be a suitable choice.

### 3.3 Nitrate, Sulfur and Chloride of Pre-sowing Soil and after Irrigation with PW and TWW

Table 3 illustrates the mean concentrations of nitrate, sulfur and chloride in different soil profiles during and at the end of cucumber growing cycle from two depths of 0-10 and 10-20 cm. Soil irrigated with PW and TWW showed higher concentrations of nitrate, sulfur and chloride in comparison with their concentrations in pre-sowing soil. The cause may reside in their high concentrations in the used irrigation water. In contrast to pre-sowing soil, nitrate concentrations were generally increased from the top to the deeper depth of soil irrigated with PW and TWW, particularly at the end of growing cycle. Sulfur concentrations were higher in the top layer of pre-sowing soil and during the growing cycle. Then, higher concentrations of sulfur were detected in the deep soil layer at the end of growing cycle. Chloride concentrations were generally higher in the top layer of pre-sowing soil as well as in soil irrigated with both PW and TWW throughout the whole experiment. Regardless such variation, it is accepted that irrigation with wastewater increased soil content of nitrate, sulfur and chloride [27].

### 3.4 Macronutrients of Pre-sowing Soil and after Irrigation with PW and TWW

Tables 4 and 5 provide macronutrients concentrations in various soil profiles during and at the end of cucumber growing cycle from two depths of 0-10 and 10-20 cm. Irrigation with PW and TWW increased soil concentrations of phosphorus, potassium, sodium, calcium and magnesium than pre-sowing soil, with the highest concentrations of phosphorus and potassium in the soil irrigated with TWW. This reflects a direct impact of water irrigation on these macronutrients soil content and confirm the enrichment of TWW with phosphorus and potassium. The top layer of pre-sowing soil showed higher concentrations of potassium, sodium and magnesium while lower concentrations of phosphorus and calcium were recorded in this soil layer. Application of PW caused a general increase in the concentrations of all these macronutrients in the deep soil layer. Upon irrigation with TWW, these macronutrients concentrations fluctuated in both soil layers with a tendency of relatively increase of their

**Table 1. Chemical and biological properties of potable and treated wastewater used in irrigation of cucumber**

| Properties | Potable water | Treated wastewater | % difference | t | *P*-value |
|---|---|---|---|---|---|
| BOD (mg $L^{-1}$) | - | 112.5±6.3 | - | - | - |
| COD (mg $L^{-1}$) | - | 274.8±15.1 | - | - | - |
| pH | 7.28±0.05 | 7.91±0.07 | 8.3 | 7.324 | .018 |
| Total alkalinity (ppm as $CaCo_3$) | 165.0±10.2 | 408.9±18.1 | 85.0 | 11.739 | .007 |
| EC (μS $cm^{-1}$) | 4148±72.0 | 3120±81.4 | 26.1 | 8.680 | .013 |
| TDS (ppm) | 2595±49.3 | 1978±56.6 | 27.0 | 8.166 | .015 |
| Nitrate (ppm) | 135.2±5.9 | 29.4±1.8 | 128.6 | 17.152 | .003 |
| Sulfur (ppm) | 118.4±6.1 | 76.2±4.2 | 43.4 | 5.635 | .030 |
| Chloride (ppm) | 1059±43.3 | 697±30.5 | 41.2 | 6.768 | .021 |
| Sodium (ppm) | 302.6±10.4 | 237.1±8.7 | 24.3 | 4.831 | .040 |
| Calcium (ppm) | 411.5±20.2 | 238.1±16.0 | 53.4 | 6.753 | .021 |
| Magnesium (ppm) | 84.9±4.0 | 63.5±3.3 | 28.8 | 4.146 | .054 |
| Total hardness (ppm as $CaCo_3$) | 1317±35.0 | 818.0±29.7 | 46.7 | 10.648 | .009 |
| Phosphorus (ppm) | 0.31±0.04 | 1.70±0.10 | 138.3 | 14.362 | <.001 |
| Potassium (ppm) | 4.15±0.15 | 13.2±0.80 | 104.3 | 11.119 | .008 |
| Copper (mg $L^{-1}$)* | <0.041 | <0.041 | - | - | - |
| Manganese (mg $L^{-1}$) | 0.041±0.006 | 0.055±0.005 | 29.2 | 1.951 | .190 |
| Nickel (mg $L^{-1}$)* | <0.063 | <0.063 | - | - | - |
| *Total coliform* (CFU/100ml) | Negative | $5 \times 10^3$ | - | - | - |
| *Fecal coliform* (CFU/100ml) | Negative | 204 | - | - | - |

