BIRZEIT UNIVERSITY

Faculty of Graduate Studies
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“Reuse of reclaimed wastewater to irrigate corns designated for animal feeding”

"استخدام المياه العادمة المعالجة لري نباتات الذُرة المنوي استعمالها لتغذية الحيوانات"

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To who lost her fight! Her body did not have the strength to hold that great soul! That soul which instilled in me the reasoning power! Mother, I'll miss you terrible! You created a vacuum in my heart today!

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الملخص

يعتبر استخدام المياه العادمة المعالجة في الري من الأمور الهامة في البلدان التي تعاني من نقص في الموارد المائية كونه مصدراً إضافياً للماء والغذاء للنبات، كما انه يشكل وسيلة أمنة للتخلص من المياه العادمة بصورة غير مضرة بالبيئة. استخدام المياه العادمة المعالجة يمكن ان يؤدي الى اثار سامة على الانسان والحيوان لما قد يحتويه من تراكيز عالية من الملوثات الكيمائية والبيولوجية. إن الاهتمام بدراسة التأثيرات الايجابية والسلبية لهذه المياه يعتبر من الأولويات في الدراسات التي تهتم بمستقبل الزراعة في فلسطين.

أجري هذا البحث في حديقة حرم جامعة بيرزيت – فلسطين، بهدف دراسة تأثير استخدام مياه الصرف الصحي المعالجة معالجة ثانوية الناتجة من محطة البيرة لمعالجة مياه الصرف الصحي مقارنة مع مياه الصنبور النظيفة على نبات الذرة الصفراء المنوي استخدامها لتغذية الحيوانات بالإضافة الى تأثير ذلك على خواص التربة الفيزيائية والكيميائية خصوصا على نسبة العناصر الثقيلة فيها. تمت زراعة بذور الذرة في احواض بلاستيكية في تربة زراعية احضرت من منطقة قلقيلية في الضفة الغربية. اشتملت التجربة على خمسة معاملات للري والتسميد وكانت كالتالي: 1- ري بمياه الصنبور فقط، 2- ري بمياه الصنبور مع تسميد كامل، 3- ري بمياه الصرف المعالجة فقط، 4- ري بمياه الصرف المعالجة مع تسميد كامل، اخيراً 5- ري بمياه الصرف المعالجة مع نصف تسميد. كررت كل معاملة ستة مرات ووزعت الوحدات بشكل عشوائي حسب تصميم القطاعات الكاملة العشوائية، وقد أظهرت النتائج ما يلي:

مياه الري: درجة حموضة المياه كانت تميل إلى القاعدية قليلا (7.9). تركيز الصوديوم في المياه المعالجة وصل تقريبا إلى أعلى قيمة مسموح بها وفقا للمعايير الفلسطينية. متوسط تركيزات المعادن الثقيلة كان أقل بكثير من القيم القصوى المسموح بها للري غير المقيد وفقا لمعايير سلطة جودة البيئة الفلسطينية. أظهرت الفحوصات ارتفاع كبير اعداد بكتيريا الكوليفورم في مياه الصرف الصحي المعالجة، والتي تجاوزت الحد الموصى به.

التربة: تم تسجيل انخفاض في قيمة pH للتربة في نهاية التجربة في كل المعاملات بالمقارنة مع ما قبل الزراعة. من ناحية أخرى، فإن الري بمياه الصرف المعالجة أدت إلى

زيادة بمقدار 18.5% في **EC** للتربة مقارنة مع الري بمياه الصنبور**.** لم يلاحظ أي تغير في قوام التربة بعد نهاية التجربة، في حين زادت **CEC** للتربة نتيجة للري بمياه الصرف الصحي المعالجة**.** استخدام مياه الصرف الصحي المعالج أدى إلى زيادة معنوية في مستوى **P** و **K** في التربة مقارنة بمياه الصنبور في حين لم يلاحظ اي فرق معنوي في تركيز **N**. كان تركيز كل من (**Ag, Cd, Pb**) في نهاية التجربة اقل من الحد الممكن قياسه في التربة. بشكل عام، فإن استخدام مياه الصرف الصحي المعالجة من محطة البيرة لم ينتج عنه زيادة محتوى المعادن الثقيلة في التربة، بالمقارنة مع مياه الحنفية.

النبات: لوحظ ارتفاع النمو باستخدام مياه الصرف الصحي المعالجة على محصول الذرة، حيث كان هناك فرق معنوي في طول وعدد اوراق النباتات المروية بالمياه العادمة المعالجة بالمقارنة مع تلك المروية بمياه الصنبور، بينما لم يلاحظ فرق في عدد الثمار مقارنة مع مياه الصنبور، في حين أن الفارق في الوزن الجاف كان أعلى بشكل ملحوظ (~ الضعف). التسميد من ناحية أخرى، أدى الى زيادة معنوية في طول النباتات، عدد الاوراق و وزن الثمار. فحص بكتيريا (***E.coli***) لثمار الذرة لم يظهر اي تلوث في أي من المعاملات، ومياه الصرف المعالجة من محطة البيرة ليس من المرجح أن تشكل خطراً لتلوث نباتات الذرة حسب نتائج هذه التجربة**.** كان تركيز**Ag, Al, As, Cd, Co, Pb** أقل من الحد الممكن قياسه في جميع عينات بذور الذرة المحصودة من هذه التجربة. من ناحية أخرى، تم الكشف عن وجود **Cu, Ni, Fe, Zn** حيث لم يكن هناك فرق معنوي في التركيز في بذور الذرة الأصلية قبل الزارعة وبعد الحصاد. من ناحية أخرى تظهر نتائج فحص بذور الذرة انخفاض في تركيز **Fe** بمقدار 50-60 ٪ من تركيزه الأصلي (50 إلى 22 مغ / كغ على التوالي)، في حين انخفض **Na** الى 40-50٪ من تركيزه الأصلي (26 الى 18 ملغم / كغم، على التوالي). أظهرت النتائج زيادة في محتوى الاوراق من الكلوروفيل والبرولين عند استخدام مياه الصرف المعالجة في الري، كما ان استخدام الاسمدة ايضاً ادى الى نفس النتيجة.

ABSTRACT

The use of treated wastewater (TWW) in irrigation is one of the important things in countries that suffer from a shortage of water resources, since it is an additional source of water and nutrients for the plants; it is also a safe way to get rid of wastewater without harmful effects on the environment. Using TWW can lead to toxic effects on humans and animals, because it may contain high concentrations of chemical and biological contaminants. Interest in studying the positive and negative impacts of this water resource is one of the priorities in the studies concerned with the future of agriculture in Palestine.

This research was conducted in the research field of Birzeit University (BZU) - Palestine, in order to study the effect of using secondary TWW from Al-Bireh wastewater treatment plant (WWTP) in comparison with tap water on corn intended to be used for animal feeding as well as the impact on the physical and chemical properties of soil, especially on its content of heavy elements. Corn seeds were planted in plastic pots filled with agricultural soil brought from the area of Qalqilia in the West Bank. The experiment includes five treatments of irrigation and fertilization, as follows: **1-** Irrigation with Tap Water (TpW) only, **2-** Irrigation with TpW + full fertilization, **3-** Irrigation with TWW only, **4-** Irrigation with TWW + full fertilization. **5-** Irrigation with TWW + half-fertilization. Each treatment was repeated six times and the experimental units were randomly distributed according to Complete Randomized Block Design (CRBD). Results show the following:

Irrigation water: pH of irrigation water was slightly alkaline (7.9) and it was within the acceptable range of the Palestinian Environmental Quality Authority (EQA) standards. **Na** in the TWW was almost up to the highest allowable value according to the Palestinian standards. The average concentrations of heavy metals were considerably lower than the maximum allowable values for the unrestricted irrigation according to the EQA standards. Results showed high numbers of coliform bacteria in the TWW, which exceeded the recommended range.

Soil: soil pH was significantly decreased in all treatments at the end of the experiment compared to its value before planting. On the other hand, TWW increased soil EC by 18.5% in comparison to TpW. There has been no significant change in the texture of the soil between treatments at the end of the experiment, while, soil Cation Exchange Capacity (CEC) increased significantly due to irrigation with TWW. The results indicated that the use of treated sewage water led to a significant increase in the level of P and K in the soil compared to TpW, while there is no significant difference in the concentration of N in the soil. Concentrations of soil Ag, Cd and Pb after cultivation were not detected. In general, the use of TWW from Al-Bireh did not result in an increased content of heavy metals in the soil compared to TpW.

Plant: high growth rate was observed as a result of irrigation with TWW and there was significant difference in the number of leaves of plants irrigated with wastewater compared to those irrigated with TpW. On the other hand, there was no significant difference in the number of fruits compared with TpW, while the difference in dry weight was significantly higher (~doubled). Fertilization led to significant increase in plant height and fruit weight. *E.coli* bacteria was absent in the fruits from all treatments units. Ag, Al, As, Cd, Co, and Pb concentrations were lower than the detection limit for all corn grains samples of the experiment. On the other hand, heavy metals, Cu, Fe, Ni and Zn were detected without significant difference between their concentrations on the original corn seeds before plantation and after harvesting. However, Fe dropped to 50-60% of its original concentration, while Na dropped also to 40-50% of its original concentration. Results showed also an increase in the chlorophyll and proline content of leaves when using TWW in irrigation, and fertilizer also led to the same result.

ABBREVIATIONS

Acronym	Definition
°C	Degree Centigrade
µg/L	Microgram per Liter
µS/cm	Micro-Siemens per Centimeter
APHA	American Public Health Association
ARIJ	Applied Research Institute - Jerusalem
Avg	Average
AWC	Arab Water Council
BDL	Below Detection Limit
BOD_5	Biochemical Oxygen Demand (after five days)
BZU	Birzeit University
CEC	Cation Exchange Capacity
CEDARE	Center for Environment and Development for the Arab Region and Europe
CFU	Colony-forming unit
COD	Chemical Oxygen Demand
CRBD	Complete Randomized Block Design
DO	Dissolved Oxygen
EAS	Extended Aeration System
EC	Electrical Conductivity
E-coli	Escherichia coli bacteria
EQA	Environmental Quality Authority
FAO	Food and Agriculture Organization
FC	Faecal Coliform
FEW	Friends of Environment and Water
GTZ	German Agency for Technical Cooperation
Ha	Hectare (10,000 square meters)
HBU	Heidelberg University
HWE	House of Water and Environment
IC	Ion Chromatography
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectroscopy
ISO	International Organization for Standardization
JS	Jordanian standards
KfW	German Development Bank
Kj-N	Kjeldahl Nitrogen
km	Kilometers
LC	Lower Crust
m	Meter
Max	Maximum
mg/L	Milligram per Liter
Min	Minimum
MoA	Ministry of Agriculture
MRD	Maximum Recovery Diluent
NGO	Non-Governmental Organization
PARC	Palestinian Agricultural Relief Committees

PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
ppm	parts per million
PSI	Palestinian Standard Institute
PWA	Palestinian Water Authority
RCBD	Randomized Completely Blocks Design
SAR	Sodium Adsorption Ratio
SD	Standard Deviation
SE	Standard Error
TC	Total Coliform
TDS	Total Dissolved Salts
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TpW	Tap Water
TpWF	Tap water with complete fertilization
TSS	Total Suspended Solids
TWW	Treated Wastewater
TWWF	Treated Wastewater with complete Fertilization
TWWF½	Treated Wastewater with half Fertilization
UC	Upper Crust
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International
USDA	United States Department of Agriculture
UV	Ultra-Violet
WHO	World Health Organization
WW	Wastewater
WWTP	Wastewater Treatment Plant

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is one of the renewable natural resources on earth and the most important characteristic of it, as a chemical compound, is its stability. Most parts of the Arab world suffer from water scarcity, due to their occurrence in arid and semi-arid areas of the globe. With the growth of the population, the problem is exacerbated as a logical consequence of the increasing demand for water to meet the needs of domestic, industrial and agricultural products. Not only the water problem in the Arab world rarely, but extends to the quality of water, which is low and turns into unsuitable water for use due to various reasons such as over pumping, excessive application of fertilizers and pesticides and the industrial, agricultural and domestic pollution (AWC and CEDARE 2004).

To alleviate the water crisis, serious consideration should be taken such as wastewater reclamation and reuse in many areas, including agricultural irrigation, and this is considered as an adequate strategy to dispose of the effluents of conventional WWTPs. Reclaimed wastewater contains considerable amounts of nutrients, mainly N and P, which can substitute proportional quantities of artificial fertilizers.

1.2 Objectives

The objective of this research is to study the possibility of reusing reclaimed municipal wastewater of Al-Bireh wastewater treatment plant for corn irrigation rather than discharging it into wadis. Moreover, soil quality will be studied before and after the experiment in order to study the effect of using reclaimed wastewater in irrigation. The specific objectives of this research are:

- To compare the effect of treated wastewater (TWW) and tap water (TpW) in combination with artificial fertilizer on the corn constituents and dry yield and on soil properties by determining soil physical and chemical characteristics.
- To identify the impact of TWW on plant morphology, growth rate, number of leaves, fruits and chlorophyll and proline contents.

The following research questions were addressed:

1. *Can treated wastewater (TWW) effluent from Al-Bireh Wastewater treatment plant (WWTP) meet the water and nutritional demands of fodder corn plants designated for animal nutrition?*

2. *Is TWW effluent from Al-Bireh WWTP safe to use as an irrigation source for fodder corn plants without causing significant heavy metals pollution to soil and fruits (grains)?*

1.3 Agriculture in Palestine

The total area of West Bank is 5,655 km^2, while the total area of the Gaza Strip is 365 km^2 (PCBS 2011). According to the PCBS and MoA agricultural survey, the total area of agricultural land in the Palestine is 1,207,061 dunums (91.6% in the West Bank and 8.4% in the Gaza Strip). Palestine characterized by the diversity of its terrain and climatic environments in terms of the earth, temperature, rainfall and elevation from sea level. These factors together gave the unique property of the land which is divided into the territory of a coastal, semi-coastal, mountain, valley, semi-valley, desert and semi-desert. Over the centuries Palestine was considered as an important center in terms of strategic location as a forum of the three continents Asia, Europe and Africa. Moreover, climate variability in Palestine is unique to agriculture.

Jordan Valley is considered as the first natural green house in the world (Hötzl, Möller and Rosenthal 2009), because the climate is characterized by a mild climate during the winter and because of the availability of water. It is an important source of food basket of Palestine, especially in the production of vegetables. Due to the limited water resources in West Bank, irrigated agriculture did not constitute more than 6% of the cultivated area in Palestine. Therefore, reuse of treated wastewater will be another source of irrigation water which will lead to increase in agricultural production and will be reflected positively on the country's economy and will reduce the amount of fresh water used in agriculture.

1.4 Water in Palestine: supply and demand

The most important water sources in Palestine are rain, runoff, groundwater, and springs. As part of the Arab world, Palestine suffers from an additional problem, in addition to the arid and semi-arid climate conditions and rainfall variability, Palestinian territory suffers from a high population density and a lack of natural resources. The population density in the Palestinian territory reached 663 person/km^2 in 2009 (439 person/km^2 in the West Bank and 4,140 person/km^2 in the Gaza Strip), compared to 350 person/km^2 in ‘Israel’ (PCBS 2010). More than 177 thousands persons in the Palestinian territory (22.9% of West Bank localities) are not served by water services, About 454 thousand persons (12.1% of the total population in Palestine) obtain their water through the ‘Israeli’ company (Mekorot); 110 of these localities are in the West Bank and 6 localities are in the Gaza Strip (PCBS 2009a).

Moreover, Palestine suffers from abnormal political situation. Since the beginning of the occupation of historic Palestine in 1948, ‘Israel’ has turned to control the water sources in the Palestinian territories and adopted several resolutions providing for the ownership of water in Palestine, and followed these decisions several measures on the ground to identify areas along the Jordan River, building of ‘Israeli’ settlements on Palestinian water resources, confiscation of Palestinian wells for the benefit of ‘Israeli’ settlements, impounding the waters of the valleys, as in eastern Gaza Strip, and not to give license to Palestinians to dig new wells. This is clear from the World Bank report (World Bank 2009). The report showed that the amount of water consumed by one ‘Israeli’ settler is four times the amount consumed by a Palestinian. ‘Israeli’ settlements control water resources and waste a lot of fresh water quantities, producing a lot of wastewater which is disposed on the Palestinian areas contaminating the soil and the limited Palestinian water resources (Al-Tamimi, A; Rabi, A; Abu-Rahma, A 2007). About 142.7 million liters of water drained daily by settlers in the West Bank ‘Israeli’ settlements. Furthermore the establishment, expansion and annexation of the separation wall led to a large loss of western basin water; Palestinians lost 23 wells and 51 springs which produce about 7 million cubic meters of (PCBS 2009a). Currently water demand exceeds water supply. Groundwater is the major source of fresh water in Palestine and provides about 70% of drinking and domestic water needs. The main source of groundwater in the West Bank is in the Mountain Aquifer System (Figure 1.1), which is divided into three subsurface drainage basins: Northeastern; Western and Eastern (Qannam 1997). The Palestinian territories depend on two main sources of water: groundwater from wells and

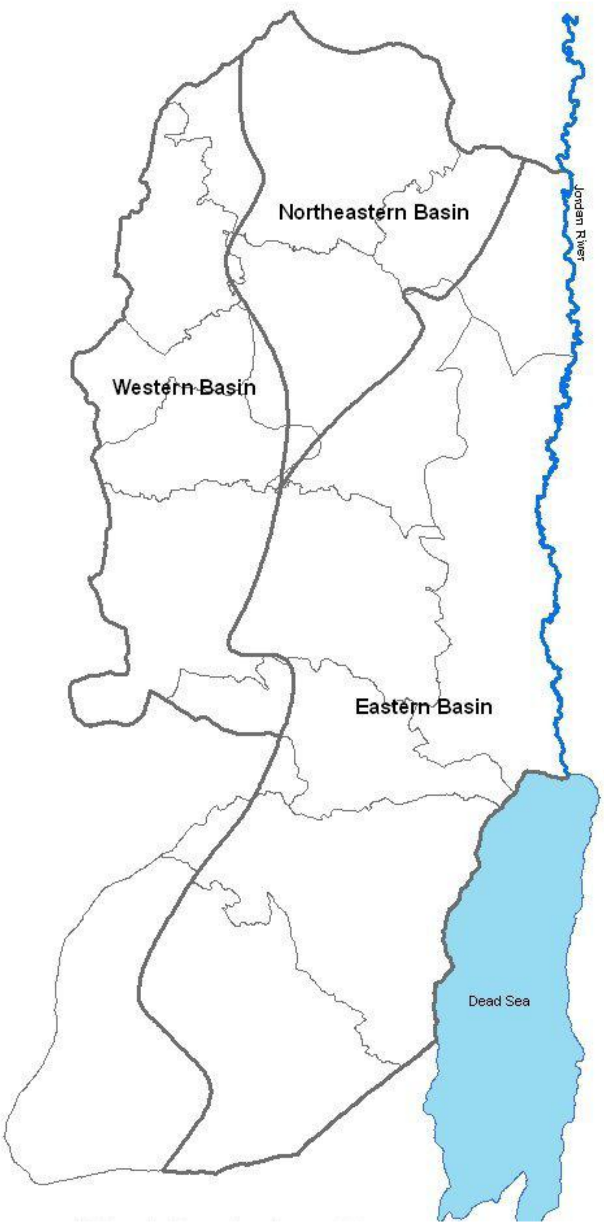


Figure (1.1) Mountain aquifer system in Palestine springs and the water purchased from the ‘Israeli’ water company (Mekorot). According to water statistics in the Palestinian territory annual report (PCBS 2009b) groundwater is the largest source of water and it represents about 73.1% of the total water, followed by water purchased from Mekorot company and springs water, which accounted for 18.7% and 8.2% respectively (Figure 1.2).

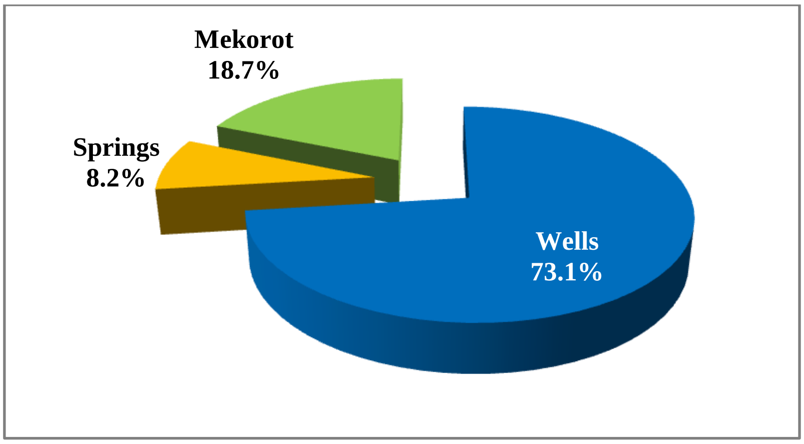


Figure (1.2) Percentage distribution of water resources in the Palestinian territory, 2008

Palestinians have access to one-fifth of their resources on the Mountain Aquifer (World Bank 2009) and the Palestinian territories are expected to experience a serious water deficit in the year 2020 (Mimi, Ziara and Nigim 2003). Shortage in water supply for domestic, industrial and agricultural purposes is a chronic problem (Isaac 1995), and the available water quantities for Palestinians are less than the minimum recommended by the WHO standards (World Bank 2009), whereas the average of consumption for the Israeli is about four times (Figure 1.3).

