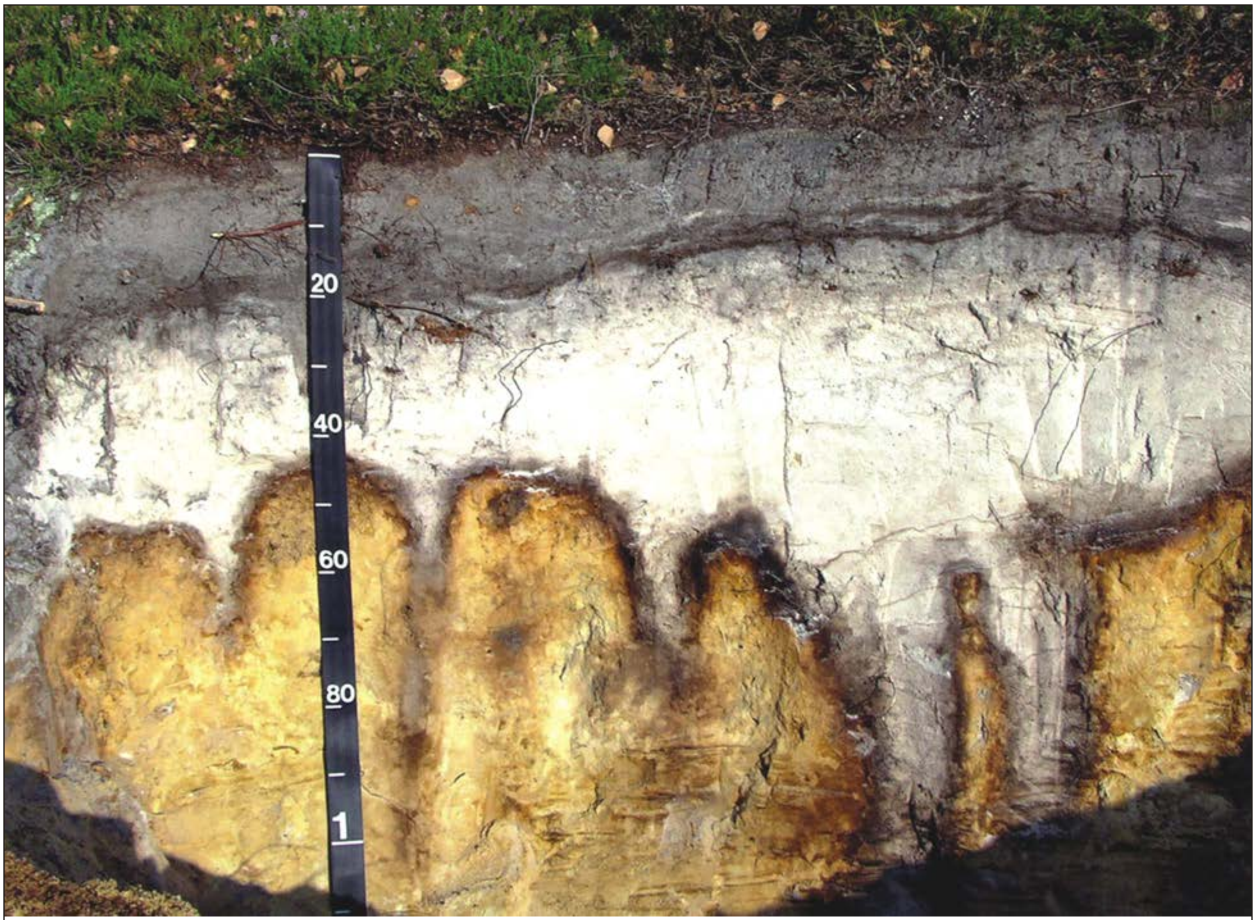

# International Journal of
# Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS **International Journal of Soil Science**

ISSN 1816-4978
DOI: 10.3923/ijss.2017.104.112

# Research Article
# Impact of Treated Wastewater Irrigation on Soil Properties and Production of *Cucumis melo* inodorus in Gaza Strip

[1,2]Maged Mohamed Yassin, [2]Mohamed Jamal Safi and [2,3]Jamal Mohamed Safi

[1]Faculty of Medicine, The Islamic University of Gaza, Gaza Strip, Palestine
[2]Environmental Protection and Research Institute, Gaza Strip, Palestine
[3]Faculty of Agriculture and Environment, Al-Azhar University, Gaza, Palestine

## Abstract

**Background and Objective:** The use of treated wastewater (TWW) for agricultural irrigation becomes increasingly important in water stressed regions like Gaza Strip for substituting potable water (PW) resources. This study aimed to assess the impact of TWW irrigation on soil properties and production of *Cucumis melo* inodorus in Gaza Strip. **Materials and Methods:** Melon was planted in a design of one block with randomized treatments plots scattered within. Six treatments were used: 4 treatments included application of PW and TWW to the field by above surface drip irrigation, with and without plastic ground cover and 2 treatments of TWW sub-surface drip irrigation at depth of 20 cm with and without ground cover. Each treatment was replicated in 5 plots. PW and TWW samples were analyzed for physico-chemical and biological properties. Soil samples were collected from 0-10 and 10-30 cm depths and also analyzed for physico-chemical properties. The weight of the harvested melon fruit (total fruit weight/total fruit quantity) as well as the plant biomass (total plant biomass/total plant quantity) were determined. Data was analyzed by SPSS. **Results:** Water analysis showed that biological oxygen demand (BOD) of TWW meets the World Health Organization (WHO) standards whereas chemical oxygen demand (COD) was higher than the acceptable WHO limit. The pH, total alkalinity, P and K levels were significantly increased in TWW compared to PW whereas electrical conductivity (EC), total dissolved salts (TDS), $NO_3$, S, Cl, total hardness, Ca, Mg and Na were significantly decreased in TWW. However, EC and TDS values were higher than the WHO acceptable range. Heavy metals were below the detected limit. Total and fecal coliforms contamination in TWW exceeds that of the WHO standards. Irrigation with PW and TWW increased soil EC, TDS, $NO_3$, S, Cl, P, K, Na, Ca and Mg, with the highest effect of TWW. The weight of the harvested melon fruit as well as the plant biomass were higher in plots irrigated with TWW than those irrigated with PW. **Conclusion:** This study suggests a future possibility of TWW reuse in Gaza Strip in terms of its low content of heavy metals, enhancement of soil fertility and crop yield.