*BOD: Biological Oxygen Demand, COD: Chemical Oxygen Demand, EC: Electrical Conductivity, TDS: Total Dissolved Salts. *Below detected level. All physico-chemical and biological values are expressed as mean±SEM*

**Table 2. pH, EC and TDS of pre-sowing soil and after irrigation with PW and TWW during and at the end of cucumber growing cycle from two depths of 0-10 and 10-20 cm**

| Parameter | Depth (cm) | Pre-sowing | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC |
| pH | 0-10 | 8.19±0.07 | 7.81±0.05 | 7.79±0.06 | 7.74±0.05 | 7.80±0.05 | 7.80±0.06 | 7.79±0.04 | 7.67±0.03 | 7.67±0.07 | 7.77±0.05 | 7.85±0.08 | 7.83±0.11 | 7.78±0.08 |
| | 10-20 | 7.97±0.05 | 7.58±0.05 | 7.59±0.05 | 7.51±0.05 | 7.61±0.05 | 7.67±0.03 | 7.56±0.04 | 7.52±0.02 | 7.54±0.01 | 7.49±0.06 | 7.50±0.04 | 7.58±0.02 | 7.54±0.03 |
| EC ($\mu$S cm$^{-1}$) | 0-10 | 131.1±8.3 | 164.6±19.8 | 186.0±19.7 | 191.2±28.6 | 191.4±17.3 | 191.2±29.1 | 191.2±29.5 | 198.3±15.2 | 189.3±13.9 | 208.1±17.4 | 180.5±12.7 | 166.9±15.3 | 182.6±18.9 |
| | 10-20 | 133.8±8.3 | 163.8±20.1 | 166.0±14.9 | 191.8±23.4 | 187.8±21.3 | 160.6±21.9 | 162.4±21.7 | 271.0±25.7 | 226.6±15.8 | 291.3±31.5 | 273.2±28.2 | 214.1±24.2 | 223.5±26.0 |
| TDS (mg L$^{-1}$) | 0-10 | 83.8±5.4 | 106.8±10.2 | 116.5±9.5 | 124.2±14.1 | 115.0±12.0 | 128.9±17.5 | 112.8±9.3 | 116.7±8.8 | 111.3±7.9 | 124.6±11.5 | 110.7±9.4 | 100.3±8.7 | 108.5±9.9 |
| | 10-20 | 85.7±5.3 | 107.7±12.4 | 109.1±7.8 | 123.5±13.7 | 121.7±13.1 | 102.5±18.6 | 105.8±10.6 | 154.3±12.5 | 130.8±13.3 | 168.226.3 | 156.3±13.0 | 126.1±10.4 | 127.3±11.2 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. EC: Electrical Conductivity, TDS: Total Dissolved Salts. All values are expressed as mean±SEM*

**Table 3. Nitrate, sulfur and chloride concentrations of pre-sowing soil and after irrigation with PW and TWW during and at the end of cucumber growing cycle at two depths of 0-10 and 10-20 cm**