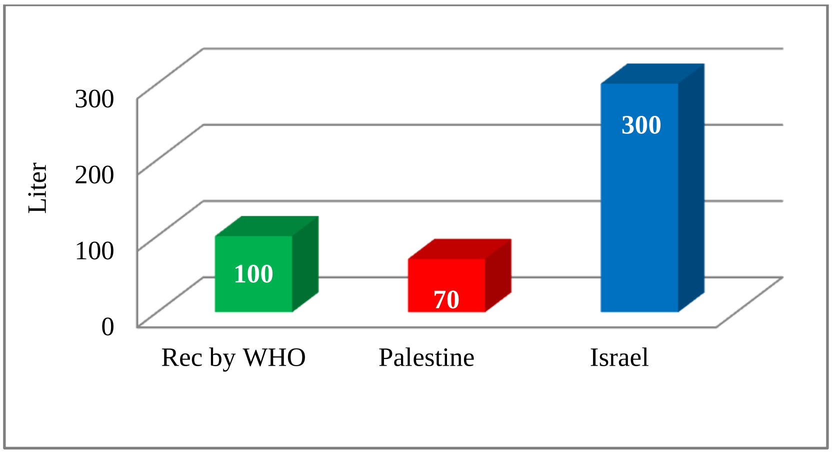


Figure (1.3) Average daily water needed per person in liter

Agricultural sector is the biggest consumer of water in Palestine; it consumes around 70% of the total water consumption, followed by the domestic sector by 27% and the industrial sector by 3% (World Bank 2009), as shown in Figure (1.4).

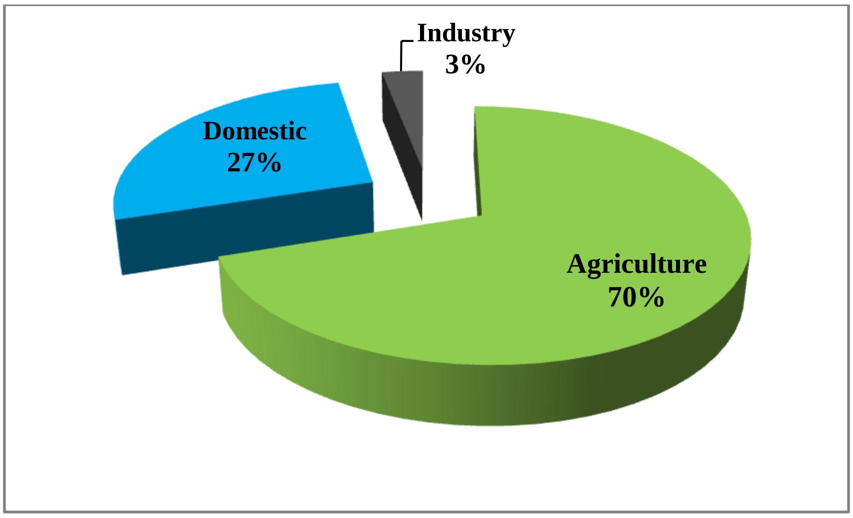


Figure (1.4) Water consumption in Palestine by sector

1.5 Wastewater in Palestine: quantity and quality

Wastewater is the next problem in Palestine after the water scarcity and it is one of the biggest polluting sources of the Palestinian environment including water resources. Sewerage system in Palestine is extremely critical, as Palestinians suffer from great weakness in their water and sanitary system infrastructures. According to Palestinian Central Bureau of Statistics, (PCBS 2009c), only 52.1 % of the population is connected to sewerage networks in West Bank and Gaza Strip, while cesspits and septic tanks receive the rest. Rural areas in Palestine either do not have running water at all or do not have wastewater collection systems, even if they have running water. Wastewater is collected in individual waste pits or cisterns where it seeps into the ground. Thus, there is no wastewater to be reclaimed in the rural areas of Palestine. Moreover, the generated wastewater is concentrated, because of low water consumption per capita. Poor drainage of wastewater adversely affects human health, environment and economic development. Groundwater pollution from wastewater is the most serious problem that threatens groundwater in Palestine, especially in the Gaza Strip, which is reflected directly on the general health of the people. Most of bacteria, protozoa, helminthes and viruses affect human health through ingestion of contaminated water and food. Wastewater disinfection will eliminate them, but it is costly and requires large budgets and high technologies, especially in developing countries including the Palestinian territories. A recorded example is that more than 50 % of children under the age of ten in Gaza Strip are living with Ascaris (MEDAWARE 2003). Moreover, ‘Israel’ pollutes the Palestinian water directly and indirectly. The ‘Israeli’ settlements in the West Bank pump millions cubic meters of wastewater in the Wadies, valleys and into the agricultural land. According to Al-khatib and Al-Remawi (2009), the amount of wastewater produced by the ‘Israeli’ settlements in the West Bank is about 40 million cubic meters (90% untreated), which is greater than the amount produced by the Palestinians (33 million cubic meters). ‘Israel’ has also played an indirect role in contaminating Palestinian water by wastewater through neglecting wastewater management and refusing the expansion of new wastewater networks to meet the growing population, to the point where about 52% of the Palestinian households are not connected to wastewater network (PCBS 2009c). Generally, the WWTPs in Palestine are inadequate to serve the volume of wastewater being discharged (EQA 2002). Treatment plants in the Gaza Strip discharge their effluent to the Mediterranean

Sea, open areas and wadies (Fatta, et al. 2004), causing further deterioration to the groundwater quality. As mentioned earlier, low water consumption is reflected in the characteristics of wastewater produced, which is mainly domestic type, and this increases the serious impacts of wastewater on the environment and human. Heavy metals contamination from industrial wastewater is not probable since the limited number of factories presented in the Palestinian territories, but the risk is still possible due to many factories concentrated in the industrial zones of the 'Israeli' settlements in the Palestinian territories. Table (1.1) represents the characteristics of raw municipal wastewater for some cities in Palestine.

Table (1.1): Characteristics of municipal wastewater in some cities in Palestine

Test	**Gaza Strip**			**West Bank**			
	Rafah	**Gaza**	**Jabalia**	**Hebron**	**Al-Bireh**	**Ramallah**	**Nablus**
BOD_5 (ppm)	555	500	670	1008	522	525	1185
COD (ppm)	1000	740	1270	3670	1230	1390	2115
Kj-N (ppm)	108	90	130	200	37	79	120
NH_4^+-N (ppm)	75	80	90	123	27	51	104
NO_3^-N (ppm)	1.4	1.3	1.5	2.8	4.4	0.6	1.7
SO_4^{-2} (ppm)	-	-	-	150	61	132	137
PO_4^{-3} (ppm)	30	30	40	18.4	4.3	13.1	7.5
Cl^- (ppm)	490	550	250	500	273	350	1155
TSS	420	265	620	-	-	1290	1188

Source: (Zimmo , et al. 2005), (PCBS 2000) and (Nashashibi and van Duijl 1995)

CHAPTER TWO: LITERATURE REVIEW

2.1 Wastewater reuse in the world

The use of wastewater in agriculture has been commonly practiced for thousands of years. It was used to fertilize fields in Asian countries in ancient times, and so far. According to Mathan (1994), irrigation with raw sewage in India was reported to improve the soil structure. Farms were used to treat municipal wastewater and to grow crops in Germany and in England as early as the sixteenth and seventeenth century. After the rapid rise of sewerage systems in the 1800s, sewage farms became a common method of wastewater treatment and disposal in Europe, North America, and Australia. The 1950s saw interest in wastewater irrigation due to rapid urbanization and water pollution by wastewater discharges. Some treatment plants have been active for decades, i.e. Werribee farm in Australia which has been operated since 1897. Reuse of municipal wastewater is a viable option for increasing water supplies in the future for agricultural purposes (Feigin, Ravina and Joseph 1991).

Industrial waste discharged into sewers make wastewater unsuitable for irrigation. According to Feigin et. al., (1991), irrigation with sewage effluent has been practiced for centuries, and lack of water and waste disposal are the main reasons for the use of TWW, and the predominance of one over the other will depend on local conditions of the country. Table (2.1) shows some examples of water reuse in the world since a long time.

Table (2.1): Selected examples of historic water reuse in the world

Year	Location	Water reuse application
1890	Mexico City	Drainage canal were built to take untreated WW to irrigate agricultural areas north to the city
1929	California	Irrigation of lawns and gardens
1962	Tunisia	Irrigation with reclaimed water for citrus plants and groundwater recharge to reduce salt-water intrusion into groundwater
1977	‘Israel’ Dan Region Project	Groundwater recharge via basins. Pumped groundwater is transferred via 1100 km long conveyance system to southern ‘Israel’ for unrestricted crop irrigation

Source: (Tchobanoglous, Burton and Stensel 2003)

Jordan, Tunisia and ‘Israel’ are among the leading countries in the use of TWW, since water resources are limited. Whereas, water scarcity isn't a problem in Belgium however, reuse has been performed due to water quality issues there. United Arab Emirates is one of the world's poorest countries in water, but the wastewater treatment program, in Sharjah, has enabled the use of wastewater recycled for the irrigation of gardens and orchards and the preservation of a valuable source of groundwater supplies (Kretschmer, Ribbe and Gaese 2010). Wastewater reuse projects increased in Saudi Arabia after the Fatwa of Council of Leading Islamic Scholars (CLIS) in Saudi Arabia in

1978. According to the Fatwa wastewater reuse is not unlawful according to Islam, even it can be used for wudu (ablution before prayer) and drinking, provided that it presents no health risk. The proportion of treated water reached in 1995 about 15%, moreover, ablution water for the two holy mosques in Mecca and Medina are recycled and used in toilet flushing (Faruqui, et al., 2001).

2.2 Status of wastewater treatments in Palestine

Reclaimed water as defined by (Tchobanoglous, Burton and Stensel 2003) is "water that, as a result of wastewater treatment, is suitable for a direct beneficial use or a controlled use that would not otherwise occur". Water reclamation in the Palestinian Territories is limited due to technical, economic and socio-cultural aspects of Palestinian rural and urban sanitation facilities (BZU 2008). Sanitation sector in Palestine is characterized by poor sanitation, different quality of wastewater, inadequate treatment, unsafe disposal of waste-water and the use of raw wastewater in some areas for irrigation of edible crops. Table (2.2) represents the main eight WWTPs in the Palestinian Territory. Three are located in Gaza Strip while the rest in the West Bank. In addition there are six small-scale wastewater treatment facilities located in the West Bank (Table 2.3).

Table (2.2): Existing WWTPs in Palestine

Plant location		**Year of construction**	**Treatment type**	**Number**	**Efficiency [%]**	**Incoming Flow [m^3/d]**	**Disposal Method**
West Bank	Jenin	1970’s	AL SP	2 1	NW NW	1200	Valleys
	Tulkarem	1970’s	SP	3	20	1200	Not available
	Ramallah	1970’s	AL SP	2 2	30	2900	Wadi Bitunia
	Al-Bireh	2000	EAS	2	95	4000	Irrigation
	Hebron	1970’s	SP	3	NW	2100	Wadis
Gaza Strip	Beit Lahia	1997	AL F P	4 1 1	70	9400	To sand dunes
	Gaza	1977 1986, 1999 expanded	AP AL	2 2	60	42000	Mediterranean Sea, Irrigation, Infitration
	Rafah	1980	AL	1	45	3816	Mediterranean Sea
NW: Not working, AL= Aerated Lagoon, SP= Stabilization Pond, EAS= Extended Aeration System, F= Facultative, P= Polishing, AP= Anaerobic Pond							

Source: (MEDAWARE 2004), (FEW and HWE 2007)

Table (2.3): General characteristics of community’s treatment plants in Palestine

Plant location		**Type of treatment pond**	**Population Served (Capita)**	**Effluent Quantity [m^3/d]**	**Disposal Method**
West Bank	**Al Aroub agriculture school**	Duckweed-based pond system	Not available	12-15	The effluent is used for producing seedling in a forest-tree nursery constructed for reuse in irrigation or groundwater recharge
		Small-scale biochemical system (JOHKASOU system)			
		Aeration tank			
	BZU	Screen	6000	100	Irrigation
		Equalization Tank			
		Activated sludge			
		Sand Filters			
	Deir-Samit-Hebron	Sedimentation tank	400	40	Valleys
		bio-filters			
	Ijnsnya-Nabuls	Septic tank Anaerobic filter	250	30	Valleys
	Kharas - Hebron	Anaerobic stage	2000	120	Valleys
		Wetlands			
		Sludge drying beds			
		Effluent storage tank			
	Sarha- Nabuls	Septic tank	600	40	Valleys
		Constructed wetland			

Source: (MEDAWARE 2004)

Most of the treatment plants in the West Bank, namely in Tulkarem, Jenin, Hebron and Ramallah, are overloaded, badly maintained and very old, they were constructed in the beginning of the 1970s and consist of lagoon technology (Table 2.4). All of these are not functioning well, and consequently hardly achieve any treatment higher than primary, Hebron station did not work at all since its establishment because of conflicts between the municipality of Hebron and the ‘Israeli’ authorities (Zimmo et. al., 2005).

Table (2.4): Wastewater treatment plants in the West Bank

Name of WWTP	**Status of WWTP**	**Population served * 1000 (year)**	**Capacity (mcm/yr)**	**Funding Agency**	**Technology**
Nablus East	Planning phase	240 (2021)	9.2	Germany KfW	EA
Nablus West	Construction phase	225 (2021)	9	Germany KfW	EA
Salfeet	Detailed study	24 (2025)	2.3	Germany KfW	EA
Jenin	Rehabilitation is needed	13.5 (1997)	0.5	‘Israel’	WSP
Al-Bireh	Constructed	40 (2000)	1.1	Germany KfW	OD
Tulkarem	No study yet	223 (2030)	7.5	Germany KfW	EA
Abu-Dees	Feasibility study	26 (2020)	1	Norway	OD
Tafuh	Feasibility study	16	0.5	UNDP	ARF
Halhul	Preliminary design	42 (2020)	1	Not funded	AP
Birzeit area	Preliminary study	28 (1994)	1.2	Not funded	IT + TF
Hebron	Planning stage	695 (2020)	25	USA	AS
Jericho	Preliminary study	26 (2000)	1.2	Not funded	-
Biddya	Preliminary study	24 (2000)	1.1	Not funded	-
Ramallah	Feasibility study	40-North, 40-South	1.5, 1.5	Not funded	EA
Al-Ram	Preliminary study	86.5 (2000)	3.3	Germany KfW	ASS + AS

EA= Extended Aeration, WSP= Waste Stabilization Pond, OD= Oxidation Ditch, ARF= Anaerobic Rock Filter, AP= Aerated Pond, TF= Trickling Filter, AS= Activated Sludge, ASS= Anaerobic Sludge Stabilization, IT=Imhoff Tank

Source: (Zimmo et. al., 2005)

According to Zimmo (2005), establishment of WWTPs in Palestine facing financial and political difficulties, and among the fifteen proposed projects, only Al-Bireh project has been implemented so far. The reuse of treated wastewater is limited on a small scale projects and this option usually neglected in the plans of wastewater treatment (World Bank 2009). Currently, farmers do not pay for reuse of treated wastewater and they do not pay a fine for irrigation of agricultural crops with raw wastewater. Most of the houses in the Palestine territories are not connected to sewage systems, 52% of the communities are connected only (PCBS 2010). Also, there is no separation between rainwater and sewage system. In the villages there are no sewerage systems and wastewater is collected in septic tanks. In refugee camps the situation is worst, and wastewater flow in an open channels throw the camps and it either goes into a nearby city system or simply to be transferred outside the boundaries of the camp. Moreover, Israeli settlements in the West Bank disposed there sewage in the valleys without any treatment.

2.3 Palestinian policies and strategies

Palestinian Water Authority has prepared strategies for TWW reuse in 2003 to promote and implement the reuse of treated wastewater; the following are the key principles of the strategy:

- Water reuse strategies must be adopted in all wastewater reuse projects.
- Cooperation and coordination must be adopted with all concerned parties.
- Appropriate reuse plans should be developed to enable the reuse and storage in winter season or when the effluent quality drops.
- Developments of planning tools, standards, guidelines, etc., for reuse and recharge projects.
- Treated wastewater discharges to surface water can be regarded as a temporary measure, if it is not possible for reuse.
- Irrigation of crops eaten raw is prohibited, enforcement means should be applied.
- Strategies and management practices should be applied to get the best quality of water resources and efficient use, consider (a) treated effluent mixing with urban and surface runoff, (b) groundwater recharge with treated effluent wherever possible, and (c) establish surface storage of treated effluent with or without harvested runoff.
- The involvement and investment of public and private sectors in the wastewater reuse projects.

- Development and expansion of reuse of treated wastewater in urban centers (Greening, fountains, gardens and landscaping irrigation, etc.).

Moreover, the challenges facing the sanitation sector through the presence of a multitude of government institutions and nongovernmental organizations in the water sector, leading to fragmentation of institutions, and lack of coordination. Overall, there is a clear understanding regarding the roles and responsibilities of each institution in the field of treatment and reuse of wastewater. Today, most municipalities are responsible for water supply and sanitation, but these institutions have limited financial and administrative capacities for the performance of their duties. The PWA will be responsible for all planning, organization and research tasks. This is reflected in the institutional arrangement of the Palestinian water law of 2002.

Efforts have been made by the PWA for the adoption of WHO and EPA standards, but more should be done in terms of the quality control of wastewater and the application of the regulations. Moreover, there is no comprehensive policy or prices for reuse in the Palestinian territories.

2.4 Al-Bireh wastewater treatment plant

Al-Bireh WWTP is located 2 km south east of Al-Bireh city, 12 km north to Jerusalem (Figure 2.1).

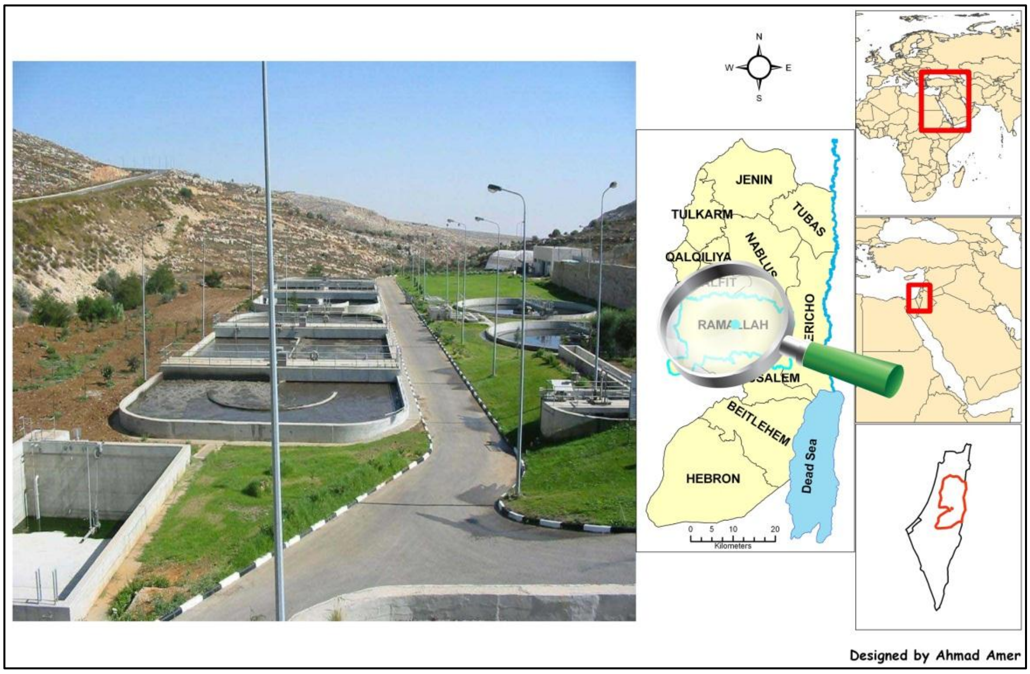


Figure (2.1) Al-Bireh WWTP

Al-Bireh city is considered to have a central location of the mountain area of Palestine extending from the north to the south During the period 1960 – 1970, Al-Bireh city was served through a primitive WWTP consisted of two sedimentation ponds. This WWTP was no longer in operation due to high population growth, the influx of returnees, and economic boom due to the peace process and establishment of the Palestinian Authority in 1994.

It is operated currently as the only treatment plant so far that is well functioning. The sewage treatment plant, entailing oxidation ditches and sludge processing units are working effectively. It was planned to utilize the treated effluent in agricultural purposes. In order to serve the citizens of Al-Bireh city and to eliminate the environmental risks caused by wastewater flow towards Wadie Al-Ein and Wadie Al-Qelt in Jericho, and consequently protects the environment and groundwater from further contamination, Al-Bireh municipality called for the help from the German Government, which indeed provided funds for the construction of a WWTP and sewerage network in north and south of Al-Bireh city. Another goal was to provide a nonconventional water resource that can be used for agricultural purposes, under the increasing rates of irrigation water consumption and water shortage in the area. Funds were mobilized through the German Agency for Technical Cooperation (GTZ) and the German Development Bank (KfW). Total value of German funds was €18 million (Zimmo , et al. 2005) n. Construction of the existing WWTP commenced in 1998 and inaugurated in February 2000. It has started work on 15 of May 2000, where it serves 50,000 people in the first phase with possibility to serve 100,000 people at the second phase with an extended aeration treatment technology. Currently, it treats about 4,500 m^3/d, and produces high quality effluent in compliance with WHO for wastewater reuse in agriculture irrigation of crops likely to be eaten cooked, sports field and parks. However, the treated effluent is being discharged into Wadie Al-Ein towards the Jordan Valley without any reuse (Tomaleh 2010).