Key words: Treated wastewater, potable water, drip irrigation, soil properties, biomass

Citation: Maged Mohamed Yassin, Mohamed Jamal Safi and Jamal Mohamed Safi, 2017. Impact of treated wastewater irrigation on soil properties and production of *Cucumis melo* inodorus in Gaza Strip. Int. J. Soil Sci., 12: 104-112.

Corresponding Author: Jamal Mohamed Safi, Environmental Protection and Research Institute, Gaza Strip, Palestine
Tel: +972 (8) 2822131 Fax: +972 (8) 2823441

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

The Gaza Strip is an elongated costal area of the Palestinian territories bordered by Egypt from the South, the Negev Desert from the East and the Mediterranean Sea from the West. The total surface area of the Gaza Strip is only 365 km$^2$ and its population is estimated to be more than two million people making it the most densely populated area in the world[1]. The Gaza Strip is located in a semi-arid area where water resources are scare anyhow but with the crowded conditions of the Gaza Strip the shortage in water is further aggravated to catastrophic properties threatening health and food security. The annual average rainfall varies from approximately 400 mm in the North to 200 mm in the South of the Gaza Strip[2]. Most of the rainfall occurs between November and March, with the rest of the year being dry. The entire population depends totally upon ground water as the only source of potable water.

In order to meet the growing needs of the population, groundwater pumping far exceeds the aquifers recharge capacity. As a result, groundwater level is falling and the salinity is increasing making the water unsuitable either for human consumption or for irrigation purpose. The agriculture alone consumes a round two-thirds of groundwater pumped through more than 4000 well slocated overall the Gaza Strip[3].Therefore, one effective strategy of conserving water is by recycling wastewater for agricultural irrigation. However, chemical and biological contamination of TWW is one of the fundamental obstacles to more widespread reuse of TWW for crop irrigation[4].

The pooled wastewater through the sewage network system is pumped to three wastewater treatment plants established in the Gaza Strip Governorates: BeitLahia, Gaza and Rafah. The amount of generated TWW in Gaza is about 120,548 m$^3$/day and this quantity is expected to increase in the coming years as a result of rapid population growth[5]. This necessitates adoption of TWW reuse in agricultural sector in the Gaza Strip. However, guidelines for safe and effective reuse of TWW for agricultural purposes should be followed to minimize its impact on soil and crops. Although reclaimed wastewater reuse for agriculture is increasingly being used as an essential component in the management strategy for water shortage in the neighboring countries[6-8], such practice is still not officially followed for agriculture in Gaza Strip.

Studies carried out in the Gaza Strip to evaluate the quality of TWW for reuse in agriculture at a nation level were limited to some scattered pilot field trials funded mostly by the international institutions. Recently, few published studies investigated, at a small field scale, the effect of TWW irrigation on Chinese cabbage and white corn plants growth as well as on some soil properties in Gaza Strip were emerged[5,9]. The present work is carried out at a large field scale to compare two types of water quality and to bridge the gap of knowledge in the effect of secondary effluent irrigation on soil properties and production of melon which is consumed in large quantities in the Gaza Strip.

## MATERIALS AND METHODS

**Field experiment set-up:** The field experiment was set up in the Environmental Protection Research Institute (EPRI) agricultural station at the North Zone of the Gaza Strip where the sandy soil prevail (92-94%) with low content of clay and slit (6-8%). The EPRI agricultural experimental station specializes in the study of effluent irrigation of agronomic production fields. Six treatments were designed to be drip irrigated by PW and secondary TWW as follows: The first and second treatments were above surface irrigated with PW, with and without plastic ground cover. The third and fourth treatments were above surface irrigated with secondary TWW, with and without plastic ground cover. The fifth and sixth treatments were sub-surface irrigated with secondary TWW, with and without plastic ground 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×6 treatments). Plot dimensions were 5×2 m. Each plot was planted with 12 melon plants/running 5 msec at 40 cm apart. The experiment was conducted in a design of one block with randomized treatments plots scattered within. This set up satisfies the validity of the results, as 5 replicates/treatment would yield statistically significant data. Melon seedlings were planted in the season period from 16 April, 2016-21 July, 2016.

**Water collection, irrigation and analysis:** The municipal secondary TWW was collected from Beit Lahia wastewater treatment facility located in the North Zone of the Gaza Strip. Then, transported by a specialized TWW tank vehicle to the experimental station and pumped into a 5 L tank. Before used in the field irrigation, TWW were filtered through a screen filter with 80-mesh sieve to avoid introducing particles to the system that might have otherwise clogged the drippers[10]. The PW was obtained from a local well near the experimental station in the North Zone of the Gaza Strip. Both water types were applied to the field by a drip irrigation system with discharge of 4 L/plant h$^{-1}$ according to the standard water requirements[11]. Irrigation of melon plant as a summer crop was performed twice/day, at early morning and at evening. Samples of TWW and PW were analyzed for physico-chemical, biological and microbiological properties at 3 weeks intervals of the growing season according to standard methods for the examination of water and wastewater[12].

**Soil sampling and analysis:** Before the field experiment set-up and initiation of treatments, ten soil samples were taken randomly from the field at 2 depths, five samples from 0-10 and five samples from 10-30 cm, and transferred to EPRI laboratory to be tested for physico-chemical properties. This initial analysis of the soil will serve as a base line to follow the changes in the soil physico-chemical properties thus following possible changes inflicted 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 m long designed sampling zone in each replicated plot. Soil was sampled within the row, 20 cm from the dripper. Each soil sample was collected by removing approximately 200 g of soil from 2 depths, from 0-10 and 10-30 cm, thus covering top soil and major root growing layer. Therefore, at each sampling event 60 soil samples were collected corresponding to 5 plots×6 treatments×2 depth. The soil samples were placed in individual plastic bags (Whirl-Pak, USA) and transported to EPRI laboratory to be air dried and sieved through 2 mm mesh[13]. 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 $NO_3$, S, Cl, P, K, Na, Ca and Mg, using the standard methods[12].