| Chemicals | Depth (cm) | Pre-sowing | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC |
| Nitrate(mg kg$^{-1}$) | 0-10 | 13.0±1.1 | 24.2±2.1 | 23.0±1.6 | 23.8±2.0 | 27.7±2.4 | 48.0±3.5 | 26.1±2.7 | 24.6±1.9 | 26.5±2.2 | 28.0±2.4 | 26.0±2.6 | 25.9±2.7 | 32.3±1.8 |
| | 10-20 | 11.1±1.0 | 24.5±2.3 | 25.3±2.1 | 25.8±2.0 | 26.2±2.1 | 37.0±2.6 | 32.2±1.1 | 31.0±1.2 | 28.7±1.0 | 47.0±2.4 | 32.4±1.6 | 26.7±2.0 | 30.5±1.9 |
| Sulfur(mg kg$^{-1}$) | 0-10 | 8.0±0.7 | 11.6±1.1 | 11.1±0.9 | 10.3±1.2 | 12.0±0.7 | 13.7±1.1 | 11.3±0.9 | 11.1±0.8 | 12.4±1.2 | 11.3±0.9 | 11.2±0.7 | 11.4±0.6 | 12.0±0.6 |
| | 10-20 | 6.4±0.5 | 11.0±0.7 | 11.8±0.9 | 9.7±1.0 | 10.5±0.6 | 11.4±0.8 | 11.0±0.7 | 12.7±0.9 | 12.6±0.8 | 12.2±0.7 | 11.6±0.6 | 11.8±0.7 | 13.0±1.0 |
| Chloride(g kg$^{-1}$) | 0-10 | 17.2±1.3 | 21.2±1.5 | 19.8±1.2 | 25.7±1.6 | 28.1±1.9 | 26.4±1.7 | 30.0±2.3 | 38.1±3.0 | 36.0±2.2 | 33.0±1.6 | 35.4±2.0 | 37.0±2.5 | 46.1±3.2 |
| | 10-20 | 14.8±1.1 | 19.9±1.4 | 18.0±1.6 | 23.0±1.9 | 25.6±1.8 | 27.1±2.1 | 28.2±2.2 | 35.0±2.5 | 35.0±2.6 | 32.5±2.5 | 29.1±2.0 | 36.1±2.3 | 33.5±2.1 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. All values are expressed as mean±SEM*

**Table 4. Phosphorus, potassium and sodium concentrations in pre-sowing soil and after irrigation with PW and TWW during and at the end of cucumber growing cycle at two depths of 0-10 and 10-20 cm**

| Macro-nutrient | Depth (cm) | Pre-sowing | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC |
| Phosphorus | 0-10 | 0.17±0.03 | 0.21±0.04 | 0.23±0.05 | 0.27±0.03 | 0.40±0.05 | 0.26±0.03 | 0.50±0.06 | 0.24±0.05 | 0.26±0.04 | 0.36±0.06 | 0.52±0.09 | 0.44±0.07 | 0.40±0.06 |
| (mg $kg^{-1}$) | 10-20 | 0.20±0.04 | 0.27±0.05 | 0.25±0.04 | 0.34±0.03 | 0.46±0.06 | 0.35±0.05 | 0.48±0.07 | 0.26±0.05 | 0.23±0.06 | 0.40±0.08 | 0.49±0.07 | 0.55±0.08 | 0.45±0.06 |
| Potassium | 0-10 | 1.80±0.11 | 2.06±0.16 | 1.96±0.17 | 2.50±0.19 | 3.48±0.23 | 4.11±0.27 | 3.25±0.21 | 2.01±0.15 | 1.90±0.15 | 2.71±0.22 | 2.92±0.23 | 3.05±0.18 | 3.01±0.20 |
| (mg $kg^{-1}$) | 10-20 | 1.68±0.09 | 2.08±0.14 | 1.89±0.16 | 2.52±0.20 | 2.97±0.18 | 3.61±0.22 | 3.50±0.19 | 1.97±0.18 | 2.03±0.16 | 2.74±0.20 | 2.81±0.19 | 3.49±0.21 | 3.54±0.17 |
| Sodium | 0-10 | 7.40±0.53 | 19.4±1.5 | 11.5±1.1 | 14.0±1.3 | 17.6±1.5 | 10.4±1.2 | 24.1±1.7 | 21.0±1.4 | 12.9±1.2 | 21.2±1.5 | 26.0±2.0 | 14.7±1.1 | 18.5±1.4 |
| (mg $kg^{-1}$) | 10-20 | 7.32±0.56 | 20.0±1.6 | 13.3±1.2 | 12.5±1.0 | 25.3±1.5 | 16.8±1.4 | 25.3±1.6 | 16.1±1.3 | 19.0±1.2 | 18.5±1.4 | 24.9±1.8 | 17.8±1.3 | 25.1±1.7 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. All values are expressed as mean±SEM*