- **Treatment Process**

Wastewater originates from different sources, domestic, commercial and industrial. These are treated by two main types of treatment processes; physical and biological treatment, as well as a tertiary treatment unit by a UV-disinfection system. Raw wastewater reaches the plant through the sewerage system, which then goes into a screening unit removing large debris. The flow is then diverted into a grit chamber to remove sand and heavier particles. Next, wastewater is transferred into an extended aeration tank for biological treatment, followed by final sedimentation tanks for sludge separation from treated water. Finally, TWW passes through a tertiary treatment unit (UV-disinfection system) for pathogen removal (Figure 2.2).

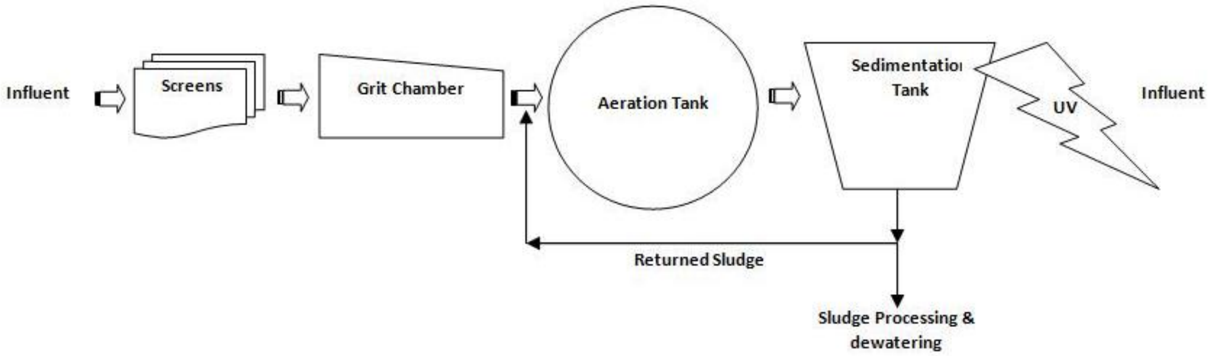


Figure (2.2) Major units of Al-Bireh WWTP

Sludge is treated and managed by a sludge line that entails a gravity thickener and two filter presses for sludge dewatering. Wastewater treatment process is a multi-stages process, consisting of pretreatment unit and biological treatment unit.

2.5 Treated wastewater reuse for irrigation

Wastewater reuse is not something new. Indicators showed that irrigation with wastewater was used in ancient Greece and in the Minan civilisation (ca. 3000 – 1000 BC) (Asano and Levine 1996). Irrigation with treated wastewater is a common practice almost all over the world as one of the treatment methods for the disposal of sewage in the soil, since wastewater is considered as a cheap source of water that leads to improvement of public health and it preserves the environment and water sources from pollution. Moreover, irrigation with TWW is necessary to cope with water scarcity due to limited water resources in some regions. International organizations, i.e. WHO, showed interest in the development of standards for the use of TWW in agriculture. Irrigation with TWW reduces the pollution of the environment and water bodies, maintains high quality water for other uses and exploitation of nutrients in wastewater, thus reducing the quantity of fertilizer use and increase yields crops (Stevens, et al.

2006). Moreover, it is an easy and low cost for the disposal of sewage. Further, it is a sustainable source of water, as it depends on the production of sewage water that is relatively stable during the year (Toze 2006).

2.6 Benefits and constrains of irrigation with treated wastewater

Several studies have proven beneficial results of the use of treated wastewater, (Asano and Levine 1996) and (Lopez, et al. 2006). Their results showed increase in the production of all crops upon using sewage water for irrigation, compared with regular water. However, the use of wastewater for irrigation involves risks and potentially negative effects. The health risks of irrigation water, due to the contact with contaminated water, the health risk to consumers due to the potential transport of pollutants into the products, and the deterioration of soil quality as a result of the accumulation of chemical contaminants are the major concerns. In Italy researchers studied the effects of reclaimed urban wastewater for irrigation on tomato crop quality and soil (Aiello, Cirelli and Consoli 2007). They found that treated wastewater can be used as a valid alternative for irrigation of tomatoes, there results showed increases in microbial contamination (*E.coli*) on the soil surface and the microbial contamination was negligible in fruits. They also found a decrease in soil water retention and hydraulic conductivity. Pedrero and Alarcón investigated the effect of reclaimed wastewater and mixed reclaimed wastewater on lemon trees. They found that the possibility to mix reclaimed wastewater with well water is a good solution to avoid the problems when reusing wastewater in agriculture and the irrigation with treated wastewater did not increase the macronutrients and organic matter measured in the soil (Pedrero and Alarcón 2009). According to Kiziloglu, the characteristics of wastewater and soil should be considered in managing wastewater irrigation during crop production since irrigation with wastewater affects the physical and chemical properties of the soil, the yield and also the mineral content of cauliflower and red cabbage (Kiziloglu, et al. 2008). To obtain useful results from the use of treated wastewater for irrigation, it is necessary to monitor the major elements in the effluent, (i.e. N, K), and also minor elements such as heavy metals (Tchobanoglous, Burton and Stensel 2003), since heavy metal pollution is becoming a serious health problem in recent years. High levels of heavy metals have been reported in different parts of India due to pollution of soil, water and plants (Prasad 1999). Toxic heavy metals (i.e. Cd, Pb and

Hg) affect biological functions, which in turn affect the hormone system and growth. Some heavy metals bio-accumulate through the food chain causing hazardous effects on livestock and human health. It also can accumulate in the body, liver and kidney, causing serious public health hazard (Kaplan, et al. 2010). Some researchers studied the Pb content of fodders produced in agricultural areas near to cities, industrial plants and busy highways. The results showed that Pb contamination of plants from industrial areas and nearby busy roads were higher than that of plants from agricultural areas (Rozsa 2000).

2.7 Treated wastewater reuse in Palestine

Palestinians have recently started work on reuse of wastewater as an additional source of water. Palestinian Environmental Quality Authority (EQA) has prepared environmental law and standards for reusing the TWW (Appendix A). Moreover, Palestinian Water Authority (PWA) has prepared a national water plan with an essential part for TWW reuse. As a result of ‘Israeli’ occupation, accumulated sewage problems, non-establishment of treatment plants in addition to the neglect of maintenance and construction of sewage networks led to the pollution of the Palestinian environment because of the indiscriminate disposal of wastewater in the Palestinian territories

(MEDAWARE 2004). The Palestinian sector is considering the reuse of TWW as one of its objectives in order to meet the growing demand for water in agricultural purposes. However, the reuse of the TWW is limited only to small scale projects, mainly due to the political and financial situation, which hampers the planning, management and construction of proper sewage collection and treatment systems. On the other hand, the public acceptability of the reuse of TWW is weak. For this, the process of public awareness of the importance of reuse of TWW and to consider it a source of water and nutrients is an important condition for the safety of such use. In Palestine, the first project was constructed in Gaza on 1986 funded by UNDP (PWA 1998). The project included the expansion and development of the Gaza WWTP by constructing two additional ponds, in addition to the existing two and establishing a scheme to reuse wastewater for irrigation purposes. The TWW was distributed to farmers for reuse in irrigation. Unfortunately, the project failed and the UNDP related failure to various factors, including:

a) The municipality was unable to operate the scheme for reasons of lack of funds and lack of trained staff.

b) The idea of reuse was not readily accepted by the farmers who had no incentive to use reclaimed wastewater when they could have fresh water from private wells at lower costs than the reclaimed wastewater.

c) The treatment plant is surrounded as it was by private lands, which prevented the improvement of effluent quality.

d) The effluent quality did not meet the standard required for reuse.

Another project was initiated in Jabalia funded by UNDP too and it failed due to the same reasons mentioned above. In Beit Hanoun, the Swedish government established a reuse project, it was planned that the project irrigate about 50-70 hectares, but the ‘Israeli’ occupation forces have uprooted trees and the destruction of the project (BZU 2008). European hospital project in Khan Younis was funded by the European Commission, 2001, which has been installed a small WWTP in the hospital with a generation capacity of 150 to 200 m^3/day in summer and 300 m^3/day in winter. The effluent was used to irrigate nine hectares of olive and other trees (BZU 2008). Small scale university programs for restricted irrigation were constructed in West Bank area. BZU is a leader in the application of reuse of treated effluent for flushing toilets and for landscape purposes. The system has been constructed since 1980 at BZU campus and it consists of a contact stabilization system serving about 9000 students and employees. It has been functioning in excellent condition; however, the operational cost is so high due to the cost of electricity for aeration. Al-Quds University too has constructed a small scale WWTP too. Al-Bireh bio-solids composting and reuse of reclaimed wastewater which was established in 2004 funded by USAID at Al-Bireh WWTP in partnership with the PWA, the Al-Bireh Municipality, the CH2M-Hill team in West Bank, and MoA. The project was aimed to composting the bio-solids generated at the Al-Bireh WWTP in a windrow system and subsequent reuse in agriculture. The main activity of the project includes the construction and management of six dunums irrigated with the treated effluent. The effluent was used to irrigate a range of common Palestinian crops: orchard and ornamental trees, grape stocks, processed vegetable and flowers and ornamental shrubs. Moreover, a 600 m^2 greenhouse with cultivation of cooked vegetables, not for commercial purposes, was irrigated with a very high quality effluent (BZU 2008).

There are also small-scale projects funded by Institutes and NGO’s such as Palestinian Agricultural Relief Committees (PARC), Palestinian Hydrology Group (PHG), Applied Research Institute in Jerusalem (ARIJ) constructed in some schools and houses in the West Bank and the Gaza Strip (Al-Tamimi, A; Rabi, A; Abu-Rahma, A 2007). Mansour studied the use of natural growth regulators (Jasmonic acid, JA) to alleviate stress may imposed by reclaimed wastewater and she concluded that application of JA tend to improve the tolerance of plants irrigated with reclaimed wastewater with EC values range between 5 to 7 $dS.m^{-1}$. Moreover, the results showed that using reclaimed wastewater increased the production even without the addition of chemical fertilizers, Health complications and plant pathogens were also tested and nonsignificant differences between variables were recorded (Mansour 2006). Shomar found that TWW is safe to use for irrigation in Gaza, and alfalfa plants irrigated TWW did not show any unsafe levels of heavy metals (Shomar, El-Madhoun and Yahya 2010).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

3.1.1 Study site

The experiment was conducted in the campus of BZU during the 2010 growing season. Figure (3.1) shows the study site in BZU which is located about 20 km northwest of the city of Jerusalem (31° 57′ 29″ **N**, 35° 10′ 24″ **E**) and characterized by mild climate as it lies at an altitude of about 770 meters above sea level.

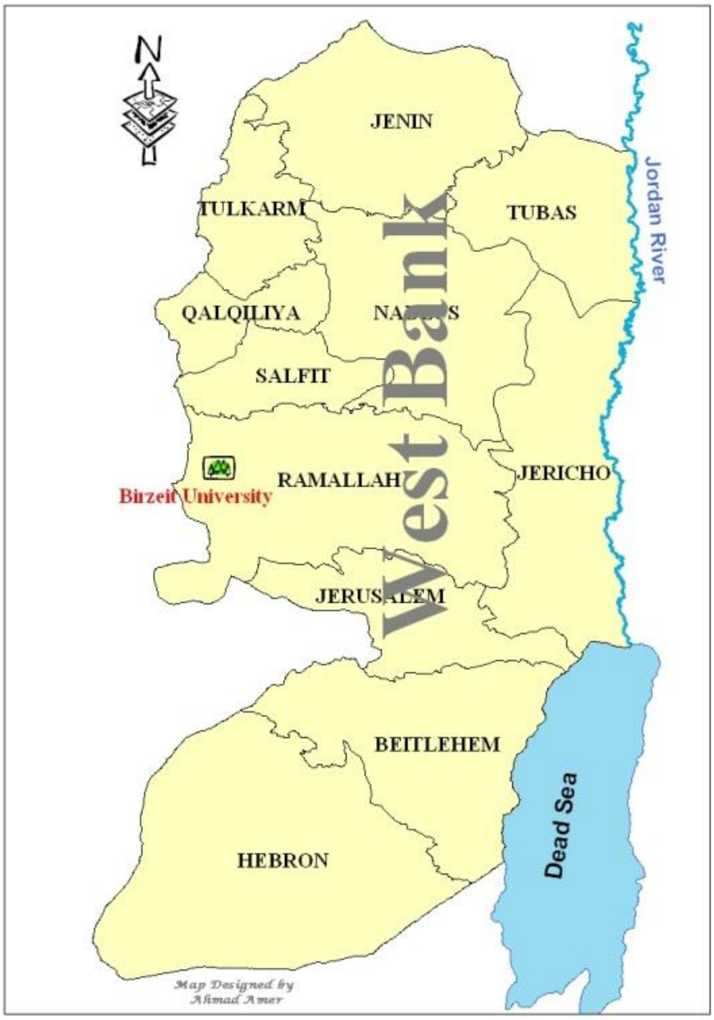


Figure (3.1) Study site map

3.1.2 Soil and pots

The soil used in the project was from the local agricultural areas of Qalqilia, north of the West Bank. Soil was obtained from 0 to 30 cm of the topsoil layer, from areas in which corn is produced commercially. The experiment was carried out using 45-liter pots, made from polyethylene plastic (PE), which is used widely by Palestinian farmers (Figure 3.2). Appendix (B) shows the steps of soil transportation and preparation for use.

3.1.3 Corn seeds

According to the local experience and market availability, corn seeds were obtained from a certified company (Syngenta 2010), which is classified as good quality seeds and it is one of the seed available in the Palestinian market (Figure 3.3).

Figure (3.2) Polyethylene Plastic pots

Figure (3.3) Corn Seeds (Syngenta®)

3.1.4 Mineral Fertilizer

The mineral fertilizer used in the experiment was a complete one with the following chemical formula $N:P_2O_5:K_2O$ (13-13-13). The fertilizer also contained the following amounts of micronutrients: 500 ppm Fe, 250 ppm Mn, 75 ppm Zn, 55 ppm Cu and 35 ppm Mo. This fertilizer, (Figure 3.4) is frequently used by farmers in the areas of Qalqilia and Tulkarem, where corn is grown in abundance in those areas.

Figure (3.4) NPK Fertilizer

3.1.5 Irrigation water

Two types of irrigation water were used in this experiment:

i. Tap water from municipal water network at BZU.

ii. TWW from Al-Bireh WWTP.

3.2 Methods

3.2.1 Experimental design

To achieve the objectives of this experiment, the municipal TWW produced by Al-Bireh WWTP was given the priority and as a control, tap water was also used for other pots as indicated in Table (3.1). The experimental design used was a randomized completely blocks design (RCBD), with five treatments each replicated six times. Accordingly, there were 30 experimental units (Figure 3.5).

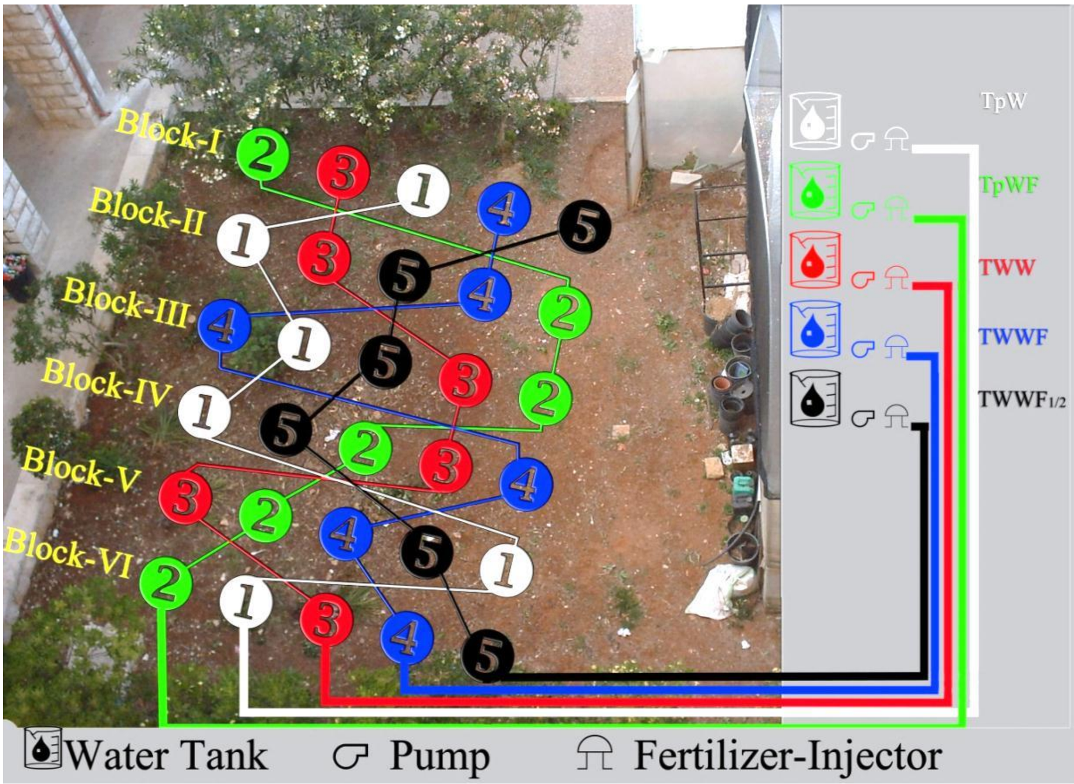


Figure (3.5) Experimental design (CRBD)

Additionally, mineral fertilizer with well-known chemical composition was injected through irrigation water in some treatments. Table (3.1) describes the treatments of the experiment.

Table (3.1) Treatments description

Treatments	Classification
Treatment 1 **(TpW)**	TpW only
Treatment 2 **(TpWF)**	TpW + Fertilizer
Treatment 3 **(TWW)**	TWW only
Treatment 4 **(TWWF)**	TWW + Fertilizer
Treatment 5 **(TWWF½)**	TWW + half Fertilizer

3.2.2 Irrigation schemes

Five tanks of water, each with a volume of one cubic meter, were used in this experiment; one tank for each treatment. Pump and Venturi fertilizer injector were connected to each tank to supply water through a plastic tube for the six replicates per each treatment, using trickle irrigation system.

Figure (3.6) Transportation and Filling of TWW

The first two tanks were filled with TpW obtained from municipal water network, whereas the other three tanks were filled with TWW obtained from Al-Bireh WWTP (Figure 3.6). Trickle irrigation was used in this experiment, since it is the only method that solves the specific problems of using wastewater (Pescod 1992), and it is preferred in water scarce countries like Palestine; for effluent irrigated agriculture, due to both hygienic issues and general water saving characteristics.

3.2.3 Planting and harvesting

Pots were filled with soil which was amended with agricultural sand (3:1 v/v) and about 200 g soil samples were taken from each pot for analysis. Corn was planted on **May 6th 2010**; three seeds were planted in each pot. Trickle irrigation was used in this experiment at rate of (0.1 L/min). The pots were irrigated regularly with TpW for ten days. The seedlings were then thinned to one plant/pot. Treatments 1 and 2 (TpW and TpWF) were irrigated with TpW while treatments 3, 4 and 5 (TWW, TWWF and TWWF½) were irrigated with TWW until harvest.

All treatments were irrigated at 2-days interval for one hour during the growing season, and irrigation was applied to maintain the soil moisture at field capacity. The standard mineral nutrients program is seven Kg/1500 plant every ten days, as each treatment is composed of six plants; 28 g of NPK 13-13-13 fertilizer (4.67 g / plant) were dissolved in 100 ml distilled water and applied through the venturi fertilizer injector. Table (3.2) displays the fertilization schedule during the growing period.

Table (3.2) Fertilization schedule

Date	TpW	TpWF	TWW	TWWF	TWWF½
31, May 2010	0	28 g	0	28 g	14 g
10, June 2010	0	28 g	0	28 g	14 g
20, June 2010	0	28 g	0	28 g	14 g
30, June 2010	0	28 g	0	28 g	14 g
10, July 2010	0	28 g	0	28 g	14 g
20, July 2010	0	28 g	0	28 g	14 g
30, July 2010	0	28 g	0	28 g	14 g
Total	**0**	**196 g**	**0**	**196 g**	**98 g**

The following parameters were monitored and recorded weekly: Plant high, number of leaves, number of fruits (Figure 3.7).

Figure (3.7) Sampling and daily monitoring

At the final growth stage, leaves were obtained, frozen in liquid nitrogen and stored in a refrigerator at – 20°C until analysis.

Upon harvest (**August 14th 2010**), samples were taken from plants and fruits for analysis. Soil samples were collected from the top 30 cm layer from each pot for analysis. Figure (3.8) shows an example of the harvested plants. After harvesting, the samples were collected and prepared according to the methods for the intended parameter to be analyzed.

Figure (3.8) Harvested plants

3.3 Sampling Action and Analysis

According to research proposal, the following parameters were analyzed.

3.3.1 Water sampling and analysis

Physical parameters (T, pH, EC and TDS) were taken during the sampling action for both type of irrigation water. These measurements were done using portable instruments and kits that have been calibrated and operated according to the manufacturer's instructions. Appendix (C) summarizes the instruments and the methods of analysis used in irrigation water analysis.