**Fruit and plant harvesting:** Melon fruits were harvested at the end of growing season, counted and weighted using an electronic balance (TORREY, L-PCR-40, USA) and used as an indicator for yield of each experimental treatment. Melon plants were also gathered and weighted for determination of plant biomass which is used as an indicator for plant growth of each experimental treatment.

**Statistical data 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 Physico-chemical properties. The results were accepted as statistical significant when the p-value was less than 5% ($p<0.05$). The percentage difference was calculated according to the formula[14]: Percentage difference equals the absolute value of the change in value, divided by the average of the 2 numbers, all multiplied by 100.

$$\text{Percent difference} = (|(V1-V2)|/((V1+V2)/2))\times 100$$

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

## RESULTS

Physico-chemical, biological and microbiological properties of PW and TWW: Physico-chemical, biological and microbiological properties of PW and TWW used in irrigation of melon throughout its whole cultivation cycle were compared in table 1. The BOD and COD were nil in PW while they recoded mean values of 83.3±3.4 and 248.7±14.5 mg $L^{-1}$, respectively in TWW. The mean value of pH was significantly ($p<0.05$) increased in TWW compared to PW. In this context, TWW exhibited higher significant total alkalinity than PW. Conversely, EC and TDS were significantly ($p<0.05$) decreased in TWW than PW. Nitrate, S and Cl levels were significantly lower in TWW than PW. Calcium and Mg concentrations were also significantly ($p<0.05$) lower in TWW. Hence, total hardness was significantly lower in TWW. K and P levels were significantly higher in TWW whereas Na level was significantly lower. Heavy metals were<0.063 mg $L^{-1}$ in both PW and TWW, indicating low levels of these metals. Microbiological analysis revealed that PW was free (negative) of total and fecal coliforms whereas their content in TWW were $8.8\text{x}10^4$ and 215 CFU/100 mL, respectively.

**pH, EC and TDS of pre-sowing soil and after irrigation with PW and TWW during and at the end of melon growing cycle from two depths of 0-10 and 10-30 cm:** The mean values of pH, EC and TDS from different soil profiles are illustrated in Table 2. The mean pH values ranged between 7.59±0.06-7.79±0.07, 7.45±0.13-7.73±0.11 and 7.53±0.09-7.79±0.10 of pre-sowing soil and after irrigation with PW and TWW during and at the end of growing season, respectively. The pre-sowing soil was less acidic at the top layer (0-10 cm) and more acidic at the deep layer (10-30 cm). Conversely, soil irrigated with PW and TWW of different

Table 1: Physico-chemical, biological and microbiological properties of potable and treated waste water used in irrigation of melon

| Properties | Potable water | Treated waste water | (%) difference | t | p-value |
|---|---|---|---|---|---|
| BOD (mg L$^{-1}$) | - | 83.3±3.4 | - | - | - |
| COD (mg L$^{-1}$) | - | 248.7±14.5 | - | - | - |
| pH | 7.12±0.05 | 7.68±0.09 | 7.6 | 5.298 | <0.001 |
| EC (µS cm$^{-1}$) | 4736±102.1 | 2955±74.2 | 46.3 | 14.096 | <0.001 |
| TDS (ppm) | 3521±78.5 | 1832±40.9 | 68.0 | 21.324 | <0.001 |
| Nitrate (ppm) | 156.5±6.0 | 42.5±2.1 | 114.6 | 17.736 | <0.001 |
| Sulfur (ppm) | 178.2±8.1 | 81.3±3.8 | 74.7 | 10.875 | <0.001 |
| Chloride (ppm) | 1429±33.7 | 530±20.7 | 91.8 | 22.810 | <0.001 |
| Phosphorus (ppm) | 0.34±0.03 | 2.25±0.11 | 147.5 | 17.436 | <0.001 |
| Total alkalinity (ppmas CaCo$_3$) | 182.1±9.0 | 629.7±23.6 | 110.3 | 17.616 | <0.001 |
| Total hardness (ppmas CaCo$_3$) | 1677±35.2 | 682.8±24.9 | 84.3 | 23.031 | <0.001 |
| Calcium (ppm) | 516.3±19.4 | 148.7±6.2 | 110.6 | 18.080 | <0.001 |
| Magnesium (ppm) | 95.6±4.4 | 77.5±3.9 | 20.9 | 3.165 | 0.034 |
| Potassium (ppm) | 5.73±0.18 | 22.1±1.3 | 117.6 | 11.760 | <0.001 |
| Sodium (ppm) | 520.7±17.9 | 332.0±11.8 | 44.3 | 8.789 | 0.001 |
| Copper (mg L$^{-1}$)* | <0.041 | <0.041 | - | - | - |
| Manganese (mg L$^{-1}$) | 0.061±0.005 | 0.039±0.004 | 44.0 | 3.859 | 0.061 |
| Nickel (mg L$^{-1}$)* | <0.063 | <0.063 | - | - | - |
| *Total coliform* (CFU/100 mL) | Negative | 8.8x10$^4$ | - | - | - |
| *Fecal coliform* (CFU/100 mL) | Negative | 215 | - | - | - |

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

treatments became more acidic at the top layer and less acidic at the deep layer, particularly at the end of growing season. EC and TDS of the soil showed an increasing trend towards the end of growing season with the highest effect in soil irrigated with TWW. In addition, the mean values of EC and TDS were lower in the top layer of pre-sowing soil whereas their mean values were generally increased in the top soil layer irrigated with PW and TWW.

**$NO_3$, S and Cl of pre-sowing soil and after irrigation with PW and TWW during and at the end of melon growing cycle from two depths of 0-10 and 10-30 cm:** The mean levels of $NO_3$, S and Cl in different soil profiles are provided in Table 3. There were higher concentrations of $NO_3$, S and Cl in the soil irrigated with PW and TWW in comparison with their concentrations in pre-sowing soil. Nitrate concentration was generally decreased from the top to the deeper depth of pre-sowing soil as well as in PW and TWW irrigated soil, particularly at the end of growing season. Sulfur concentration was less in the top layer of pre-sowing soil and after irrigation with PW. In contrast, higher concentrations of S were detected in the top soil layer irrigated with TWW. Chloride concentration was lower in the top layer of pre-sowing soil, but became generally higher upon irrigation with both PW and TWW.