**Table 5. Calcium and Magnesium concentrations (mg/kg) of pre-sowing soil and after irrigation with PW and TWW during and at the end of cucumber growing cycle at two depths of 0-10 and 10-20 cm**

| Macro-nutrient | Depth (cm) | Pre-sowing | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC | Sur PW | Sur PWC | Sur TWW | Sur TWWC | Sub TWW | Sub TWWC |
| Calcium(mg $kg^{-1}$) | 0-10 | 24.1±1.6 | 27.1±1.9 | 24.7±1.7 | 31.0±2.4 | 28.1±1.7 | 35.4±2.5 | 30.0±2.2 | 25.8±1.7 | 32.0±1.8 | 24.3±1.4 | 26.9±1.5 | 27.0±1.4 | 29.3±1.7 |
| | 10-20 | 26.8±1.9 | 30.0±1.6 | 29.2±1.7 | 26.7±1.4 | 28.9±1.6 | 24.5±1.7 | 32.0±1.8 | 31.0±1.4 | 25.4±1.5 | 27.1±1.2 | 29.2±1.4 | 32.1±2.0 | 26.0±1.3 |
| Magnesium(mg $kg^{-1}$) | 0-10 | 5.1±0.4 | 10.1±0.8 | 7.4±0.5 | 9.0±0.7 | 8.5±0.5 | 8.1±0.4 | 12.3±0.9 | 8.6±0.5 | 10.0±0.7 | 8.4±0.4 | 12.9±1.1 | 7.6±0.5 | 12.8±1.2 |
| | 10-20 | 4.3±0.3 | 10.2±0.6 | 13.6±1.2 | 11.2±0.8 | 14.0±1.3 | 11.5±0.8 | 13.1±1.2 | 10.1±0.9 | 10.2±0.8 | 12.6±1.0 | 13.0±1.3 | 7.7±0.6 | 12.4±1.1 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. All values are expressed as mean±SEM*

**Table 6. Weight of harvested cucumber fruit (g) from different treatments at 3 weeks interval sampling**

| Sampling interval | Parameter | SurPW | SurPWC | SurTWW | SurTWWC | SubTWW | SubTWWC |
|---|---|---|---|---|---|---|---|
| 1st Sampling | Total weight | 659.7±174.9 | 878.9±206.5 | 1103.4±250.8 | 850.7±189.4 | 754.2±174.5 | 1160.8±377.1 |
| | Total quantity | 9.4±1.3 | 10.8±1.6 | 11.6±1.7 | 9.6±1.4 | 8.8±1.2 | 11.2±2.0 |
| | Weight/fruit | 70.2±18.6 | 81.4±19.1 | 95.1±21.6 | 88.6±18.2 | 85.7±19.8 | 103.6±33.7 |
| 2nd Sampling | Total weight | 410.4±66.1 | 506.7±120.3 | 816.0±224.5 | 736.8±150.2 | 986.4±113.7 | 1071.6±493.8 |
| | Total quantity | 5.2±0.6 | 5.4±0.4 | 6.4±0.8 | 6.4±0.7 | 7.2±0.4 | 6.6±1.9 |
| | Weight/fruit | 78.9±13.2 | 93.8±26.2 | 127.5±35.1 | 115.1±23.5 | 137.0±15.8 | 162.4±74.2 |
| 3rd Sampling | Total weight | 875.4±180.3 | 1517.2±340.7 | 1574.2±619.2 | 1363.8±175.4 | 1566.0±499.0 | 1800.8±664.3 |
| | Total quantity | 7.8±0.9 | 11.0±1.3 | 9.0±1.9 | 9.6±1.2 | 10.0±1.4 | 9.8±2.0 |
| | Weight/fruit | 112.2±23.1 | 137.9±31.0 | 174.9±68.8 | 142.1±18.3 | 156.6±49.9 | 183.8±67.8 |
| 4th Sampling | Total weight | 1055.7±351.4 | 1482.3±472.5 | 1342.4±376.5 | 881.2±213.7 | 1130.7±436.1 | 1503.6±620.2 |
| | Total quantity | 9.2±1.9 | 12.0±3.0 | 8.0±1.9 | 6.8±1.2 | 8.4±2.5 | 8.8±3.1 |
| | Weight/fruit | 114.8±38.2 | 123.5±39.4 | 167.8±47.1 | 129.6±31.4 | 134.6±51.9 | 170.9±70.5 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. Weight/fruit (g) is calculated as total weight (g)/total quantity. All values are expressed as mean±SEM*