3.3.1.1 Tap water

Composite tab water samples were collected from the water source at BZU. Samples were collected in four different days to show the variations (if any) in water quality. Samples were collected in clean labeled bottles, transported on an ice chest with ice to the lab and treated according to the standard methods American Public Health Association (APHA 2005). Temperature, pH, EC and TDS were measured using Hanah HI-98129 multifunctional meter in the field, while the turbidity was measured with Hach 2100P turbidity meter. Dissolved oxygen was measured by Oxi-197 DO meter. After collection and filtration via membranes $< 45\ \mu$m pore size, each sample was divided into two subsamples; one for the analysis at BZU and the second to be analyzed at HBU. For the samples designed for HBU, each sample was also divided into two parts: one was reserved using concentrated nitric acid (HNO_3, Merck, ultra-pure) for the determination of cations (Na, K, Ca, Mg), and heavy metals (Ag, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn) using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP/OES VISTA-MPX, Varian); Figure (3.9) . The second was kept without preservatives for the determination of anions (Cl, F, NO_3, PO_4 and SO_4) by Ion Chromatography (IC DIONEX DX120); Figure (3.10).

Figure (3.9) Inductively Coupled Plasma Optical Emission Spectroscopy (ICP/OES)

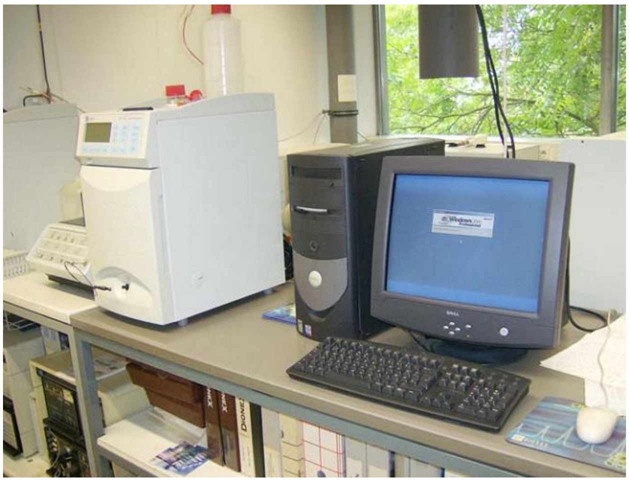


Figure (3.10) Ion Chromatography (IC DIONEX DX120)

Total and fecal coliforms were measured by filtration of 100 mL sample through a 0.45 μm Millipore membrane filters and the filters were incubated at 37 ^{o}C and 44.5 ^{o}C for 24 h, respectively.

Figure (3.11) Coliform analysis of irrigation water

3.3.1.2 Treated wastewater

Composite wastewater samples were collected from the outlet chamber of Al-Bireh WWTP; the physical parameters were measured onsite using same instruments as with tap water samples. The effluent samples were transported directly in an ice box to the laboratories of BZU where they were filtered via membranes <45μm pore size, and divided into two parts for analysis at BZU and HBU, and treated as with TpW samples in the previous section. COD, BOD, and TSS were determined according to standard method of analysis for water and wastewater (APHA 2005), appendix (C).

3.3.2 Soil sampling and analysis

Composite sample of soil from each pot was collected at the beginning of the experiment (May 2010) and at the end of the experiment (August 2010). Samples were cleaned from plant tissues and stones and dried in vacuum oven at 40 - 45^{o}C. After drying, soil samples were manually grinding using mortar and pestle, and further sieved through a 2-mm sieve. After that, soil samples were filled in polyethylene cups, labeled and divided into two parts; one for analysis at BZU and the other one for analysis at HBU.

Approximately, 0.5-1.0 g of each homogenized sample was digested in 10.5 ml of concentrated HCl (37% p.a.) and 3.5 ml of concentrated HNO_3 (65% p.a.) in 50-ml retorts (digesting flask). The samples were degassed (12 h) and then heated to 160 ^{o}C on a sand bath until a complete extraction had taken place (3 h). After cooling, the solutions were diluted with distilled water in 50-ml volumetric flasks and kept in 100-ml polyethylene bottles for analysis. Samples were analyzed by ICP/OES (VISTA-MPX, VARIAN) for the alkali and alkaline earth elements Mg, Ca, K, and Na, the trace metals Ag, Al, As, Ba, Cu, Zn, Ni, Pb, Mn, Fe, Cr, Co, and Cd, and the metalloid As (Shomar 2006). Soil texture was determined according to Bouyoucos Method (Ryan, George and Abdul Rashid 2001), three composite samples were collected from each treatment before planting and one sample from each pot was collected at the end of experiment measured. Soil pH was measured in 0.01 M $CaCl_2$ solution (Carter and Gregorich 2008), using Metrohm-827 pH meter, while EC was measured in 1:1 aqueous soil extract (Carter and Gregorich 2008), by using Jenway-4010 EC-meter. CEC was measured by Donald method with ammonium acetate buffer (pH 7), (Donald 1995), Cary-50 Varian spectrophotometer was used to determine CEC in cmol/kg. Soil TKN was measured according to Kjeldahl method (Carter and Gregorich 2008), four composites samples from each treatments was measured before and after planting. Flame photometer (4110 Sherwood) was used to measure both, exchangeable K by extraction with 1N ammonium acetate buffer (Ryan, George and Abdul Rashid 2001), and available P according to Olsen's method (Bashour and Sayegh 2007).

3.3.3 Fertilizer analysis

Two samples of mineral fertilizer were taken and analyzed for their content of heavy elements using ICP/OES.

3.3.4 Leaves sampling and analysis

The third leaf from the top was taken during the final stage of the growing season to measure both chlorophyll and proline content in the leaves. Leaves were washed with distilled water, frozen in liquid nitrogen, transferred to the refrigerator and stored at -20°C until the analysis. The chlorophyll contents were determined according to (Sadasivam and Manickam 1996). Shortly, chlorophyll a, b and total chlorophyll were extracted with 80% acetone and the absorbance of the extract was read at 645, 663 and 652 nm using Varianic cary-50 spectrophotometer and chlorophyll was determined as mg /g fresh weight.

Proline content was measured in the middle of the growing season by extraction and calorimetric assay with acidic ninhydrine reagent using a spectrophotometer (Varianic Cary 50) at 520 nm and calculated as μmol per gram of fresh weight leaf samples according to the method of (Ábrahám, et al. 2010) against standard Proline.

3.3.5 Fruit sampling and analysis

3.3.5.1 Grains pathogenic *E-coli*

Analysis for pathogenic *E.coli* was carried out according to the ISO 16649-2:2001 (Ed.1, Microbiology of food and animal feeding stuffs). Samples of corn grains were collected from all plants in 5 August, 2010. Each sample was placed separately in a sterile plastic bag and taken immediately to the laboratory for analysis. About 5.0g was weighed into sterile stomacher bags and homogenized with 45 ml sterile Maximum Recovery Diluent (MRD) for 1 min. Dilutions up to 10^{-4} was prepared from the suspension of MRD. One milliliter of each dilution was transferred to a sterile Petri dish for *E.coli* counts. *E.coli* was determined in Chromocult TBX® agar (Merck, Germany) using the pour plate method. The plates were incubated for 24 h at 44 ^{o}C. Colonies on the plates were enumerated and colony counts in 5.0g sample were determined.

3.3.5.2 Grains heavy metals

At the end of the experiment, corn cobs were reaped and the husk was removed from the cobs. Fruits from each plant were put in a paper bag, labeled and dried in oven at 40 - 45^{o}C. After drying, corn grains were removed from the cobs by hand, grinded by electric mill into powder, filled in Poly Ethylene (PE) plastic cup, and stored for analysis. Trace elements were analyzed in each sample by ICP/OES, yielding a total of four analytical values per sample.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Characteristics of irrigation water

The suitability and compliance of the two sources of irrigation water used (TWW and TpW) were evaluated (Table 4.1) according to the guidelines and standards of local, regional and international references, (EQA standards; Jordanian standards JS:893/2002; FAO 2003; WHO guidelines). Appendix D shows the details results of analysis of both types of irrigation water. Beside the known parameters, it is advisable to monitor NO_3-N, NH_4-N, P and K, to estimate additional fertilizers needed for optimum plants yield and quality. In addition, monitoring these parameters help to determine the pattern of cultivation of crops suitable for treated effluent at the best possible and efficient use of soil nutrients. Furthermore, this approach is needed to protect surface and underground water from pollution.

The results (Table 4.1) showed that the treated effluent was colorless and the average pH of both water sources was alkaline (7.9) and it was within the acceptable range of reuse guidelines. The electrical conductivity (EC) of the TWW (1360 μS/Cm) was considered slight to moderate according to the WHO guidelines.

Table (4.1) Characteristics of irrigation water

Parameter	**TpW***	**TWW***	**Max. Value** [a]
Temperature (^{o}C)	18 ± 1	18 ± 2	25
pH	7.9 ± 0.2	7.8 ± 0.3	6-9
EC (μS/Cm)	634.0 ± 5.4	1359.5 ± 54.2	*700-3000* [b]
TDS (mg/L)	308.8 ± 14.3	663.3 ± 24.4	1500
DO (mgO$_2$/L)	5.28 ± 0.25	7.0 ± 1.4	>0.5
SAR	2.11 ± 0.03	5.11 ± 0.14	==
Turbidity (NTU)	4.3 ± 0.3	6.0 ± 1.6	50
TC (CFU/100 ml)	0	$5.4\times10^{9} \pm 2.9\times10^{9}$	1000
FC (CFU/100 ml)	0	$31.5\times10^{3} \pm 14.1\times10^{3}$	==
Na (mg/L)	82.4 ± 2.5	202.8 ± 3.8	200
K (mg/L)	4.15 ± 0.11	30.2 ± 0.3	==
Ca (mg/L)	65.9 ± 2.2	67.9 ± 1.5	400 [c]
Mg (mg/L)	29.9 ± 1.0	32.0 ± 1.7	60 [c]
NH$_4$ (mg/L)	<0.5	<0.5	=
Fe (μg/L)	38.18 ± 26.94	80.23 ± 31.25	5000
Mn (μg/L)	0.93 ± 0.60	38.95 ± 12.47	200
Cl (mg/L)	251.0 ± 8.3	202.5 ± 13.3	500 [c]
F (mg/L)	0.69 ± 0.05	0.62 ± 0.02	1.5
NO$_3$ (mg/L)	6.5 ± 0.3	5.8 ± 2.0	50
HCO$_3$ (mg/L)	228.8 ± 28.6	255.8 ± 25.9	==
PO$_4$ (mg/L)	<0.1	6.3 ± 0.4	30
SO$_4$ (mg/L)	40.0 ± 0.0	65.9 ± 6.9	500
Br (mg/L)	0.59 ± 0.04	BDL	==
Ag (μg/L)	BDL	0.27 ± 0.05	==
Al (μg/L)	23.6 ± 9.6	28.9 ± 9.1	5000
As (μg/L)	5.8 ± 1.5	9.0 ± 1.9	*50* [d]
Ba (μg/L)	56.6 ± 0.9	43.1 ± 3.1	2000
Cd (μg/L)	0.16 ± 0.07	0.15 ± 0.05	20
Co (μg/L)	BDL	0.61 ± 0.08	1000
Cr (μg/L)	0.33 ± 0.06	2.95 ± 2.85	500
Cu (μg/L)	13.90 ± 2.59	0.89 ± 1.09	200
Ni (μg/L)	2.04 ± 1.46	13.76 ± 9.02	200
Pb (μg/L)	2.3 ± 0.8	2.2 ± 0.5	1000
Sr (μg/L)	656.8 ± 7.1	575.5 ± 7.9	==
Zn (μg/L)	449.2 ± 245.3	42.4 ± 25.1	2000
COD (mgO$_2$/L)	---	63.2 ± 5.2	200
BOD$_5$ (mgO$_2$/L)	---	17.6 ± 1.8	60
TKN mg/L	---	1.31 ± 0.45	
TSS (mg/L)	---	30.8 ± 2.0	50

*** Mean of 4 samples ± Standard Error**

a: Water quality standards for wastewater reuse for unrestricted Irrigation (EQA 2001).

b: WHO Guidelines

c: Recommended guidelines by the Palestinian Standard Institute (PSI) for TWW characteristics

d: Jordanian Standard (JS: 893/2002)

Results showed that Na concentration in the treated effluent was almost up to the highest allowable value according to the

Palestinian standards. The Sodium Adsorption Ratio (SAR) and the EC are the most commonly used parameters to evaluate the potential of irrigation water that affect soil and plants (Weiner 2000). The SAR compares the level of Na to both Ca and Mg according the following equation:

$$\boldsymbol{SAR} = \frac{[\boldsymbol{Na^{+}}]}{\sqrt{\frac{[\boldsymbol{Ca^{2+}}] + [\boldsymbol{Mg^{2+}}]}{\mathbf{2}}}}$$

If EC and SAR are in an appropriate ratio, the loss of aggregate stability of soil will not occur.

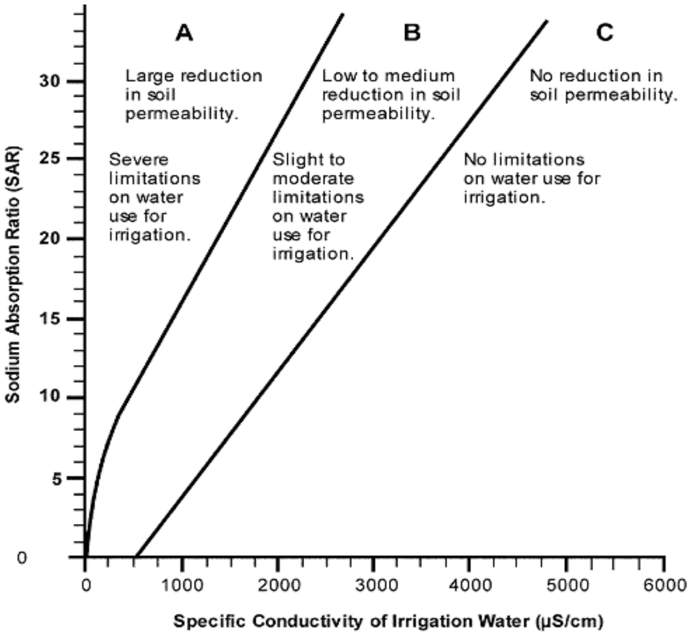


Figure (4.1) Effects of SAR and specific conductivity on soil permeability (Ayers and Westcot 1985)

According to results in table (4.1) and figure (4.1), there was no restriction to use the wastewater effluent in irrigation. Due to the high concentrations of Ca^{2+} and Mg^{2+}, the SAR and EC were in an appropriate ratio to avoid infiltration problems (Ayers and Westcot 1985). In case where the irrigation water had moderate to severe salinity, effluent dilution as a management strategy can be used to reduce the potential problems of using saline water.

The average concentrations of heavy metals and all other chemical parameters were considerably lower than the maximum allowable values for the unrestricted irrigation according to the Palestinian EQA standards and PSI guidelines. It is well known that heavy metals are toxic to plants and animals at high concentrations, and they represent a limiting factor for wastewater to be used in irrigation (FAO 2003).

However, results showed high values of fecal coliform in the TWW, which exceeded the recommended range. This agrees with our field surveys and observations at Al-Bireh WWTP where the disinfection system was not functioning.

4.2 Evaluation of Al-Bireh WWTP treatment efficiency

In order to evaluate the treatment efficiency of Al-Bireh WWTP which is performing secondary treatment, eight hour composite samples were taken over four days. Samples were taken from the influent and from the effluent. Parameters such as BOD, COD, TOC, TDS, and TSS are generally used for evaluation of effluent quality (Tchobanoglous, Burton and Stensel 2003). The parameters used for the determination of the efficiency of the WWTP were COD, BOD_5, TKN, NO_3-N, TSS, TDS, Turbidity, PO_4, SO_4, pH, TC and FC. The characteristic parameters (Table 4.2) were measured according to Standard Methods of Analysis (APHA 2005).

Table (4.2) Removal efficiency of Al-Bireh WWTP (average ± SD, n=4)

Parameter	Influent	Effluent	Efficiency %
pH	7.29 ± 0.09	7.81 ± 0.37	
COD (mg/L)	1025 ± 103	63 ± 5	93
BOD (mg/L)	467.5 ± 42.6	17.5 ± 1.7	96
TKN (mg/L)	36.5 ± 5.4	17.0 ± 3.9	53
NO_3 (mg/L)	5.97 ± 2.87	1.31 ± 0.45	78
TSS (mg/L)	468.2. ± 80.0	30.8 ± 1.9	93
TDS (mg/L)	926.7 ± 42.4	663.2 ± 24.4	28
Turbidity (NTU)	422.2 ± 69.4	6.0 ± 1.5	98
SO_4 (mg/L)	1881.50	65.9375	96
PO_4 (mg/L)	926.75	6.275	99
TC (CFU/100 mL)	2.37×10^{13}	5.43×10^{9}	99
FC (CFU/100 mL)	5.9×10^{6}	3.15×10^{4}	99

It was found that the pH of wastewater samples taken from influent and from effluent was alkaline, and it was in the accepted range to be reused in agricultural according to EQA standards. Influent from Al-Bireh WWTP considered as high strength domestic sewage with average COD concentration of 1025 mg/L. Moreover, the average BOD_5 and TSS concentration were 467.5 mg/L and 468.2 mg/L, respectively (Table 4.2).

The average TSS through the treatment plant was reduced from 468 mg/L to 31 mg/L (removal of 93%). The average removal of NO_3-N is becoming a more important issue in wastewater treatment. NO_3 is of concern, as it percolates easily to groundwater. The average NO_3-N concentration decreased from 5.97 mg/L (influent) to 1.31 mg/L (effluent) with an average NO_3 removal of 78%. Even when BOD_5 was reduced to 17.5 mg/L, the treated effluents may still contain large amount of pathogenic organisms. The populations of total and fecal coliform were reduced to more than 99%. However, the number of fecal coliform still more than the limit allowed by WHO guidelines for irrigation that specify the maximum concentration to be 10^3 Fecal coliform colonies per 100ml. Therefore, advanced treatment is needed to improve the pathogenic removal, especially in those areas where the effluent is to be used for irrigation.

Generally the results (Table 4.1) showed that heavy metals in the effluent are low and they comply with the standards for wastewater reused in agriculture EQA (2001).

4.3 Characteristics of experimental field soils

Absorption of heavy metals by plants depends primarily on both chemical and physical properties of soil, in particular pH, CEC and texture.

4.3.1 Soil pH

The soil pH is a major variable and greatly affects many chemical and biological interactions, since it affects significantly the availability of nutrients important to plant growth as shown in figure (4.2), (Sparks 2003).

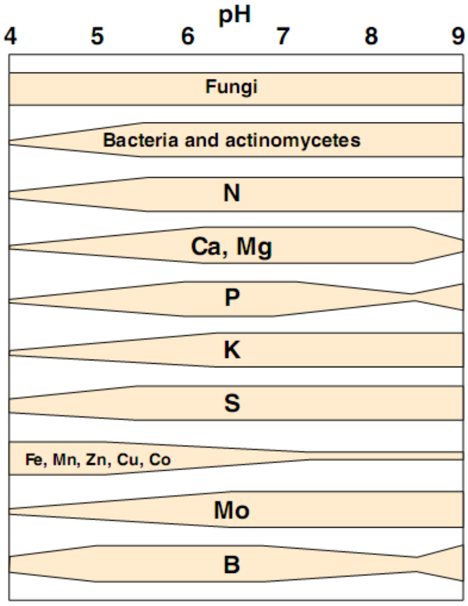


Figure (4.2) pH effects on nutrients availability (Sparks 2003)

It is important to note that maintaining soil pH above 6.5 reduces the availability of heavy metals to plants. A decrease in soil pH value was recorded at the end of the experiment in all treatments compared to soil pH before planting (Figure 4.3). Appendix D presents the results of analysis of all samples.

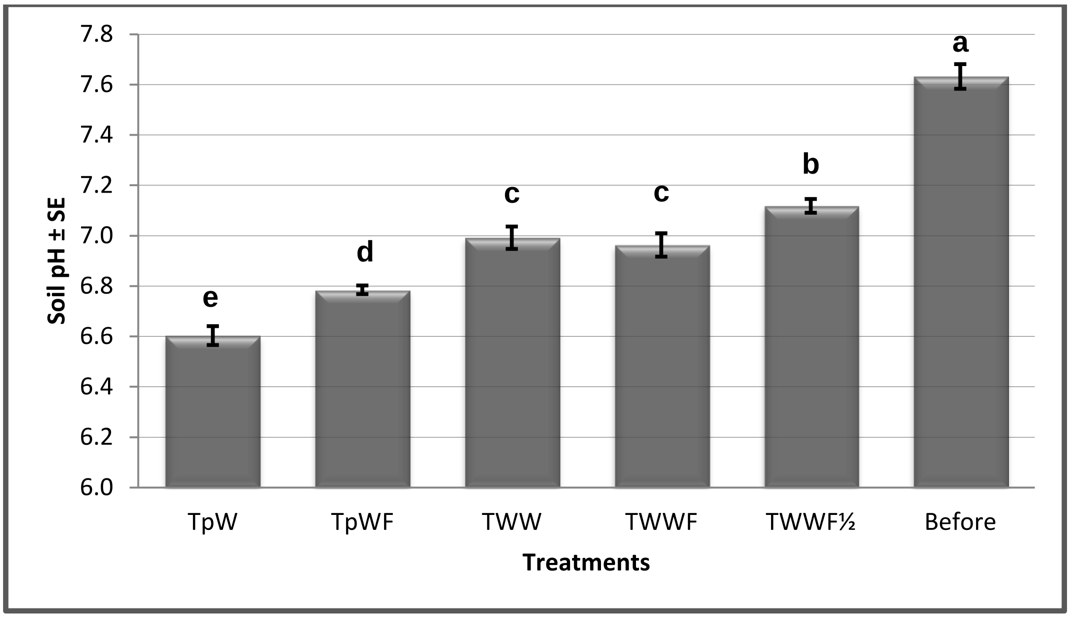


Figure (4.3) Soil pH before and after planting

Plants can strongly reduce rhizosphere pH by excreting organic acids or protons, upon the uptake of cations (e.g., K^+). In calcareous soils, the acid excretion occurs to an extent that the bulk soil pH is lowered (Lambers, Chapin and Pons 2008). Moreover, deficiencies of certain nutrients may cause plants to reduce the rhizosphere pH. Furthermore, the mineralization of organic material may also decrease the soil pH, since decomposition of organic matter produce carbon dioxide (CO_2), which reacts with water to form the carbonic acid, H_2CO_3, (Sparks 2003). Moreover, NH_4-nitrification process in the soil may release protons which contribute to the pH lowering (Bolan, Hedley and

White 1991). The results of this study correspond with the findings of Mohammad and Mazahreh (2003), who found that the decrease in the soil pH might not persist longer, due to the soil buffering capacity. The recorded decrease in soil pH will increase the availability of micro and macro nutrients, mainly Ni, Fe, P as well as Cu and Zn.