**Macronutrients of pre-sowing soil and after irrigation with PW and TWW during and at the end of melon growing cycle from two depths of 0-10 and 10-30 cm:** Macronutrients concentrations in various soil profiles are presented in Table 4 and 5. The mean levels of P, K, Na, Ca and Mg in the soil showed an increasing trend towards the end of growing season with the highest concentrations in the soil irrigated with TWW. In general, the top layer of pre-sowing soil showed lower concentrations of these macronutrients while higher concentrations were recorded in this soil layer irrigated with PW. However, macronutrients concentrations fluctuate in both layers of soil irrigated with TWW with a tendency of relatively increase of these micronutrients in the deep soil layer.

**Quantity and weight of harvested melon fruit/treatment at the end of the experiment:** The total quantity and weight of harvested melon fruit were generally higher in plots irrigated with TWW than those irrigated with PW as indicated in Table 6. The highest weight/melon fruit was registered in surface TWW-irrigated plots showing mean weight of 186.0±59.7 g whereas the lowest weight/fruit was recorded in surface PW-irrigated plots displaying mean weight of 132.4±40.5 g.

**Biomass of melon plant/treatment at the end of the experiment:** The biomass of melon plant from different treatments at the end of the experiment is presented in Table 7. The total plant biomass/treatment in plots irrigated with TWW was higher than those irrigated with PW. The highest biomass/plant was registered in surface TWW-irrigated covered plots showing the mean biomass of 72.8±11.8 g whereas the lowest biomass was recorded in surface PW-irrigated plots displaying mean biomass of 47.8±9.3 g.

Table 2: pH, EC and TDS of pre-sowing soil and after irrigation with PW and TWW from two depths of 0-10 and 10-30 cm

| | | | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Depth (cm) | Pre-sowing | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC |
| pH | 0-10 | 7.79±0.07 | 7.60±0.08 | 7.64±0.06 | 7.52±0.06 | 7.67±0.13 | 7.61±0.09 | 7.54±0.06 | 7.67±0.06 | 7.61±0.09 | 7.64±0.06 | 7.68±0.08 | 7.53±0.09 | 7.63±0.04 |
| | 10-30 | 7.59±0.06 | 7.68±0.11 | 7.67±0.07 | 7.45±0.13 | 7.62±0.13 | 7.73±0.11 | 7.52±0.07 | 7.72±0.04 | 7.72±0.03 | 7.57±0.07 | 7.79±0.10 | 7.71±0.07 | 7.72±0.07 |
| EC (µS cm$^{-1}$) | 0-10 | 185.50±8.0 | 196.00±15.8 | 202.8±20.2 | 237.40±16.3 | 237.60±16.6 | 232.20±29.0 | 242.00±16.7 | 282.20±24.1 | 296.80±20.6 | 316.80±14.9 | 336.80±36.6 | 296.80±28.7 | 296.80±28.7 |
| | 10-30 | 220.10±23.3 | 163.40±18.0 | 166.2±12.2 | 249.20±35.6 | 210.80±23.2 | 209.60±30.9 | 216.80±16.0 | 247.60±20.0 | 252.60±8.5 | 318.40±52.9 | 262.60±26.0 | 278.60±27.1 | 278.40±11.0 |
| TDS (mg L$^{-1}$) | 0-10 | 118.80±5.0 | 125.50±10.1 | 129.8±12.9 | 151.90±10.5 | 152.10±10.6 | 148.60±18.6 | 154.90±10.7 | 180.60±15.4 | 190.00±13.2 | 202.70±9.5 | 215.60±23.4 | 189.90±18.4 | 203.30±11.8 |
| | 10-30 | 140.80±14.9 | 104.60±11.5 | 106.4±7.8 | 159.50±22.7 | 134.90±14.8 | 134.10±19.8 | 138.70±10.2 | 158.50±12.8 | 161.60±5.4 | 203.80±33.9 | 168.10±16.7 | 178.30±17.4 | 178.20±7.1 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated wastewater, Sur TWC: Surface treated wastewater covered, Sub TW: Subsurface treated wastewater, Sub TWC: Subsurface treated wastewater covered. EC: Electrical conductivity, TDS: Total dissolved salts. All values are expressed as Means±SEM.

Table 3: Nitrate, sulfur and chloride concentrations of pre-sowing soil and after irrigation with PW and TWW at two depths of 0-10 and 10-30 cm

| | | | Growing cycle | | | | | | End of growing cycle | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemicals | Depth (cm) | Pre-sowing | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC |
| Nitrate (mg kg$^{-1}$) | 0-10 | 14.0±1.1 | 42.80±3.8 | 36.00±2.9 | 26.90±2.3 | 5.60±0.55 | 7.53±0.64 | 10.40±1.1 | 21.00±1.8 | 18.20±1.4 | 25.00±2.0 | 47.80±3.4 | 29.90±2.6 | 28.80±2.4 |
| | 10-30 | 13.1±1.0 | 6.13±0.81 | 39.9±3.9 | 26.1±2.7 | 35.0±2.8 | 26.9±2.5 | 8.0±0.98 | 18.0±1.3 | 16.1±1.4 | 21.1±1.5 | 24.0±1.7 | 25.1±1.7 | 26.1±1.9 |
| Sulfur (mg kg$^{-1}$) | 0-10 | 5.1±0.35 | 6.03±0.61 | 7.00±0.78 | 6.00±0.52 | 7.00±0.75 | 6.04±0.66 | 7.98±0.78 | 7.03±0.67 | 7.98±0.72 | 7.06±0.64 | 8.05±0.69 | 7.04±0.66 | 9.00±0.81 |
| | 10-30 | 6.0±0.52 | 6.97±0.65 | 7.98±0.71 | 5.03±0.38 | 4.07±0.29 | 6.00±0.58 | 5.00±0.35 | 8.07±0.75 | 9.03±0.84 | 6.05±0.57 | 5.13±0.41 | 7.08±0.69 | 6.10±0.55 |
| Chloride (g kg$^{-1}$) | 0-10 | 14.0±1.1 | 18.40±1.5 | 21.10±1.8 | 28.00±2.3 | 27.90±2.4 | 24.00±2.0 | 28.00±2.5 | 43.80±3.1 | 41.90±2.9 | 37.00±2.7 | 42.00±3.1 | 25.10±1.8 | 59.40±4.1 |
| | 10-30 | 17.0±1.3 | 16.90±1.4 | 18.00±1.6 | 27.00±2.4 | 25.20±1.7 | 27.90±2.2 | 27.00±2.3 | 39.00±2.5 | 42.00±2.7 | 38.00±2.7 | 31.10±2.4 | 28.20±2.1 | 32.10±2.4 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated wastewater, Sur TWC: Surface treated wastewater covered, Sub TW: Subsurface treated wastewater, Sub TWC: Subsurface treated wastewater covered. All values are expressed as means±SEM