**Table 7. Biomass of cucumber plant from different treatments at the end of the experiment**

| Treatments | Total plant quantity/treatment | Total Plant biomass/ treatment (g) | Biomass/plant (g) |
|---|---|---|---|
| SurPW | 9.2±0.58 | 871.3±182.5 | 94.7±19.8 |
| SurPWC | 9.4±0.40 | 860.4±134.7 | 91.5±14.3 |
| SurTWW | 9.6±0.51 | 1152.1±218.2 | 120.0±22.7 |
| SurTWWC | 9.0±0.71 | 872.2±117.9 | 96.9±13.1 |
| SubTWW | 9.2±0.49 | 918.4±133.1 | 99.8±14.5 |
| SubTWWC | 8.8±0.58 | 1102.6±190.4 | 125.3±21.6 |

*SurPW: Surface Potable Water, SurPWC: Surface Potable Water Covered, SurTWW: Surface Treated Wastewater, SurTWWC: Surface Treated Wastewater Covered, SubTWW: Subsurface Treated Wastewater, SubTWWC: Subsurface Treated Wastewater Covered. Plant biomass was calculated as total plant biomass/total plant quantity for each treatment. All values are expressed as mean±SEM* concentrations in the deep soil layer. It is worth mentioning that the low concentration of P in both soil depths of TWW treatments may be attributed to low solubility of P in soil solution due to relatively high soil pH. Similar findings were reported [28,29].

### 3.5 Weight of Harvested Cucumber Fruit

The mean weight of harvested cucumber fruit from different treatments at three weeks interval sampling is indicated in above Table 6. The mean weight of cucumber fruit was higher in plots irrigated with TWW than those irrigated with PW. The highest weight/cucumber fruit was recorded for sub-surface TWW-irrigated covered plots showing mean weights of 103.6±33.7, 162.4±74.2, 183.8±67.8 and 170.9±70.5 g at 1st, 2nd, 3rd and 4th sampling intervals, respectively. The higher cucumber yield in TWW-irrigated plots suggests that TWW can supply enough nutrients as indicated by water and soil analyses and confirms its beneficial role in improving soil fertility. Several investigators showed increase crop yield in TWW-irrigated soil [30,31].

### 3.6 Biomass of Cucumber Plant

Table 7 gives biomass of cucumber plant from different treatments at the end of the experiment. The mean plant biomass/treatment in plots irrigated with TWW was higher than those irrigated with PW. The highest biomass/plant was registered in sub-surface TWW-irrigated covered plots displaying the mean biomass of 125.3±21.6 g whereas the lowest biomass was recorded in surface PW-irrigated covered plots exhibiting mean biomass of 91.5±14.3 g. Such findings do confirm the role of TWW in promoting cucumber growth in terms of supplying essential nutrients and containing some bacteria that participate in the degradation of organic matter that maintain soil fertility. Husseiki and his colleagues showed that the overall biomass increased in grape plants irrigated with treated wastewater and grape production per plant increased up to 40% compared with well water irrigation [32].

## 4. CONCLUSION

Treated wastewater is a promising candidate to substitute PW irrigation for crops in Gaza Strip. This stemmed from the present results that TWW had a low level of heavy metals and proven to enhance soil fertility and cucumber productivity. However, its relatively high salinity and pathogen contamination could be overcome by implanting more salt-tolerant crops and following restricted safety guidelines, respectively. In this case, further research is highly needed to improve the quality of TWW and its impact on human health.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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