4.3.2 Soil EC

In general, soil EC significantly increased by irrigation with TpW or TWW, compared to pre-planting time. On the other hand, the use of TWW (EC=920.67 µS/cm**)** led to a significant increase (by 18.5%) in EC compared to irrigation with TpW (EC=776.0 µS/cm**) (**appendix D). The fertilizer usage with TpW or TWW led also to a significant increase in soil EC. Figure (4.4) shows no significant differences in EC between soils irrigated with TpW and completely mineral fertilized compared to soils irrigated with TWW with half amount of the same fertilizer. The greatest change in the soil EC was observed when the soil irrigated with TWW with complete fertilization. In conclusion, variations in EC appear to be related to type of water and amount of fertilizer added.

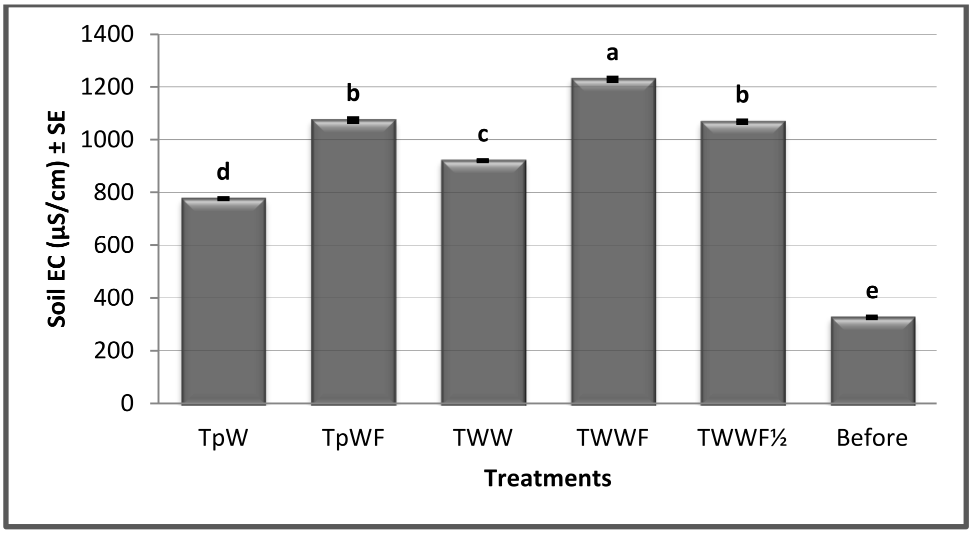


Figure (4.4) Soil EC before and after planting

The increase in EC after irrigation was from mineral salts of irrigation water that would accumulate in the soil. Crops remove small amounts of salt and the salt distribution and movement in soil is directly related to water movement. It is well known that irrigation water quality is an important factor that affects the salinity of the soil. Irrigation water contains salts, but the concentration of salts varies according to the source of water. High concentrations of TDS can reduce growth and yield of the crop (Ayers and Westcot 1985), since high salt concentrations limits the capability of the plants to absorb water through the roots. Moreover, high concentrations of salts in the soil may reduce the absorption of essential nutrients by plants. In this respect, crops can tolerate salinity up to certain levels known as “threshold level” without a measurable loss in yield. The threshold level of corn is 1.7-dS.m^{-1} and every increase of 1 unit above this value will decrease the yield by 12% (Pessarakli 2011). FAO classified corn as moderately salt tolerant crop, which requires soil salinity levels below 4 dSm^{-1} (FAO Ecocrop 2010). Other researchers reported similar increase in soil EC due to irrigation with wastewater (Vazquez-Montiel, Horan and Mara 1996). Irrigation with TWW often leads to high salts and Na concentrations in the soil (Pescod 1992). This show a very good agreement with our results, where treated effluent significantly increased the Na concentration in the soil compared to the TpW (Figure 4.5).

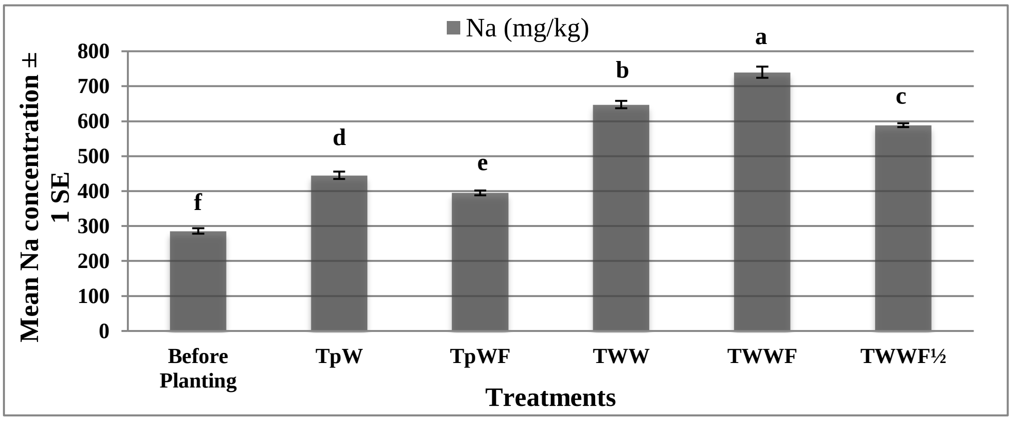


Figure (4.5) Soil Na content before and after planting

4.3.3 Soil texture

Three composite samples were taken from each treatment at the beginning of the experiment before planting and a sample from each pot was taken at the end of the growing season after harvesting.

Table (4.3) Soil texture before and after planting

Treatments		**Mean before planting** $^{n=3}$	**Mean after planting** $^{n=6}$
TpW	**% Sand**	94.1	94.1
	% Silt	4.9	5
	% Clay	1.2	1.2
TpWF	**% Sand**	94.1	93.8
	% Silt	5	5
	% Clay	1.2	1.2
TWW	**% Sand**	94.7	93.8
	% Silt	5	5
	% Clay	1.2	1.2
TWWF	**% Sand**	94.5	94.1
	% Silt	5	5
	% Clay	1.2	1.2
TWWF½	**% Sand**	94.6	94.2
	% Silt	5	5
	% Clay	1.2	1.2

Results (Table 4.3) show the soil texture analysis before and after planting. Appendix D shows the detailed results. No significant difference was observed among treatments between TpW, TWW and fertilizer in the soil texture.

According to the USDA soil textural triangle, the soil texture of the experiment was sandy and there has been no significant change in the texture of the soil (Figure 4.6).

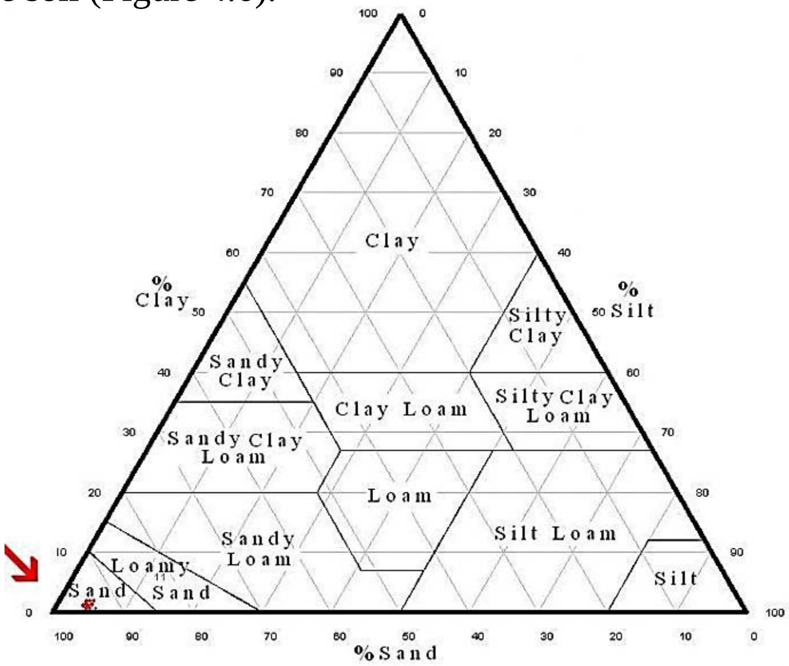


Figure (4.6) The USDA soil textural Triangle (USDA 2011)

4.3.4 Soil cation exchange capacity (CEC)

Cation exchange capacity (CEC) is the sum total of the exchangeable cations the soil can adsorb. Positively charged exchangeable cations are held on the negatively charged soil particles and those may be exchanged by other positively charged ions in the soil solution. Results showed that TWW increased significantly the soil CEC, whereas irrigation with TpW slightly increased the soil CEC (Figure 4.7). Mineral fertilizer also significantly increased the CEC in both types of water.

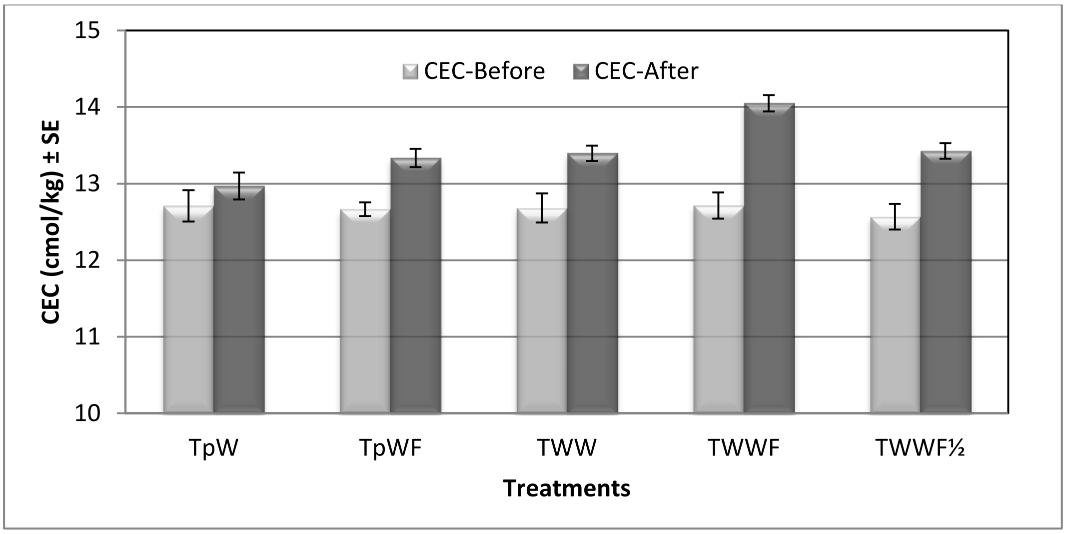


Figure (4.7) Soil CEC before and after planting

Results of this experiment were compatible with the findings of Agbede, et al. (2010), who have found that the use of fertilizer led to an increase in soil total organic carbon (TOC), which means an increase in the soil CEC (Agbede, et al. 2010). Moreover, Singh and

Mishra (1987) studied the effect of fertilizer factory effluent on soil and crop productivity, and they found that the factory effluent rich with mineral fertilizer significantly increased the soil CEC (Singh and Mishra 1987). According to Donald (2010), CEC less than 3 cmol/kg in sandy soils corresponds with low organic matter, while CEC of the sandy soil higher than 25 cmol/kg corresponds to high organic matter (Donald 1995). Further, soil organic matter will develop greater CEC at near neutral pH than under acidic conditions. Consequently and based on our finding, it is probable that the main reason behind the rise in the soil CEC was the increase of organic matter in soil, from TWW. Heavy metals are generally less available to plants in soils of high pH and high CEC compared with soils of low pH and low CEC (FAO 2003).

4.3.5 Soil nutrients

Table (4.4) showed the concentration of soil nutrients (N, P and K), and the effect of irrigation water and fertilization on them.

Table (4.4) Soil nutrients (N, P and K) before and after planting

	TpW		**TpWF**		**TWW**		**TWWF**		**TWWF½**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
TKN*	0.307	0.311	0.303	0.303	0.307	0.307	0.311	0.303	0.299	0.303
± SE	0.005	0.003	0.003	0.003	0.000	0.005	0.003	0.006	0.007	0.006
P**	9.16	0.57	9.16	30.21	9.34	39.60	9.30	33.32	9.42	68.19
± SE	0.10	0.03	0.11	0.09	0.05	0.07	0.09	0.09	0.06	0.15
K**	60.76	109.77	63.12	163.43	65.01	123.43	62.86	177.81	72.59	180.37
± SE	3.66	3.98	6.34	2.33	4.61	3.81	3.03	2.89	5.52	3.88

SE = Standard Error, * n=4, ** n=6

According to the results, there was no significant difference in the soil nitrogen (TKN) due to irrigation with both types of water (Figure 4.8), regardless the use of fertilizer, which could be due to removal of N by the plants.

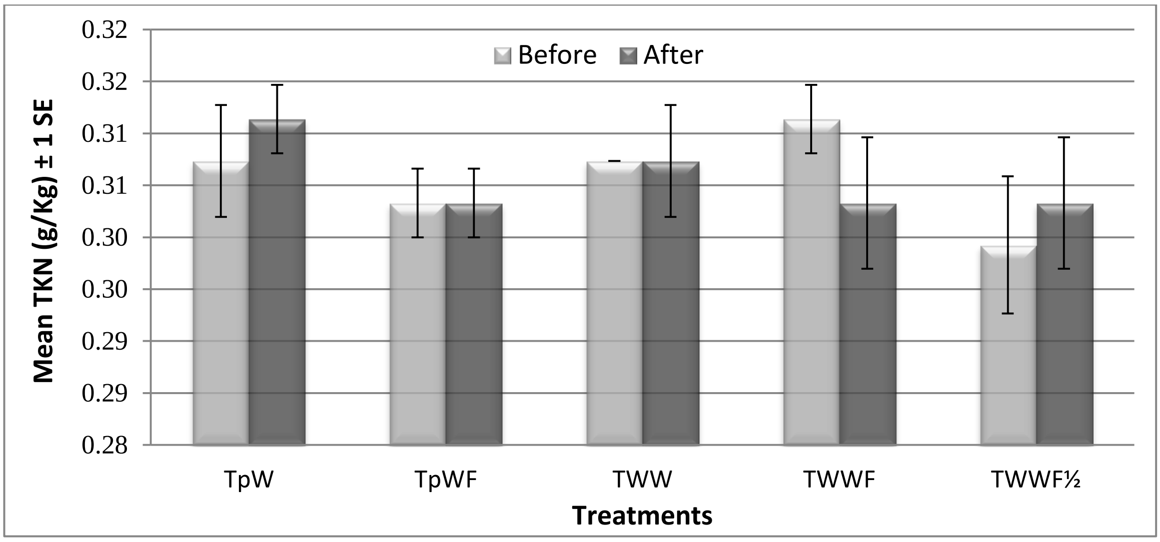


Figure (4.8) Soil TKN before and after planting

Nitrogen in the irrigation water is found mainly as nitrate, which is negatively charged and does not bind readily to soil particles; it is highly soluble and will move with soil solution. On the other hand, the use of TWW led to a significance increase in soil P and K concentrations compared to TpW treatment. The use of fertilizer has led to the same effect on P and K concentration in the soil as with TWW (Figure 4.9 and 4.10). The increase in soil P, and K contents with wastewater irrigation can be attributed to their high content in the wastewater (Table 4.1).

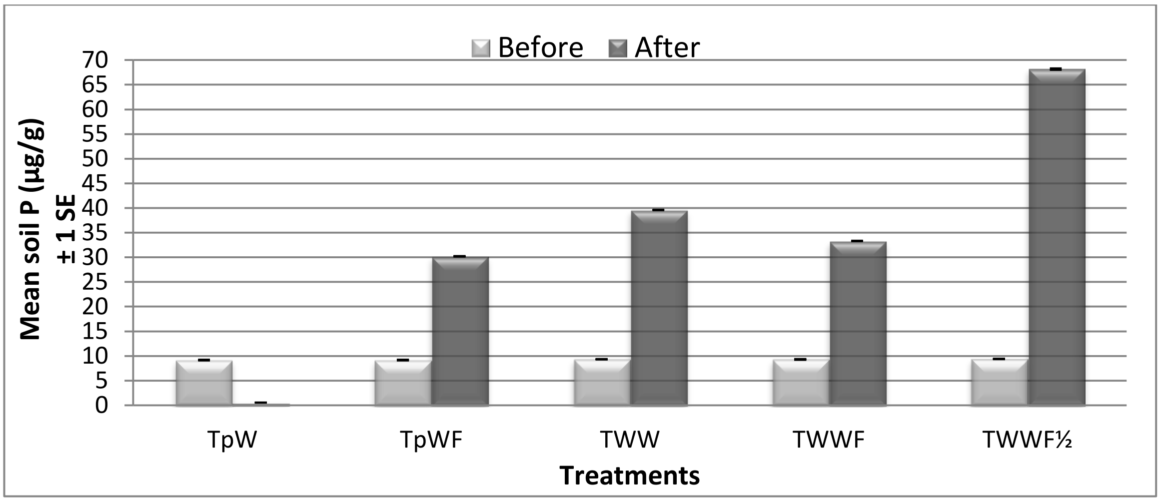


Figure (4.9) Soil P content before and after planting

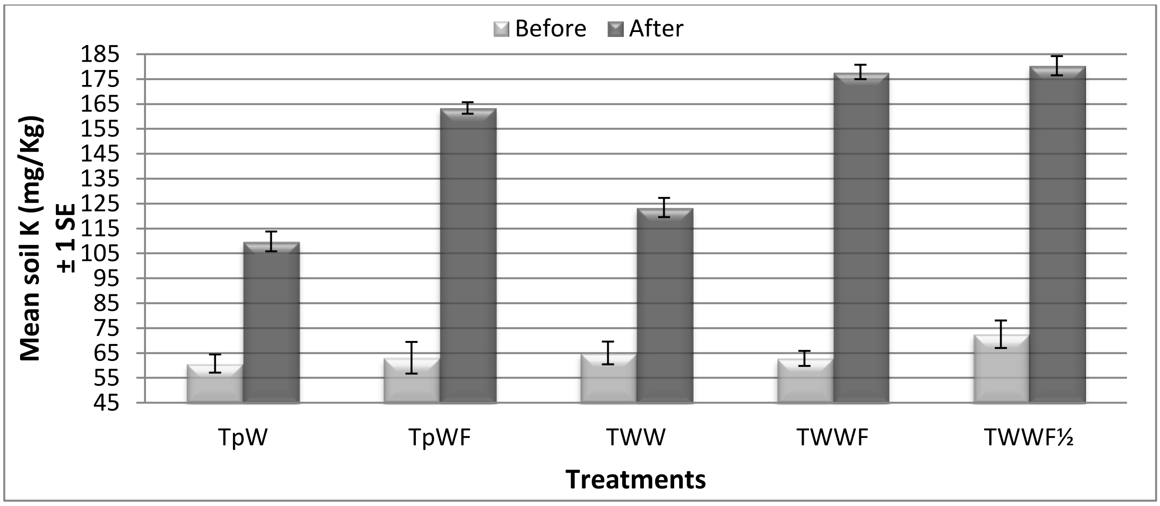


Figure (4.10) Soil exchangeable K before and after planting

4.3.6 Soil heavy metals

All types of soil contain trace levels of metals, which are primarily related to the parent material of the soil. Therefore, the presence of metals in soil is not indicative of contamination. Application of TWW may represent additional loading of these metals in the tested soils. Use of common ranges or average concentration of trace metals in a specific soil may fall out of the background ranges. Only by direct analysis of uncontaminated soils can background levels of metals be determined (Shomar, Müller and Yahya 2005). Metals in the soil may be transported to groundwater through movement with soil water. Unlike degradable compounds, metals cannot be degraded; some metals, i.e. Cr, As, can be transformed to other oxidation states in soil, reducing their mobility and toxicity (Shomar, Müller and Yahya 2005). Immobilization of metals, by adsorption, precipitation, and complexation will prevent their movement, and changes in soil conditions over time may also enhance metal mobility.

Table (4.6) showed the results of the heavy metals in soils before planting and after harvesting. Concentrations of Ag, Cd and Pb after cultivation were not detected, which means that irrigation water and fertilizer did not significantly affect the concentrations of these elements in the soil. Cadmium is of concern to human health, as it is easily absorbed by most crops and not generally phytotoxic at the concentrations normally encountered. Moreover, Cd can accumulate in plants and enters the food chain more easily than other metals such as Pb or Hg, which are not readily absorbed and transmitted to the edible portion of crops (Prasad 1999). Results of this experiment did not showed significant accumulation of heavy metals in the grains which corresponds to the FAO studies that the accumulation of heavy metals in cereal grains are lower than in the leaves (FAO 2003).