Table 4: Phosphorus, potassium and sodium concentrations in pre-sowing soil and after irrigation with PW and TWW at two depths of 0-10 and 10-30 cm

| | | | Growing cycle | | | | | End of growing cycle | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Macro-nutrient | Depth (cm) | Pre-sowing | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC |
| Phosphorus (mg kg$^{-1}$) | 0-10 | 0.16±0.03 | 0.21±0.02 | 0.18±0.04 | 0.31±0.08 | 0.33±0.06 | 0.38±0.09 | 0.35±0.10 | 0.27±0.05 | 0.25±0.04 | 0.44±0.07 | 0.49±0.08 | 0.58±0.09 | 0.55±0.07 |
| | 10-30 | 0.19±0.02 | 0.23±0.04 | 0.20±0.05 | 0.33±0.07 | 0.39±0.08 | 0.41±0.08 | 0.43±0.09 | 0.24±0.03 | 0.26±0.04 | 0.47±0.08 | 0.54±0.09 | 0.64±0.10 | 0.62±0.11 |
| Potassium (mg kg$^{-1}$) | 0-10 | 1.63±0.12 | 1.95±0.13 | 1.16±0.12 | 3.03±0.18 | 1.97±0.12 | 1.98±0.11 | 2.0±0.14 | 2.02±0.15 | 1.10±0.11 | 3.08±0.17 | 3.01±0.16 | 3.03±0.2 | 2.04±0.14 |
| | 10-30 | 2.2±0.15 | 2.05±0.12 | 1.2±0.10 | 3.0±0.22 | 2.0±0.17 | 2.06±0.12 | 1.98±0.14 | 1.20±0.11 | 1.23±0.12 | 3.07±0.17 | 2.10±0.15 | 3.10±0.20 | 2.08±0.17 |
| Sodium (mg kg$^{-1}$) | 0-10 | 5.20±0.36 | 10.2±1.1 | 10.1±0.9 | 14.9±1.3 | 16.0±1.2 | 13.1±1.2 | 15.0±1.4 | 16.07±1.4 | 17.07±1.3 | 25.1±1.9 | 30.0±2.3 | 18.03±1.2 | 25.06±1.9 |
| | 10-30 | 6.53±0.49 | 8.10±0.72 | 8.13±0.75 | 15.9±1.6 | 16.0±1.4 | 17.0±1.6 | 15.1±1.5 | 16.1±1.5 | 17.0±1.4 | 30.0±2.3 | 29.0±2.4 | 23.1±1.5 | 22.2±1.7 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated wastewater, Sur TWC: Surface treated wastewater covered, Sub TW: Subsurface treated wastewater, Sub TWC: Subsurface treated wastewater covered. All values are expressed as Means±SEM

Table 5: Calcium and magnesium concentrations of pre-sowing soil and after irrigation with PW and TWW at two depths of 0-10 and 10-30 cm

| | | | Growing cycle | | | | | End of growing cycle | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Macro-nutrient | Depth (cm) | Pre-sowing | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC | Sur PW | Sur PWC | Sur TW | Sur TWC | Sub TW | Sub TWC |
| Calcium (mg kg$^{-1}$) | 0-10 | 29.5±2.0 | 24.1±1.8 | 25.0±2.0 | 25.1±1.6 | 25.0±1.6 | 25.2±1.9 | 24.0±2.0 | 34.8±2.3 | 35.9±2.5 | 28.0±2.3 | 28.9±2.1 | 35.0±2.5 | 36.9±2.4 |
| | 10-30 | 30.7±2.2 | 23.1±1.9 | 23.0±2.0 | 24.0±2.1 | 24.1±1.8 | 23.0±1.8 | 26.0±2.0 | 30.1±2.3 | 34.0±2.3 | 27.1±2.2 | 23.2±1.7 | 29.1±2.3 | 38.0±2.6 |
| Magnesium (mg kg$^{-1}$) | 0-10 | 5.0±0.35 | 7.93±0.69 | 5.07±0.41 | 7.10±0.61 | 6.97±0.49 | 5.08±0.52 | 5.01±0.46 | 7.08±0.63 | 8.0±0.69 | 10.0±0.95 | 13.0±1.1 | 11.1±1.0 | 12.0±1.2 |
| | 10-30 | 7.0±0.64 | 6.08±0.57 | 4.14±0.35 | 7.02±0.61 | 6.03±0.54 | 5.04±0.43 | 6.06±0.52 | 15.0±1.2 | 13.1±1.2 | 14.1±1.2 | 16.0±1.3 | 19.0±1.4 | 11.2±1.0 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated wastewater, Sur TWC: Surface treated wastewater covered, Sub TW: Subsurface treated wastewater, Sub TWC: Subsurface treated wastewater covered. All values are expressed as Means±SEM