In general, the results of the experiment concluded that Ag, Cd and Pb did not constitute any impact on the soil when using treated effluent form Al-Bireh WWTP for irrigation.

Table (4.5) Chemical analysis of mineral fertilizer (NPK 13-13-13)

Parameter	**Sample 1**	**Sample 2**	**Avg ± SD**
Ag (µg/Kg)	906.084	771.234	838.659 ± 95.353
Al (mg/Kg)	18.082	20.351	19.216 ± 1.604
As (µg/Kg)	664.283	398.668	531.476 ± 187.818
Ba (µg/Kg)	BDL	BDL	BDL
Ca (mg/Kg)	1.502	BDL	0.751 ± 1.062
Cd (µg/Kg)	32.063	11.913	21.988 ± 14.248
Co (µg/Kg)	BDL	BDL	BDL
Cr (mg/Kg)	BDL	BDL	BDL
Cu (mg/Kg)	59.031	53.419	56.225 ± 3.969
Fe (mg/Kg)	444.439	461.635	453.037 ± 12.159
Hg (µg/Kg)	BDL	BDL	BDL
K (mg/Kg)	9160.317	8060.397	8610.357 ± 777.761
Mg (mg/Kg)	93.085	82.137	87.611 ± 7.742
Mn (mg/Kg)	197.467	174.077	185.772 ± 16.540
Na (mg/Kg)	3422.314	3039.239	3230.777 ± 270.875
Ni (µg/Kg)	BDL	BDL	BDL
Pb (µg/Kg)	525.814	474.582	500.198 ± 36.227
Sr (mg/Kg)	BDL	BDL	BDL
Zn (mg/Kg)	68.139	61.077	64.608 ± 4.994

BDL: Below detection limit

Table (4.6) Soil heavy metals before and after planting

Parameter		**Ag (mg/kg)**	**Al (mg/kg)**	**As (mg/kg)**	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cd (mg/kg)**	**Co (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**
Before Planting	**Avg.***	1.6	15503.95	4.207	45.255	11693.624	BDL	8.820	25.048	8.995
	±SE	0.4	959.92	0.145	1.981	125.819		0.401	1.252	0.311
TpW	**Avg.****	BDL	18144.65	4.046	50.641	11329.610	BDL	10.749	35.271	11.088
	±SE		336.18	0.106	2.408	460.726		0.411	1.438	0.163
TpWF	**Avg.****	BDL	18529.73	4.125	51.123	10623.676	BDL	10.546	33.555	11.462
	±SE		860.27	0.148	1.076	103.449		0.255	0.924	0.202
TWW	**Avg.****	BDL	19395.85	4.417	50.456	10890.405	BDL	10.724	34.223	11.148
	±SE		650.75	0.143	0.790	95.304		0.214	0.950	0.222
TWWF	**Avg.****	BDL	18788.61	4.321	52.560	11566.038	BDL	10.786	33.894	10.919
	±SE		697.29	0.188	0.925	187.077		0.120	0.763	0.119
TWWF½	**Avg.****	BDL	17278.41	4.526	55.017	10277.119	BDL	10.986	33.000	14.522
	±SE		584.01	0.265	4.157	195.337		0.764	0.553	0.238

Parameter		**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Mn (mg/kg)**	**Na (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Sr (mg/kg)**	**Zn (mg/kg)**
Before Planting	**Avg.***	16812.39	1134.68	2239.72	357.119	285.906	16.922	3.6	99.546	21.156
	±SE	772.47	82.57	98.46	17.978	7.781	0.712	0.1	0.736	1.000
TpW	**Avg.****	18302.52	1226.02	2841.78	399.183	445.353	21.245	BDL	109.298	39.636
	±SE	243.71	27.51	30.33	29.858	10.735	0.300		1.074	1.394
TpWF	**Avg.****	18978.50	1418.60	3001.67	401.000	395.111	21.503	BDL	109.306	40.742
	±SE	367.08	53.75	60.40	8.237	6.691	0.364		0.852	0.945
TWW	**Avg.****	18906.00	1615.64	3095.05	398.822	647.599	21.514	BDL	105.889	37.921
	±SE	374.72	33.25	63.15	7.363	10.648	0.462		0.847	1.001
TWWF	**Avg.****	18671.30	1435.32	2813.16	417.981	740.095	23.327	BDL	117.903	40.723
	±SE	336.44	52.35	58.03	4.984	16.239	1.660		2.165	2.154
TWWF½	**Avg.****	18255.82	1505.36	2855.95	455.484	588.569	22.257	BDL	100.831	53.308
	±SE	225.86	23.06	27.32	56.310	5.206	1.066		2.346	2.483

BDL: Below detection limit, **SE**: Standard error, * n=10, ** n=6

➢ Aluminum (Al)

As shown in Figure (4.11), irrigation water significantly increased the average soil Al concentration in comparison to its concentration before planting and after harvesting and no significant differences was observed, due to use of fertilizer, among each type of irrigation water.

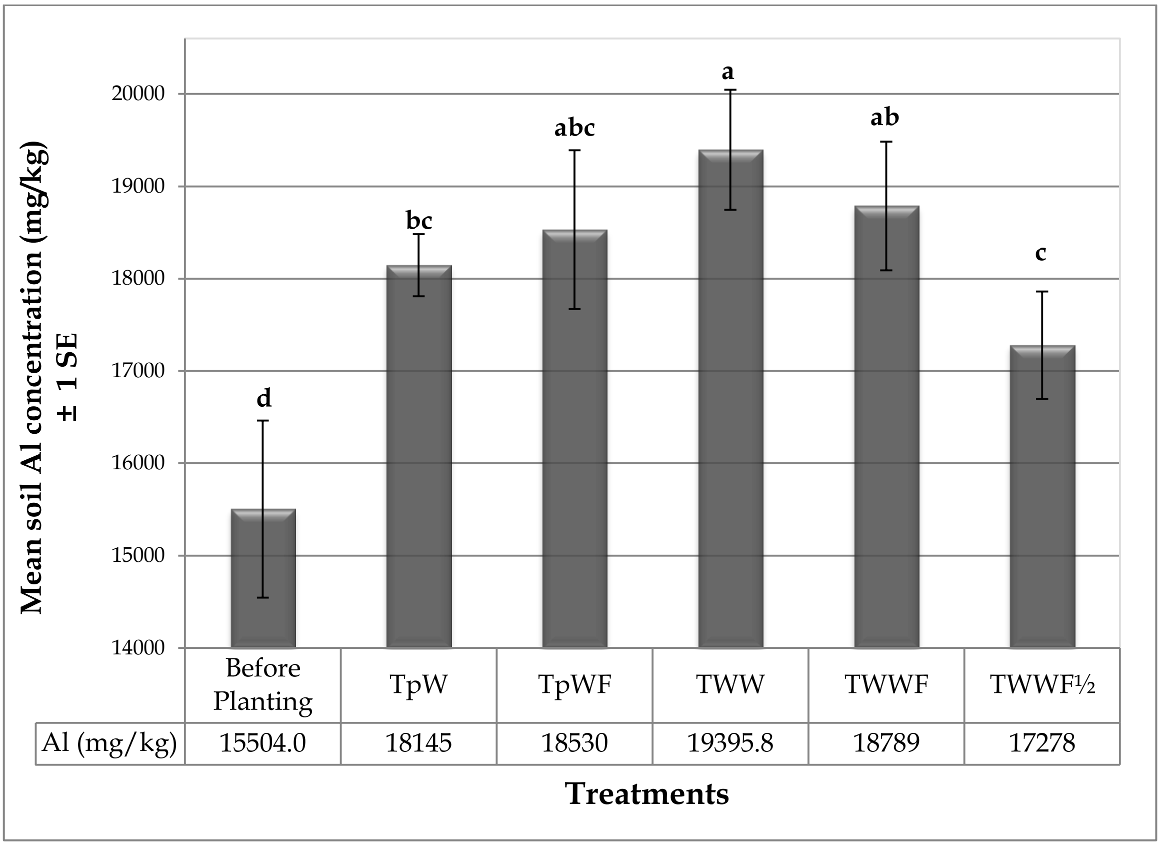


Figure (4.11) Aluminum accumulation in soil before and after planting

- **Arsenic (As)**

Arsenic occurs naturally in soils and rocks, with typical concentrations of about 2-10 mg/kg (UNICEF 2008). Irrigation water (TpW and TWW) did not led to significant difference in soil As concentration after harvesting compared to its concentration in soil before planting (Figure 4.12), regardless of the fertilizers used. However, TWW increased the soil As concentration more than TpW, since As level in TWW is about double of that in TpW (6 and 9 μg/l, respectively).

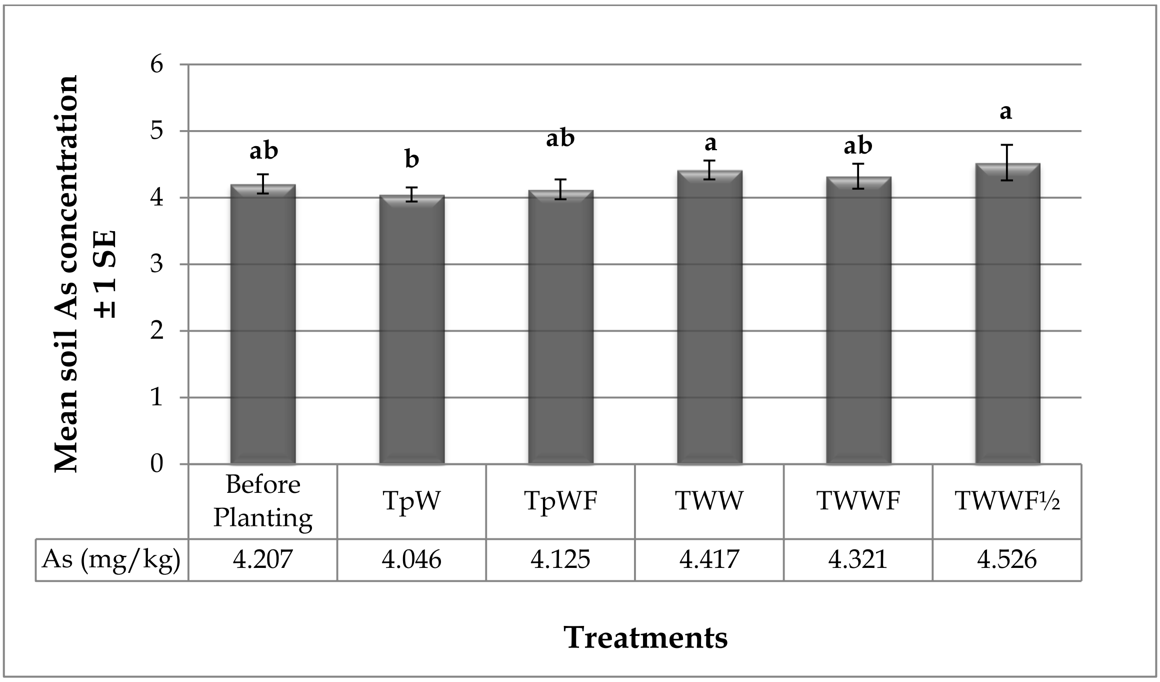
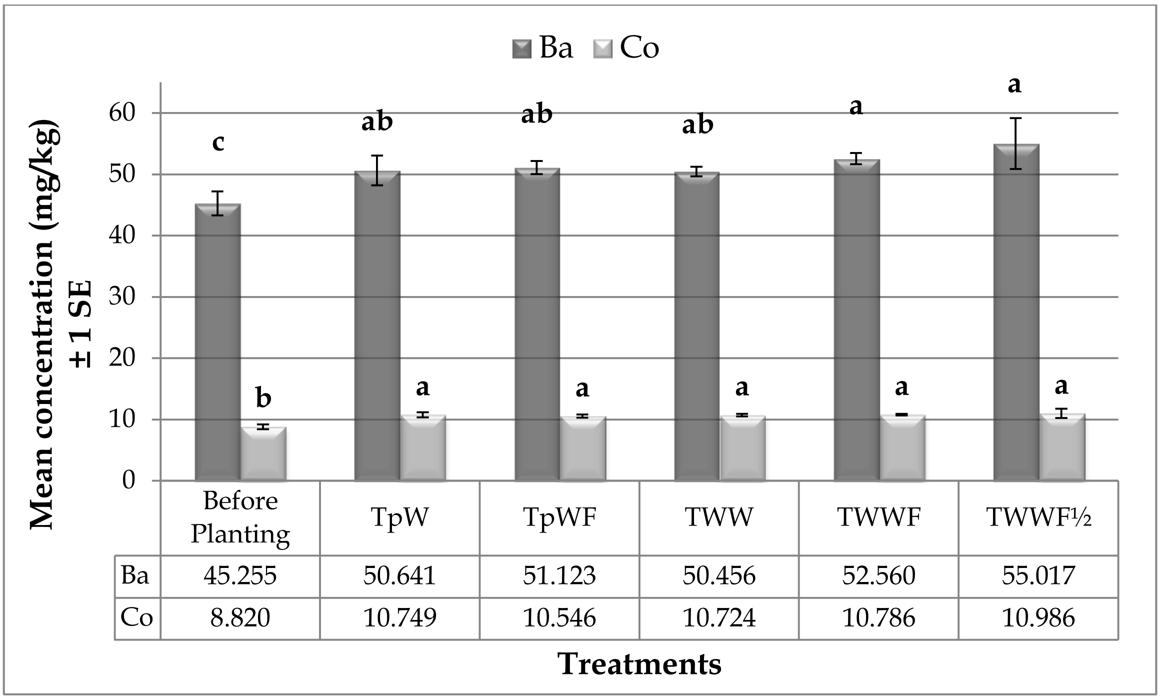


Figure (4.12) Arsenic concentration in soil before and after planting

➢ Barium (Ba) and Cobalt (Co)

Results given in (Figure 4.13) showed that average soils Ba and Co contents were significantly increased (Ba from 45.2 to 55.0 mg/kg and Co from 8.8 to 10.9 mg/kg) in all treatments due to irrigation water compared to its initial concentration in soil before planting. Fertilizer showed no significant difference in Ba and Co concentrations between all treatments (Figure 4.13).



	Before Planting	TpW	TpWF	TWW	TWWF	TWWF½
Ba	45.255	50.641	51.123	50.456	52.560	55.017
Co	8.820	10.749	10.546	10.724	10.786	10.986

Figure (4.13) Barium and Cobalt concentration in soil before and after planting

➢ Chromium (Cr)

Irrigation water (TpW and TWW) showed significant increase in soil Cr content compared with soil before planting (Figure 4.14). There was no significant effect on the accumulation of soil Cr due to irrigation with TWW in comparison with TpW. Application of fertilizer did not showed any significant difference neither with TpW nor with TWW.

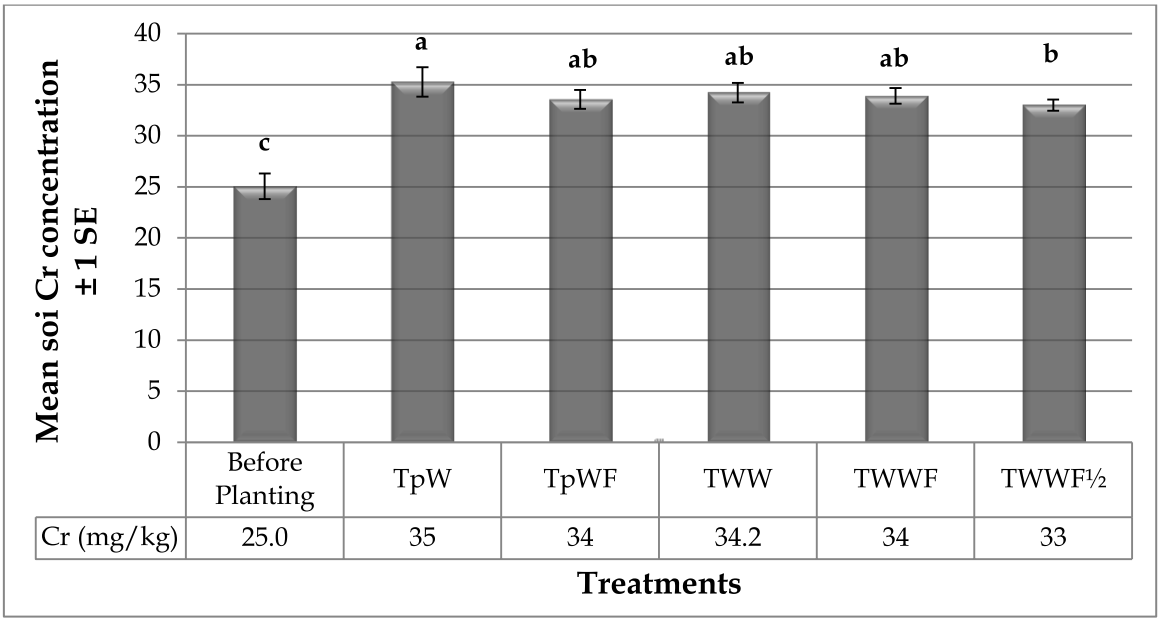


Figure (4.14) Chromium concentration in soil before and after planting

- **Copper (Cu)**

There was no significant difference in the concentration of copper in the soil in treatments irrigated with TpW or TWW (Figure 4.15). However, fertilizer contains 55 ppm of copper and the use of fertilizer led to an increase in the concentration of Cu in the soil, but the difference was not significant with both types of irrigation water used, and TWW with half fertilization gave the highest concentration of copper in the soil between all treatments.

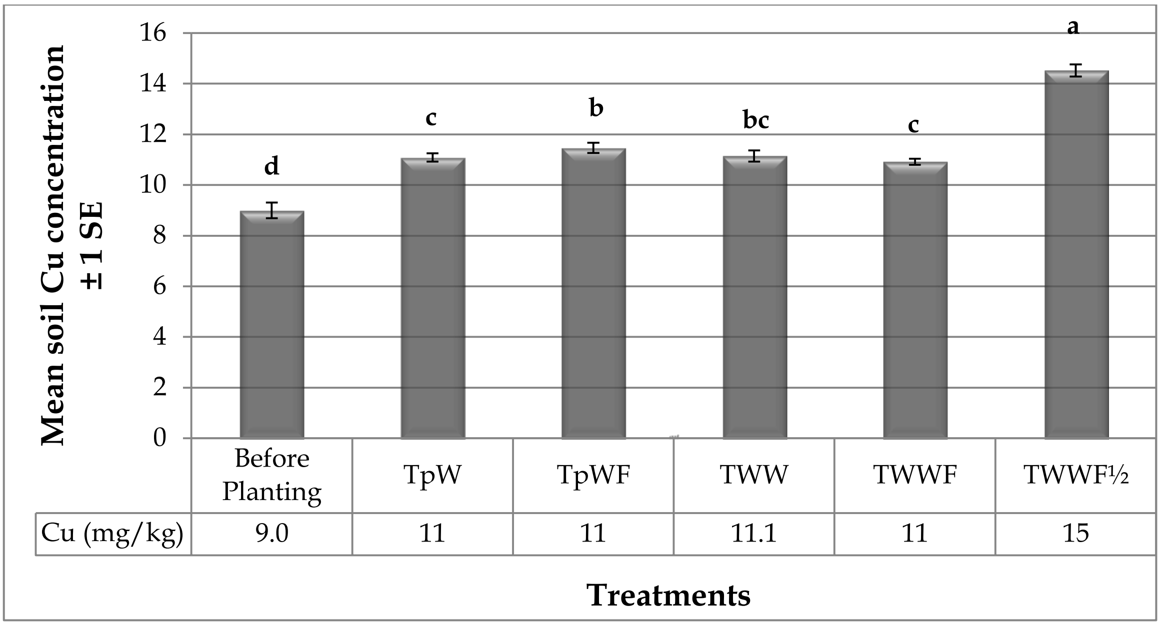


Figure (4.15) Copper concentration in soil before and after planting

- **Iron (Fe)**

All treatments significantly promoted Fe accumulation in the soil compared to its initial concentration in the soil before planting. Application of TWW alone or in combination with fertilizer had no significant effect on soil Fe concentration compared with soil irrigated with TpW. On the other hand, TpW with complete fertilization significantly increased the soil Fe concentration compared to the non-fertilized treatment irrigated with TpW (Figure 4.16). Possible explanation is due to levels of Fe measured in TpW (38.18 μg/L), TWW (80.23 μg/L) and in the fertilizer (500 ppm) used in this experiment.

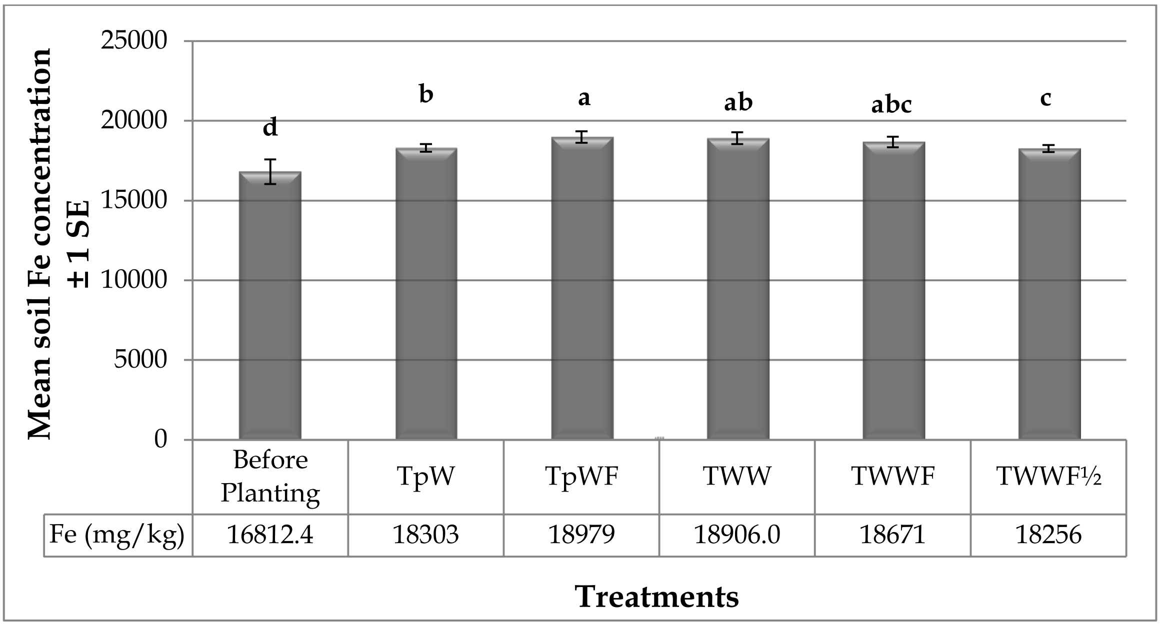
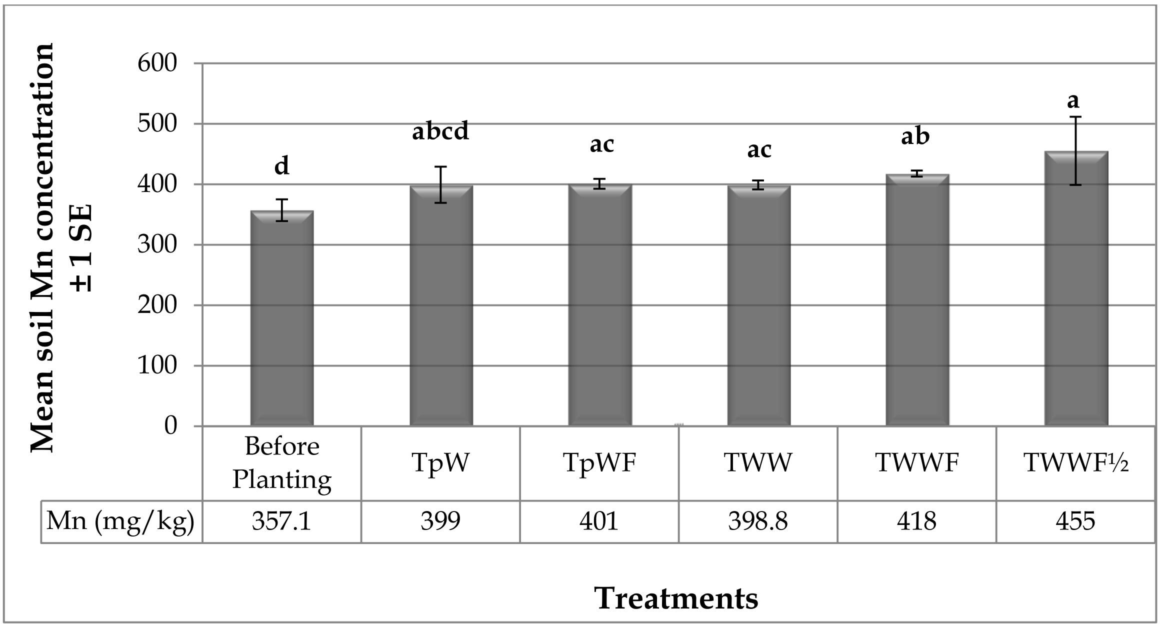


Figure (4.16) Iron concentration in soil before and after planting

➢ Manganese (Mn)

All soils, except the soil irrigated with TpW, showed significant increase in the Mn concentration compared to its initial concentration in the soil before planting (Figure 4.17). After harvesting, there was no significant difference in soil Mn content between treatments irrigated with TpW or those irrigated with TWW. The fertilizer used in this experiment contains 250 ppm Mn, which led to increase in the soil Mn content in the treatments when fertilizer is added. The increase in soil Mn was not significant with TpW where as it was significant with TWW, since the concentration of Mn in TpW and TWW was 0.93 and 38.95 *µ*g/L respectively (Figure 4.17).

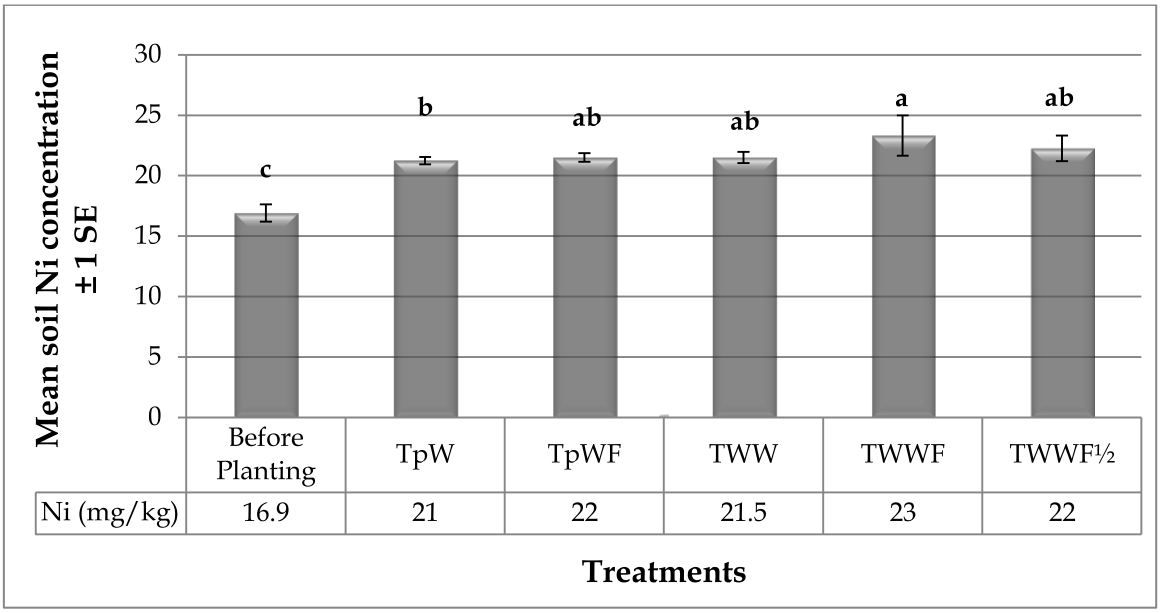


	Before Planting	TpW	TpWF	TWW	TWWF	TWWF½
Mn (mg/kg)	357.1	399	401	398.8	418	455

Figure (4.17) Manganese concentration in soil before and after planting

➢ Nickel (Ni)

Irrigation with TWW had no significant effect on the accumulation of soil Ni compared with irrigation with TpW (Figure 4.18). However, soil irrigated with wastewater, increased Ni concentration compared with soil irrigated with TpW. This could be attributed to Ni concentrations in the TWW and TpW which were 13.76 and 2.04 μg/L respectively. On the other hand, both type of irrigation water (TpW and TWW) showed significant increase in soil Ni compared with soil before planting. Application of fertilizer did not show any significant difference between treatments, whether it used with TpW or TWW.

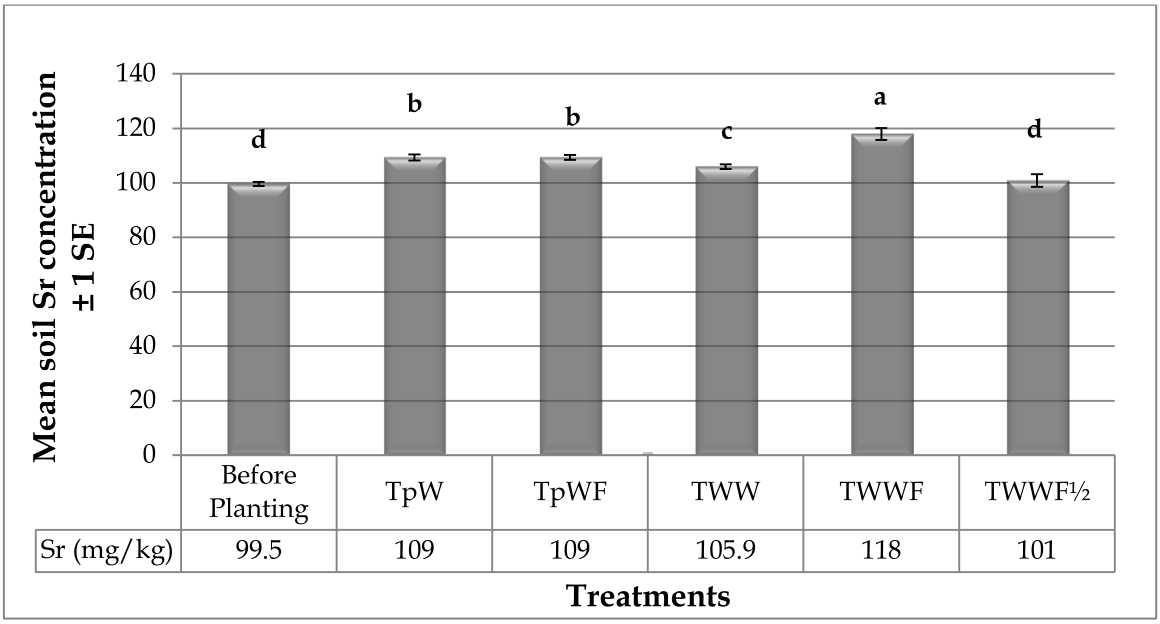


	Before Planting	TpW	TpWF	TWW	TWWF	TWWF½
Ni (mg/kg)	16.9	21	22	21.5	23	22

Figure (4.18) Nickel concentration in soil before and after planting

➢ Strontium (Sr)

TpW and TWW increased the soil Sr concentration in comparison to its concentration before planting. TpW increased soil Sr content more than TWW, since the background level of Sr in TpW (656.8 μg/L) was more than that in TWW (575.5 μg/L). Fertilizer shows significant increase with TWW whereas it was non-significant with TpW (Figure 4.19).

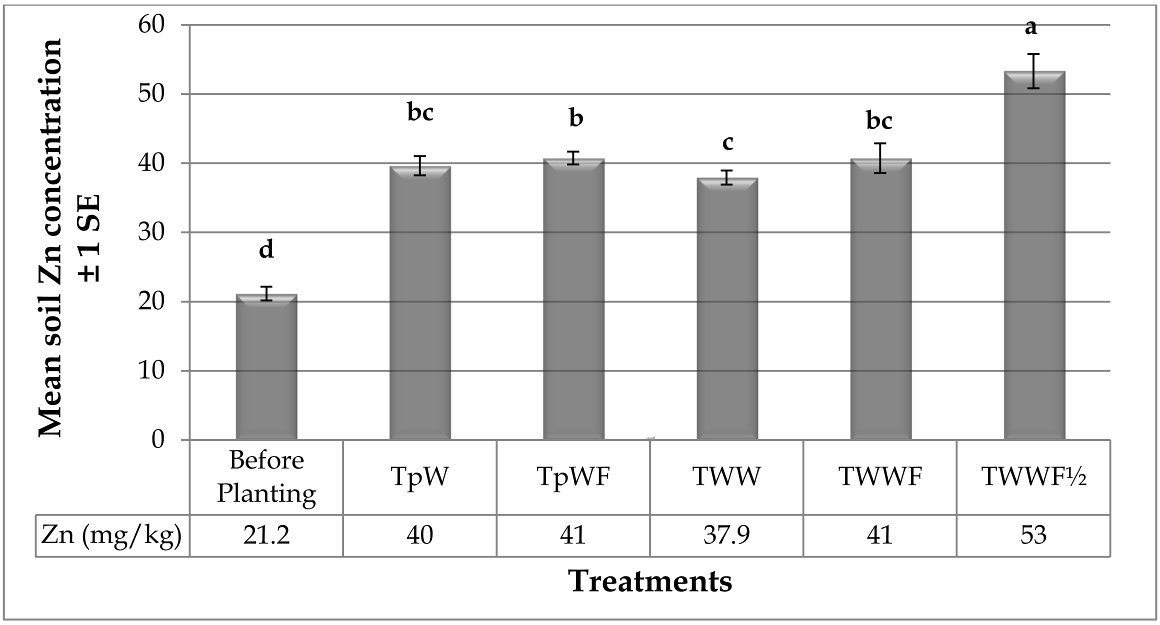


	Before Planting	TpW	TpWF	TWW	TWWF	TWWF½
Sr (mg/kg)	99.5	109	109	105.9	118	101

Figure (4.19) Strontium concentration in soil before and after planting

➢ Zinc (Zn)

Soil Zn concentration significantly increased in all treatments in comparison with its initial concentration in soil before planting. The results (Figure 4.20) showed that the amount of Zn in soils irrigated with TWW were significantly lower than the soil irrigated with TpW. This is probably because the Zn concentration in TpW is about ten times more of the TWW (Table 4.1). Fertilizer contains 75 ppm Zn, and application of fertilizer with both type of irrigation water increased Zn concentration in soil, but the difference is not significant with each type of water. TWW with half fertilization showed the highest concentration of zinc in the soil between all treatments.



	Before Planting	TpW	TpWF	TWW	TWWF	TWWF½
Zn (mg/kg)	21.2	40	41	37.9	41	53

Figure (4.20) Zinc concentration in soil before and after planting

The concentrations of elements (Table 4.6) in experiment soil were less than the values in the upper crust, except for As and Ni which showed higher values than that reported by Turekian and Wedepohl, (Turekian and Wedepohl 1961) (Table 4.7).

Table (4.7) Distribution of elements in some major units of the earth's crust

Element	**UC***	**LC****	**Element**	**UC**	**LC**
Al (%)	7.74	8.21	Li (mg/kg)	22	13
As (mg/kg)	2	1.3	Mg (%)	1.35	3.15
Ba (mg/kg)	668	568	Mn (mg/kg)	527	929
Br (mg/kg)	1.6	0.28	Na (%)	2.57	2.12
C (%)	0.32	0.06	Ni (mg/kg)	18.6	99
Ca (%)	2.95	4.86	Pb (mg/kg)	17	12.5
Cd (mg/kg)	0.102	0.101	Rb (mg/kg)	110	41
Co (mg/kg)	11.6	38	S (%)	0.95	0.41
Cr (mg/kg)	35	228	Sr (mg/kg)	316	352
Cu (mg/kg)	14.3	37.4	Th (mg/kg)	10.3	6.6
Fe (%)	3.1	5.7	Y (mg/kg)	20.7	27.2
Hg (μg/kg)	56	21	Zn (mg/kg)	52	79
K (%)	2.86	1.31	Zr (mg/kg)	237	165
(*) Upper Crust, and (**) Lower Crust					

Source: (Turekian and Wedepohl 1961)

In conclusion, TWW from Al-Bireh WWTP did not increase the heavy metals content of soils, in comparison with TpW, probably due to low metal concentrations in effluents used (Pescod 1992), since there is no heavy metal industrial pollution in Al-Bireh city. In addition, the short period of the experimentation might be another reason for the absence of effect.

4.4 Growth parameter

Plant growth requires energy, obtained from the sun through the process of photosynthesis where green pigments in the leaf, chlorophyll, absorb energy from the sun. Plants use this energy with water, and carbon dioxide to produce oxygen and simple sugars. Plants then use these sugars to make more complex carbohydrates and store them as energy reserves to make cellulose and hemicellulose of cell walls or with nitrogen to make proteins (Prasad 1999). Plant leaves get water and nutrients from the roots while oxygen enters the leaves through stomates. Plants lose water via stomates through evapotranspiration process. Water is the most limiting factor in plant growth and it is vital for growth. Plant cells do not actively take up water; water moves into the cells of the roots that contain sugar, from leaves, and salts absorbed from the soil. This concentration of sugar and salt makes the water potential in the roots less than that in the soil which generates a driving force moving water from soil to the roots. This water is then pulled to the xylem by the active transport of salt ions into the xylem. The stem of the plant is simply a plumbing system. The inner layers are the wood or xylem, which carries water from the roots up to the leaves. In the leaves most of the water is evaporated out to the air. When the water lost by plants through evaporation exceeds the amount of water coming into the leaves from the roots, the guard cells around the stomates in the leaves close the stomates and plants wilt. Contrary, when guard cells are plump and full, they hold the stomates open. A small amount of water is used in photosynthesis to make sugar and the remaining amount is used to carry the sugar through the plant. Xylem carries water and nutrients, whereas, phloem, which is the other half of the plants plumbing system, carry the sugar from leaf cells. Unlike the xylem, which is an open system, the phloem is a closed system and when water flows into it after the sugar it creates pressure that moves the plant sap to various organs that use it for growth (Lambers, Chapin and Pons 2008).

Higher growth was observed by using TWW. Domestic wastewater can provide the needed nutrients normally required for the production of agricultural crops (Pescod 1992). The morphology parameters (plant high, number of leaves, number of fruits and fruit dry weight), were studied and the following sections summarizes the findings.

4.4.1 Plant height

Figure (4.21) clearly showed that corn plants irrigated with TWW, combined with full or partial fertilization, were significantly longer compared to plants irrigated with fresh water, without any addition of chemical fertilizers. Interestingly, treatments with partial fertilization gave similar length as those with full fertilization rate. Detailed results are listed in appendix E.

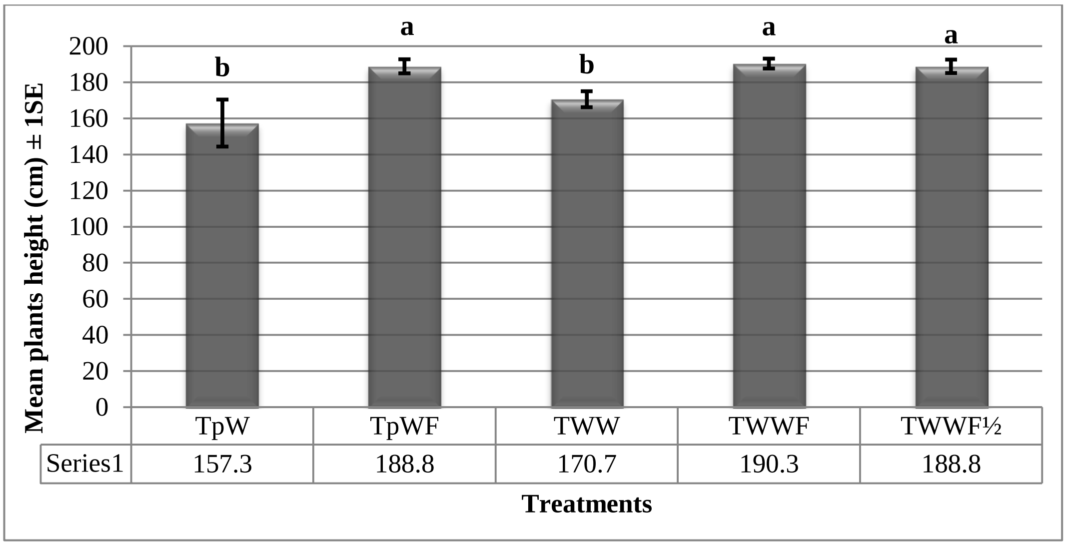


Figure (4.21) Mean of plants height

4.4.2 Number of leaves per plant

In general, fertilizers application and TWW irrigation significantly increased the numbers of leaves (Figure 4.22). Plants irrigated with TpW, without fertilization, showed significantly the lowest number of leaves compared to all other treatments. There was no significant difference in the number of leaves of fertilized plants regardless the type of irrigation water and the quantity of fertilizer. Detailed results are listed in appendix E.

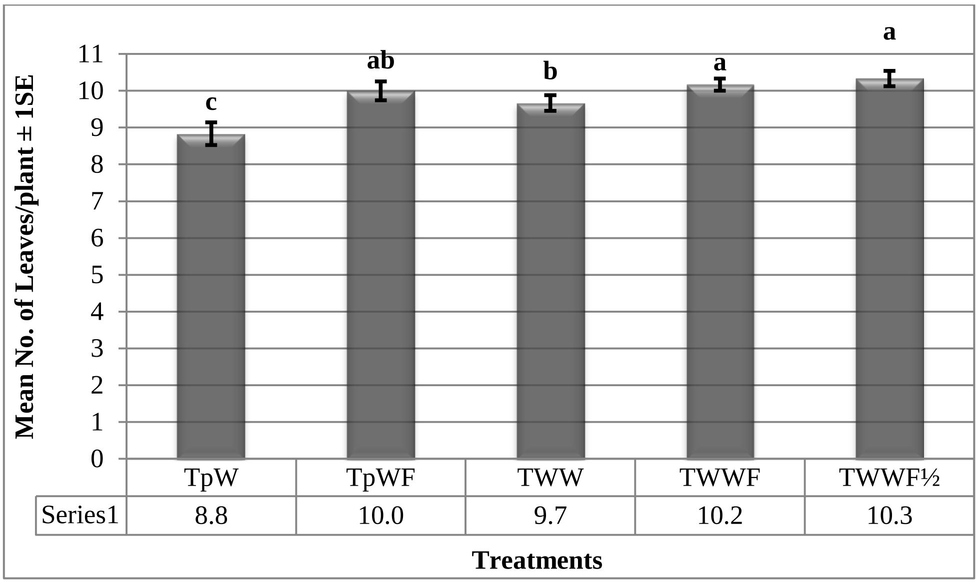


Figure (4.22) Mean of number of leaves per plant

4.4.3 Number and dry weight of fruits per plant

Fruits number and dry weight per plant showed the same significant difference between different treatments (Figures 4.23 and 4.24). Results indicated that plants irrigated with TWW showed no significant difference in the number of fruits compared to plants irrigated with TpW (Figure 4.23), while the dry weight was significantly higher, by almost double (Figure 4.24). Detailed results are listed in appendix E. The average crop yield in all treatments varied from 42.8g (in TpW) to 116.8g (in TWWF). The increase in dry weight could be due to the nutrients contained in the effluent, thereby a lower cultivation cost is expected due to less fertilizer use. Fertilization on the other hand, significantly increased the number of fruits per plant compared to non-fertilized plants. Moreover, results showed that treatment with half fertilizer rate, under irrigation with TWW, gave same yield as treatment with full fertilizer rate.