Table 6: Quantity and weight of harvested melon fruit from different treatments at the end of the experiment

| Treatments | Total fruit quantity/treatment | Total fruit weight/treatment (g) | Weight/fruit (g) |
|---|---|---|---|
| Sur PW | 65 | 8605.4±2632 | 132.4±40.5 |
| Sur PWC | 63 | 10044.0±1466.4 | 159.4±23.3 |
| Sur TW | 89 | 16555.6±5311.6 | 186.0±59.7 |
| Sur TWC | 82 | 12424.2±2690.8 | 151.5±32.8 |
| Sub TW | 77 | 12425.0±2871.7 | 161.4±37.3 |
| Sub TWC | 90 | 15686.0±3599.4 | 174.3±40.0 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated water, Sur TWC: Surface treated water covered, Sub TW: Subsurface treated water, Sub TWC: Subsurface treated water covered. The values are expressed as Mean±SEM

Table 7: Biomass of melon plant from different treatments at the end of the experiment

| Treatments | Total plant quantity/treatment | Total plant biomass/treatment (g) | Biomass/plant (g) |
|---|---|---|---|
| Sur PW | 59 | 2820.6±546.6 | 47.8±9.3 |
| Sur PWC | 57 | 3454.8±624.0 | 60.6±10.9 |
| Sur TW | 60 | 4091.4±646.8 | 68.2±10.8 |
| Sur TWC | 54 | 3933.2±639.8 | 72.8±11.8 |
| Sub TW | 60 | 4058.8±695.0 | 67.6±11.6 |
| Sub TWC | 55 | 3855.6±621.8 | 70.1±11.3 |

Sur PW: Surface potable water, Sur PWC: Surface potable water covered, Sur TW: Surface treated water, Sur TWC: Surface treated water covered, Sub TW: Subsurface treated water, Sub TWC: Subsurface treated water covered. The values are expressed as Mean±SEM

## DISCUSSION

During the next decade, water demand is expected to escalate in the whole Mediterranean area and the prospective climate change will aggravate the lack of available water. The proposed future programs is to treat 50% of the Palestinian's wastewater for agriculture settings which is the major mean for water sustainable reuse practice. However, this ambitious plan needs considerable agricultural research to support further use of TWW in terms of assessing its hazards and/or benefits associated with irrigation of the crops.

Although the mean value of BOD (83.3±3.4 mg $L^{-1}$) recorded in this study for TWW is relatively high, it still meets the World Health Organization (WHO) Standards of BOD<100 mg $L^{-1}$. However, the mean value of COD (248.7±14.5 mg $L^{-1}$) does not meet the WHO Standards of COD<150 mg $L^{-1}$[15]. In terms of physical properties, the pH was significantly increased in TWW compared to PW. Conversely, EC and TDS were significantly decreased in TWW than PW. The pH of both PW and TWW (7.12±0.05 and 7.68±0.09, respectively) was within the WHO acceptable range (6.5-9.5) whereas EC (4736±102.1 and 2955±74.2 mS $cm^{-1}$) and TDS (3521±78.5 and 1832±40.9 ppm) values were higher than the WHO acceptable range of <2500 mS $cm^{-1}$ for EC and <1600 ppm for TDS[15], indicating the salinity of both water qualities[16]. Similar results were obtained by Schacht and Marschner[17] and Rawashdeh[18]. The observed increase in pH of TWW may be attributed to increase production of ammonia under aerobic conditions. The higher total alkalinity recorded for TWW in the current study do support this idea.

Nitrate level was significantly ($p<0.05$) lower in TWW than PW. Nitrate contamination of 193 wells in Gaza Strip with levels up to 528 mg $L^{-1}$ was recorded, which exceeds the recommended limits in both WHO (50 mg $L^{-1}$) and Palestinian water Authority (70 mg $L^{-1}$) guidelines[19]. On the other hand, the low level of $NO_3$ in TWW may be explained on the basis that nitrate is being reduced to ammonium hydroxide due to anaerobic condition. Sulfur and Cl levels were also significantly ($p<0.05$) lower in TWW with respect to PW. The lower level of S in TWW may be attributed to possible transformation of sulfate to hydrogen sulfide under aerobic conditions. In addition, high concentrations of Cl in PW could be explained by seawater intrusion into the costal aquifer in the Gaza Strip[20]. Calcium and Mg concentrations were significantly lower in TWW. This finding coincides with the lower total hardness of TWW than PW. Potassium level was significantly higher in TWW whereas Na level was significantly lower. The overall high concentrations of S, Cl and Na salts may offer an explanation of higher TDS and EC in PW.

Heavy metals were below the detected limit in both PW and TWW, indicating low contents of these metals. In Gaza Strip, where the industrial sector is limited and underdeveloped, it has been shown that heavy metals in the effluent are low and they comply with the standards of reused wastewater in agriculture[21]. This is true in many developing areas around the world[16,22,23]. It is worth mentioning that Ag, As, Bi, Cd, Co, Hg, Mo, Pb, Se and Sn were not detected in both irrigation water used. Accordingly, there is a future possibility for the current water situation in terms of low heavy metals content accept able to be used for agricultural irrigation in the Gaza Strip. However, this needs further investigation.

Bacterial contamination was detected in TWW but PW was free of contamination. Total and fecal coliforms contamination in TWW ($8.8\times10^4$ and 215 CFU/100 mL, respectively) exceeds that of the WHO standards of $1\times10^3$ CFU/100 mL for total coliform and $<2\times10^2$ CFU/100 mL for fecal coliform[14]. Similar findings were reported by other authors[5,24]. The presence of these bacteria indicates insufcient water treatment and this could be a potential source of health risk. However, the fecal coliform problem can be resolved by adding advanced treatment units to the North wastewater treatment plant, (for instance disinfection units), or/and by following and concentrating on the safety guidelines and precautions when using the TWW in irrigation.

The pH of the pre-sowing soil was in the normal range of a desirable agricultural soil (7.59±0.06- 7.79±0.07), with less acidic top layer (0-10 cm) and more acidic deep layer (10-30 cm). In field irrigation with TWW and PW of different treatments, soil became generally more acidic at the top layer and less acidic at the deep layer, particularly at the end of growing season. Nevertheless, there is an overall narrow change in the pH of various experimental treatments. Such findings were in agreement with that previously reported[9,25]. The EC and TDS of the soil showed an increasing trend towards the end of the growing season with the highest effect in soil irrigated with TWW. The mean values of EC and TDS were lower in the top layer of pre-sowing soil where as their values were generally increased in the top soil layer irrigated with PW and TWW. This may be due to accumulation of less soluble salts in the top soil layer and possible formation of organic acids due to biodegradation of organic compounds in soils. These results are inaccord with that found by Castro and his colleagues, who investigated the effects of wastewater irrigation on soil properties and turf grass growth and 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]. Indeed, the high salinity previously recorded for the used irrigation water would confer such effect on the soil. In this case selecting the appropriate crops that are more salt-tolerant would be a suitable choice. It will be prudent to mention that the high salinity concentration in the TWW is deeply connected with the high salinity of PW in the Gaza Strip.

The mean levels of $NO_3$, S and Cl were increased in soil irrigated with PW and TWW in comparison with their levels in the pre-sowing soil. This was expected since PW and TWW had high content of these elements. Nitrate concentration was generally decreased from the top to the deeper depth of PW and TWW-irrigated soil, particularly at the end of growing season. High $NO_3$ content was recorded in the surface soil layers[27]. Sulfur concentration was lower in the top layers of pre-sowing and PW irrigated soils. In contrast, higher concentrations of S were detected in the top soil layer irrigated with TWW. Chloride concentration was lower in the top layer of pre-sowing soil, but became higher upon irrigation with both PW and TWW. Regardless such layer distribution variation, it is admitted that wastewater irrigation increased soil $NO_3$, S and Cl content[28].

The concentrations of P, K, Na, Ca and Mg in various soil profiles showed an increasing trend towards the end of the growing season with the highest values in the soil irrigated with TWW. Similar trend was documented[29]. This implies soil accumulation of these macronutrients as a result of their high concentrations in the used irrigation water. However, the low concentration of P in both soil depths of TWW treatments (0.31-0.64 ppm) may be attributed to low solubility of P in soil solution due to relatively high soil pH. Similar finding was reported[30]. It is accepted that available N, K, S and exchangeable and water soluble Na, K, Ca, Mg were highest in effluent irrigated soil[31]. However, the macronutrients concentrations fluctuate in both layers of soil irrigated with PW and TWW. Nevertheless, there is a higher concentrations of these macronutrients in soil irrigated with PW and TWW compared to their concentrations in pre-sowing soil, indicating a direct impact of water irrigation on their soil content.

As depicted from the present results, the total quantity and weight of harvested melon fruit were generally higher in plots irrigated with TWW than those irrigated with PW, with the highest weight/melon fruit was registered for surface TWW plots. Such findings are in the line with other studies[32,33]. The higher fruit yield in TWW-irrigated plots suggests that TWW can supply enough nutrients as indicated by water and soil analysis and confirms its beneficial alternative role in agriculture. Regarding biomass, the total plant biomass/treatment in plots irrigated with TWW was higher than those irrigated with PW, with the highest biomass/plant was registered for surface TWW covered plots. Again, application of TWW may enrich the soil with necessary nutrients that enhance plant growth. Beside the fact that TWW contains some bacteria as shown from the relatively high BOD value that participate in the degradation of organic matter which maintain soil fertility. The above views are supported by several authors, who showed that irrigation with TWW had a significant positive impact on all characters of plant quality[34-36].

## CONCLUSION AND FUTURE RECOMMENDATION

Reuse of TWW in agriculture sector in the Gaza Strip has a positive impact in terms of its low content of heavy metals, enhancement of soil fertility and plant productivity. On the other hand, its high salinity could impose negative effect on soil properties. This obstacle of salinity could be overcome either by mixing TWW with low salt-filtered water or implanting more salt-tolerant crops would put TWW as an alternative option for irrigation in the Gaza Strip. Further research is needed on the impact of long term application of TWW on human health and environment particularly in terms of pathogens.

## SIGNIFICANCE STATEMENTS

This study discovers the possible impact of treated wastewater irrigation on soil properties that can be beneficial for enhancement of melon yield. This study help the researchers to uncover the critical area of the combined effect of wastewater and soil on plant growth that many researchers were not able to explore. Thus, a new theory on wastewater and soil contribution to the extent of plant growth may be arrived at.

## ACKNOWLEDGMENTS

The authors would like to thank Dr. Osnat Gillor, Ben-Gurion University of the Negev, Israel for her support and suggestions during the research activity.

## REFERENCES

1. PCBS., 2016. Population projections, Annual statistics. Estimated Population in the Palestinian Territory Mid-Year by Governorate, 1997-2016, Palestinian Central Bureau of Statistics, Palestine.
2. Abu Amr, S.S. and M.M. Yassin, 2008. Microbial contamination of the drinking water distribution system and its impact on human health in Khan Yunis Governorate, Gaza Strip: Seven years of monitoring (2000-2006). Public Health, 122: 1275-1283.
3. Nassar, A.R., H. Al-Najar and J.Y. Al-Dadah, 2009. Socio-economic aspects of wastewater reuse in the gaza strip. J. Environ. Sci. Technol., 2: 170-178.
4. Yassin, M.M., K.M. Tubail and J.Y. Al-Dadah, 2008. Towards strategies for pollution control on the use of wastewater effluent in sustainable agriculture in the Gaza Strip. World Rev. Sci. Technol. Sustain. Dev., 5: 66-78.
5. Abu Foul, A.M., R.Y. Alkhatib, M.S. Abu Alqumboz and T.J. Abunama, 2014. Effects of irrigation with treated wastewater on the physical properties and chemical composition of white corn. IUG J. Nat. Stud., 22: 77-96.
6. Jimenez, B. and T. Asano, 2008. Water Reclamation and Reuse around the World. In: Water Reuse: An International Survey of Current Practice, Issues and Needs, Jimenez, B. and T. Asano (Eds.). IWA Publishing, London, ISBN: 9781843390893, pp: 3-26.
7. Albakkar, Y., 2014. An integrated approach to wastewater management and reuse in Jordan: A case study of the Jordan valley. Master Thesis, Trent University, Peterborough, Ontario, Canada.
8. Elbana, T.A., N. Bakr and M. Elbana, 2017. Reuse of Treated Wastewater in Egypt: Challenges and Opportunities. In: The Handbook of Environmental Chemistry, Negm, A.M. (Ed.). Springer, Berlin, pp: 1-25.
9. El-Nahhal, Y., K. Tubail, M. Safi and J. Safi, 2013. Effect of treated waste water irrigation on plant growth and soil properties in Gaza Strip, Palestine. Am. J. Plant Sci., 4: 1736-1743.
10. Duran-Ros, M., J. Puig-Bargues, G. Arbat, J. Barragan and F.R. de Cartagena, 2009. Effect of filter, emitter and location on clogging when using effluents. Agric. Water Manage., 96: 67-79.
11. FAO., 2007. CROPWAT, Version 8. Food and Agriculture Organization, Rome, Italy.
12. Eaton, A.D., L.S. Clesceri and A.E. Greenberg, 2005. Standard Methods for Wastewater Analysis. American Public Health Association, Washington, DC., USA.
13. Sessitsch, A., A. Weilharter, M.H. Gerzabek, H. Kirchmann and E. Kandeler, 2001. Microbial population structures in soil particle size fractions of a long-term fertilizer field experiment. Applied Environ. Microbiol., 67: 4215-4224.
14. Miller, J.E., 2005. The Chicago Guide to Writing about Multivariate Analysis. The University of Chicago Press, Chicago, USA., Pages: 196.
15. WHO., 2006. Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems. Alberta Public Affairs Bureau/Queens Printer, Canada, ISBN: 9780778543947, pp: 3-4.
16. Alghobar, M.A. and S. Suresha, 2016. Effect of wastewater irrigation on growth and yield of rice crop and uptake and accumulation of nutrient and heavy metals in soil. Applied Ecol. Environ. Sci., 4: 53-60.
17. Schacht, K. and B. Marschner, 2015. Treated wastewater irrigation effects on soil hydraulic conductivity and aggregate stability of loamy soils in Israel. J. Hydrol. Hydromech., 63: 47-54.
18. Rawashdeh, H.M., 2017. Sunflower seed yield under trickle irrigation using treated wastewater. Afr. J. Agric. Res., 12: 1811-1816.

19. MacDonald, E., B.G. Herrador, S. Hyllestad, V. Lund and K.Nygard *et al*., 2016. Water usage in the Gaza Strip: Recommendations from a literature review and consultations with experts. East. Mediterr. Health J., 22: 910-918.
20. Sarsak, R. and M.N. Almasri, 2013. Seawater intrusion into the coastal aquifer in the Gaza Strip: A computer-modelling study. Lancet, Vol. 382. 10.1016/S0140-6736(13)62604-5.
21. Shomar, B.H., G. Muller and A. Yahya, 2004. Potential use of treated wastewater and sludge in the agricultural sector of the Gaza Strip. Clean Technol. Environ. Policy, 6: 128-137.
22. Akaninwor, J.O., M.O. Wegwu and E.O. Nwaichi, 2007. Levels of some heavy metals and physico chemical properties of effluents from a Beverage company in Rivers State, Nigeria. J. Applied Sci. Environ. Manage., 11: 27-30.
23. Mansourri, G. and M. Madani, 2016. Examination of the level of heavy metals in wastewater of Bandar Abbas wastewater treatment plant. Open J. Ecol., 6: 55-61.
24. Balkhair, K.S., 2016. Microbial contamination of vegetable crop and soil profile in arid regions under controlled application of domestic wastewater. Saudi J. Biol. Sci., 23: S83-S92.
25. Abdel-Aziz, R., 2015. Impact of treated wastewater irrigation on soil chemical properties and crop productivity. Int. J. Water Resour. Arid Environ., 4: 30-36.
26. Castro, E., M.P. Manas and J. De Las Heras, 2011. Effects of wastewater irrigation on soil properties and turfgrass growth. Water Sci. Technol., 63: 1678-1688.
27. Jemai, I., N. Ben Aissa, T. Gallali and F. Chenini, 2013. Effects of municipal reclaimed wastewater irrigation on organic and inorganic composition of soil and groundwater in Souhil Wadi Area (Nabeul, Tunisia). Hydrol. Curr. Res., Vol. 4. 10.4172/2157-7587.1000160.
28. Alghobar, M.A., L. Ramachandra and S. Suresha, 2014. Effect of Sewage water irrigation on soil properties and evaluation of the accumulation of elements in grass crop in Mysore city, Karnataka, India. Am. J. Environ. Protect., 3: 283-291.
29. Hasan, H., A. Battikhi and M. Qrunfleh, 2014. Impacts of treated wastewater reuse on some soil properties and production of *Gladiolus communis*. J. Hortic., Vol. 1. 10.4172/2376-0354.1000111.
30. Metson, G.S., R.L. Hale, D.M. Iwaniec, E.M. Cook, J.R. Corman, C.S. Galletti and D.L. Childers, 2012. Phosphorus in Phoenix: A budget and spatial representation of phosphorus in an urban ecosystem. Ecol. Applic., 22: 705-721.
31. Boruah, D. and S. Hazarika, 2010. Normal water irrigation as an alternative to effluent irrigation in improving rice grain yield and properties of a paper mill effluent affected soil. J. Environ. Sci. Eng., 52: 221-228.
32. Ladwani, K.D., K.D. Ladwani, V.S. Manik and D.S. Ramteke, 2012. Impact of domestic wastewater irrigation on soil properties and crop yield. Int. J. Scient. Res. Publ., 2: 164-172.
33. Husseiki, M., E. Nasser, D. Raad and R. El Achkar, 2017. Economic benefit of using treated wastewater for irrigation in the Bekaa Region, Lebanon. Lebanese Sci. J., 18: 47-52.
34. Rusan, M.J.M., S. Hinnawi and L. Rousan, 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination, 215: 143-152.
35. Mousavi, S.R., M. Galavi and H. Eskandari, 2013. Effects of treated municipal wastewater on fluctuation trend of leaf area index and quality of maize (*Zea mays*). Water Sci. Technol., 67: 797-802.
36. Alghobar, M.A. and S. Suresha, 2016. Growth and yield of tomato, Napier grass and sugarcane crops as influenced by wastewater irrigation in Mysore, Karnataka, India. World Res. J. Agric. Sci., 3: 69-79.