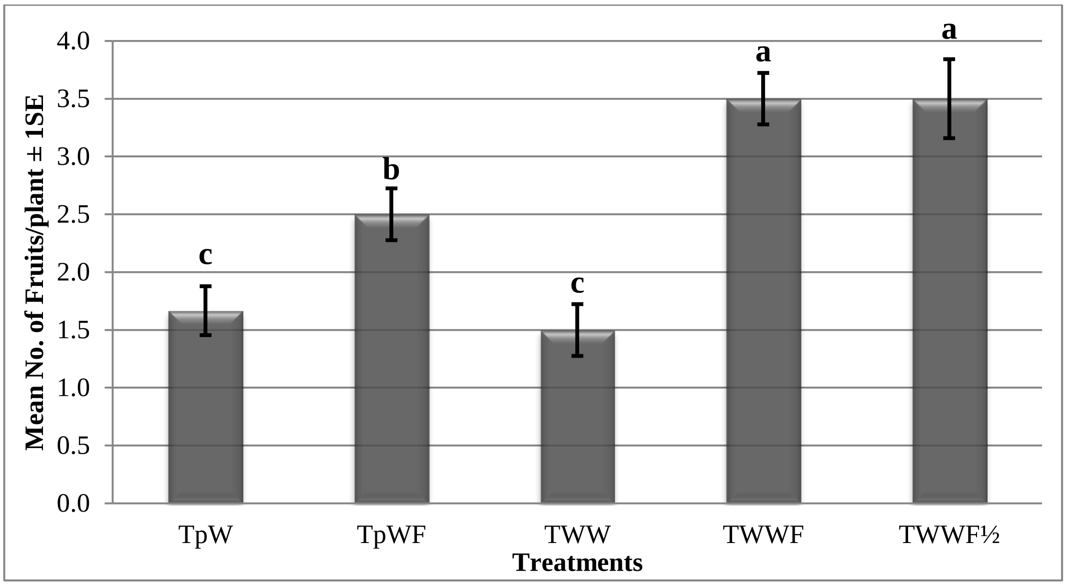


Figure (4.23) Mean of number of fruit per plant

Thus, the addition of 50% of the artificial fertilizer dose was enough to give the highest rate of the corn crop. For fruit dry weight, the addition of fertilizer increased the weight significantly compared with non-fertilized plants, and the combination of TWW and fertilizer gave the highest dry weight among the treatments. Furthermore, no significant differences were recorded in the dry weight with respect to fertilizer usage; regardless of the type of water used or amount of fertilizer (Figure 4.24).

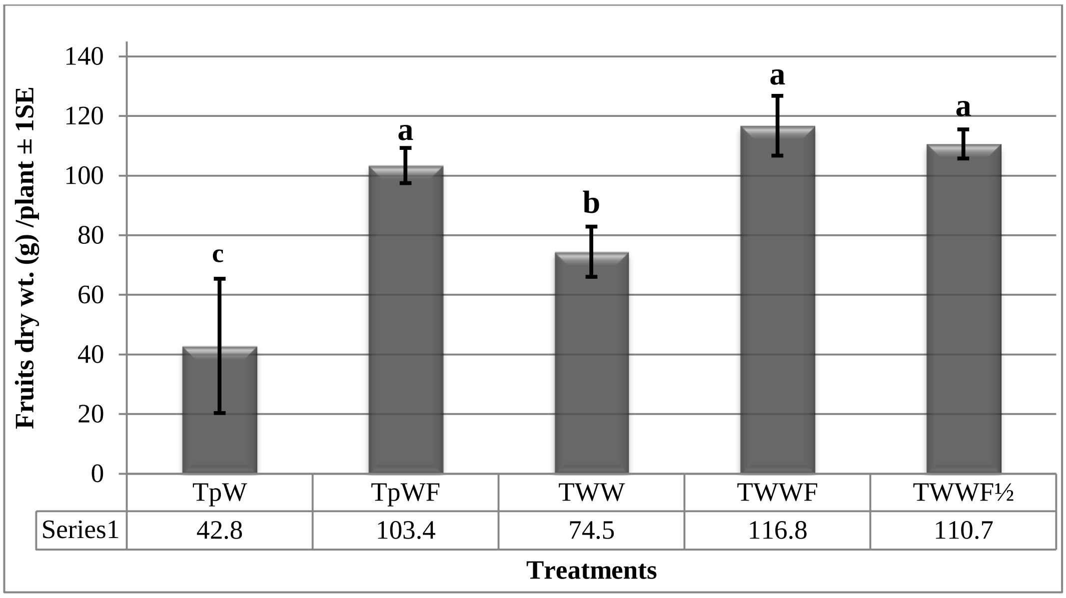


Figure (4.24) Mean of fruit dry weight per plant

4.5 Plant analysis

4.5.1 Grains pathogenic *E.coli*

The purpose of this test was to evaluate the effect of irrigation with TWW on the incidence of *E.coli* in corn that intended for use as animal feeding. Disease transmission may occur through direct physical contact of farmers with wastewater or through consumption of products irrigated with wastewater (FAO 2003). Danger lies more in agricultural products, especially vegetables consumed raw, more severe than when cooked. The WHO standards for faecal coliform in irrigation water are less than 1000 CFU/100mL. Pathogens can accumulate in the soil and enter the food chain due to irrigation with sewage effluent. In conclusion, it was found the *E.coli* was absent in all of the treatments units, and the treated effluents from Al-Bireh WWTP were not likely to pose a health risk in corn that are intended for use as animal feeding.

4.5.2 Grains heavy metals

Several elements were analyzed in the corn seeds before and after the reuse experiment. Parent seeds were used as control in the analysis for the harvested grains, since Palestinian standard for the year 2005, PS 510-3-1999, does not specify the concentrations of heavy metals in the corn used as animal feed stuff, while the concentrations of heavy metals in treated wastewater used in agriculture have been identified.

Table (4.8) showed the list of the average concentrations of these elements for the different treatments. This section focuses on the relevant elements as well as the ones with high concentrations.

As indicated, Ag, Al, As, Cd, Co, Pb and Ba were below the lower limit of detection of the ICP/OES for all samples of the experiment. On the other hand, the heavy metals Cu, Fe, Ni and Zn were detected.

Generally, the Cu, Ni and Zn contents showed no significant difference between their concentrations on the original corn seeds before plantation and after harvesting. However, Fe dropped to 50-60% of its original concentration (50 to ~25 mg/kg, respectively).

The major parameters of Ca, K and Mg showed the same trend while Na dropped also to 40-50% of its original concentration (26 to 18 mg/kg, respectively).

Table (4.8) Elements and heavy metals in the corn grains used in the experiment and the harvested grains

Parameter	Planted Grains	Harvested Grains**				
	Composite Sample*	TpW	TpWF	TWW	TWWF	TWWF½
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Ag (mg/kg)	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Al (mg/kg)	107.6	8.4 ± 6.5	<2.5	<2.5	<2.5	<2.5
As (mg/kg)	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Cd (mg/kg)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Co (mg/kg)	0.6	<0.5	<0.5	<0.5	<0.5	<0.5
Pb (mg/kg)	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Ba (mg/kg)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cu (mg/kg)	2.0	2.2 ± 0.4	1.9 ± 0.4	2.1 ± 0.3	2.5 ± 0.2	2.3 ± 0.2
Fe (mg/kg)	50	25.7 ± 8.3	19.3 ± 2.9	17.8 ± 2.1	23.7 ± 1.8	20.8 ± 2.6
Ni (mg/kg)	1.37	2.04 ± 0.75	1.50 ± 0.12	1.90 ± 0.10	1.44 ± 0.12	1.4 ± 0.1
Zn (mg/kg)	40	48.7 ± 9.8	38.9 ± 4.9	49.9 ± 4.9	48.1 ± 3.9	46.8 ± 6.6
K (mg/kg)	4778	4714.4 ± 240.1	4745.1 ± 398.5	5053.4 ± 503.0	4914.2 ± 284.2	5175.0 ± 259.6
Mg (mg/kg)	1284	1263.8 ± 238.3	1141.8 ± 68.4	1275.3 ± 89.6	1314.5 ± 207.4	1240.3 ± 148.4
Mn (mg/kg)	9.5	8.6 ± 1.8	8.1 ± 0.7	9.0 ± 0.7	12.4 ± 8.2	9.5 ± 2.6
Na (mg/kg)	26.4	13.4 ± 1.2	18.9 ± 7.0	20.6 ± 6.3	15.2 ± 3.4	17.2 ± 3.2
Cr (mg/kg)	1.1	0.9 ± 0.6	<0.5	<0.5	<0.5	<0.5
Ca (mg/kg)	220	126.0 ± 15.4	138.4 ± 26.4	153.8 ± 21.8	127.0 ± 17.6	141.0 ± 24.8
Sr (mg/kg)	0.52	0.56 ± 0.07	0.82 ± 0.2	0.88 ± 0.14	1.50 ± 1.97	0.86 ± 0.16

*** mean of 2 samples, ** mean of 6 replicates**

4.5.3 Leaves analysis

4.5.3.1 Chlorophyll content

Chlorophyll is one of the basic pigments in plants and its deficiency causes chlorosis, and a reduction in the growth and plant yield (Khayatnezhad, et al. 2011). Chlorophyll content of plants was often measured to assess the amount of environmental stress, due to the fact that changes in chlorophyll content associated with the appearance of visible symptoms on plants (Pessarakli 2011). Some studies indicated that heavy metals had negative effects on chlorophyll content of plants, (Zengin and Munzuroglu 2005), since heavy metals inhibit the action of enzymes in several metabolic processes. In respect to heavy metals, they may directly inhibit enzymes responsible for chlorophyll biosynthesis or indirectly affect the uptake of some essential nutrient (e.g. Mg; the major element in chlorophyll molecules).

Results (Figure 4.25) showed that treatments irrigated with TWW led significantly to higher chlorophyll content. Moreover, leaf chlorophyll content was significantly higher in treatments where fertilizer was added compared to non-fertilized treatments.

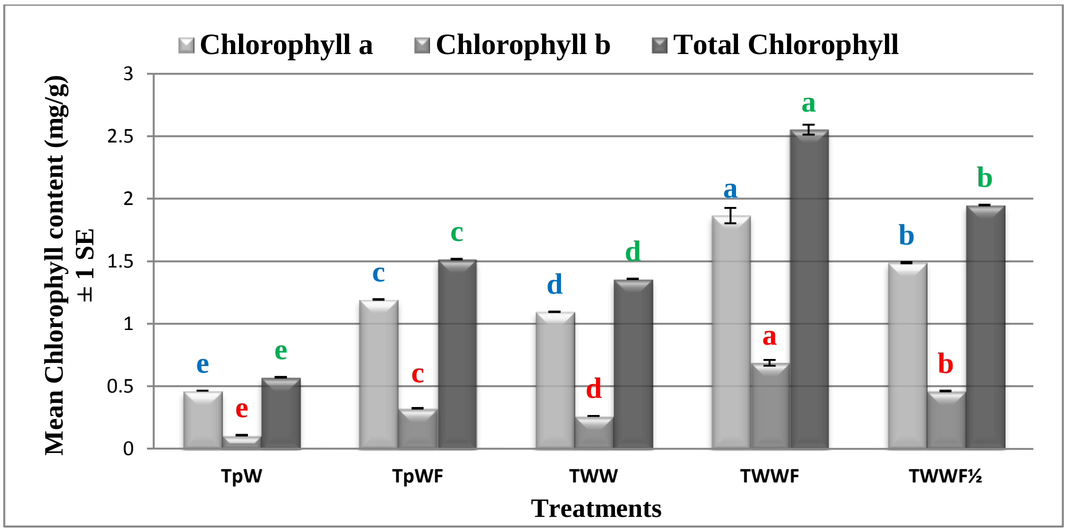


Figure (4.25) Corn leaves chlorophyll content

TWW with complete fertilization (TWWF) showed the highest chlorophyll content among all treatments. Increasing the dose of applied fertilizer resulted in an increase of the leaf chlorophyll and this agrees with the findings of other research, (Labrecque, Teodorescu and Daigle 1995). In general, TWW and fertilizers have stimulated the synthesis of chlorophyll in plant leaves.

The impact of inorganic fertilizers on the contents of chlorophyll was due to the fact that nitrogen is a constituent of chlorophyll molecule and nitrogen is the main component of all amino acids in proteins, which are important constituents of chloroplast (Zengin and Munzuroglu 2005). Researchers reported that maize growth and chlorophyll content were enhanced by using brewery effluent rich in nutrients, due to high plant/nutrient uptake, synthesis and translocation in maize plant, (Orhue, Osaigbovo and Vwioko 2005). Chlorophyll content can also be used as an indicator to the nutritional status of some nutrients. Deficiency in Mg, Fe, and other nutrients such as Ca, Mn and Zn can reduce chlorophyll formation and results in leaf chlorosis (Shaahan, El-Sayed and Abou El-Nour 1999).

4.5.3.2 Proline content

Proline is an amino acid which maintains the vitality of the plant cells under conditions of drought and salinity, because it prevents or reduces the breakdown of proteins in the cell. Proline accumulation has been reported during conditions of drought, high salinity, and heavy metals (Pessarakli 2011). Wastewater can negatively affect plants due to a combination of several causes, mainly osmotic injury and specific ion toxicity. The decline in osmotic potential in response to salinity is achieved by accumulation of solutes within the cell (Szabados and Savoure 2010). Salinity increase proline accumulation in plants for the osmoregulation (Al-Absi 2008). On the other hand, proline accumulations in plant tissues can be considered as nitrogen storage compound. (Udayasoorian and Prabakaran 2010).

Proline content in plants irrigated with TWW showed significant increase compared to plants irrigated with TpW (Figure 4.26).

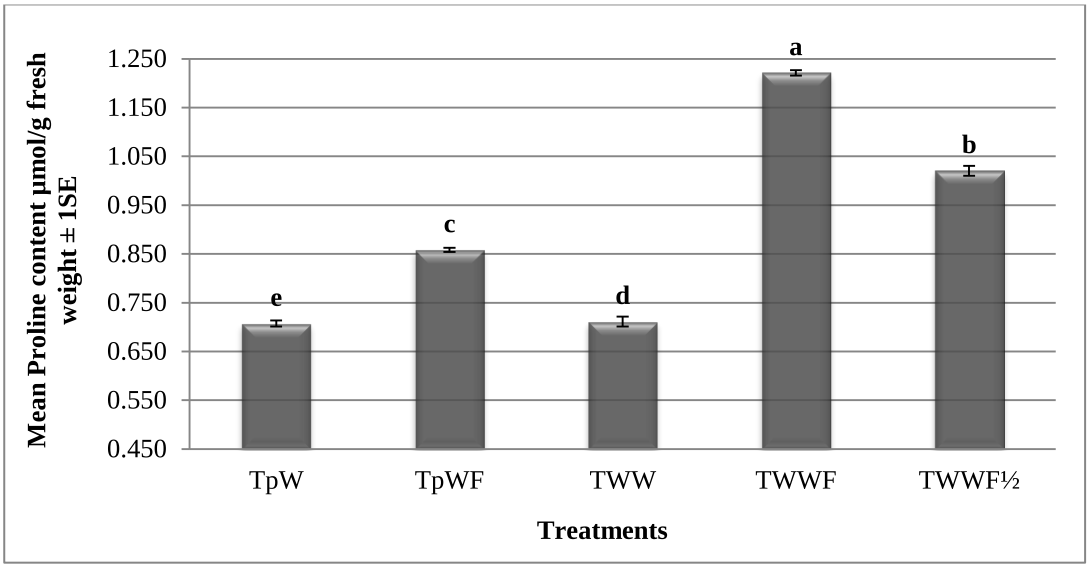


Figure (4.26) Corn leaves proline content

Moreover, the use of fertilizer led to a significant increase in the concentration of proline content. The highest concentration of proline was in fully fertilized plants irrigated with TWW, whereas, half-fertilized plants had significant lower concentration compared with fully fertilized plants.

Research has shown that the accumulation of proline was a normal response of plants under stress conditions (Szabados and Savoure 2010). Plants can adapted to the stress conditions from irrigation with wastewater based on a mechanism to avoid salts as well as to increase in specific organic solutes (Proline) that help in osmoregulation and prevent the accumulation of salt within the cells (Mousa 2008).

Treatments with high proline content gave higher growth and yield compared to other treatments, which means that the impact of salinity, which led to the high proline content, did not have significant impact on plant growth and production. Corn used in the experiment has the ability to acclimate with the salinity resulting from the wastewater and fertilizer.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, the impact of TWW, from Al-Bireh WWTP, in comparison to TpW, in combination with mineral fertilizers, has been studied on corn plants.

The following conclusions can be drawn from this experiment:

- TWW has major benefits since it can be an alternative irrigation source to fresh water resources.
- TWW can increase corn fodder production and reduce fertilizer usage.
- TWW effluent is safe to use for corn irrigation without causing significant heavy metals pollution to soil and fruits.
- The yield of those treatments which used TWW was higher than treatments which used TpW.
- TWW and fertilization stimulated the synthesis of chlorophyll and proline in corn leaves.
- With regard to health problems, the drip irrigation systems generated minimum contact between the effluent and the aerial

parts of the plants; the fruits (grains) were free from *E.coli* pathogenic bacteria.

5.2 Recommendations

- Workshops, presentations and study tours should be held to the public about the benefits of using treated wastewater in irrigation to ease people's fears and increase their awareness of the importance of the topic.
- Proposed action is recommended to reduce pathogenic contaminants in the effluent of Al-Bireh WWTP.
- It is possible to expand fodder irrigated areas to maximize the use of TWW.
- Studies should be done on the economic benefits expected from similar projects on a larger scale.
- More detailed long-term studies are necessary, to monitor the heavy metal concentrations in the soil irrigated with TWW.

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APPENDIX A

Water quality standards for wastewater reuse for restricted and unrestricted irrigation (EQA 2001)

Restricted Irrigation		Unrestricted Irrigation	
Parameter	**Max. Value**	**Parameter**	**Max. Value**
Temperature (^{o}C)	25	Temperature (^{o}C)	25
pH	6-9	pH	6-9
Turbidity (NTU)	50	Turbidity (NTU)	50
Color	--	Color	--
BOD_5 (mg/L)	45	BOD_5 (mg/L)	60
COD (mg/L)	150	COD (mg/L)	200
DO (mg/L)	>0.5	DO (mg/L)	>0.5
Dry residues at 150^{o}C (mg/L)	1800	TDS (mg/L)	1500
SS (mg/L)	40	TSS (mg/L)	50
SO_4 (mg/L)	1	SO_4 (mg/L)	500
Oil and Grease (mg/L)	5	Oil and Grease (mg/L)	5
Petroleum Hydrocarbon (mg/L)	0.5	Artificial Detergents (mg/L)	15
PO_4 (mg/L)	30	PO_4 (mg/L)	30
NO_3 (mg/L)	50	NO_3 (mg/L)	50
Phenol (mg/L)	0.002	Phenol (mg/L)	0.002
Fluorides (mg/L)	1.5	Fluorides (mg/L)	1.5
Boron (mg/L)	0.7	Boron (mg/L)	0.7
Aluminum (mg/L)	5	Aluminum (mg/L)	5
Ammonium-NH_4 (mg/L)	--	Ammonium (NH_4) (mg/L)	--
Mercury (mg/L)	0.001	Mercury (mg/L)	0.001
Lead (mg/L)	1	Lead (mg/L)	1
Cadmium (mg/L)	0.02	Cadmium (mg/L)	0.02
Arsenic (mg/L)	0.02	Arsenic (mg/L)	0.02
Total Chromium (mg/L)	0.5	Total Chromium (mg/L)	0.5
Copper (mg/L)	0.2	Copper (mg/L)	0.2
Nickel (mg/L)	0.2	Nickel (mg/L)	0.2
Iron (mg/L)	5	Iron (mg/L)	5
Manganese (mg/L)	0.2	Manganese (mg/L)	0.2
Zinc (mg/L)	2	Zinc (mg/L)	2
Silver (mg/L)	0.1	Na (mg/L)	200
Barium (mg/L)	2	Barium (mg/L)	2
Cobalt (mg/L)	1	Cobalt (mg/L)	1
Total pesticides (mg/L)	0.2	Total pesticides (mg/L)	0.2
Cyanides (mg/L)	0.05	Cyanides (mg/L)	0.05
Total Coliforms (Colony/100ml)	1000	Total Coliforms (Colony/100ml)	1000

APPENDIX B

Soil collection, transportation and preparation

Image on the left shows the land in Qalqilia, where the soil taken from

The image on the right shows the preparation of the soil in order to fill in bags and transfer to the University of Birzeit

Image on the left shows the arrival of the soil to the University of Birzeit

The image on the right shows soil mixing and filling in the pots

APPENDIX C

Water and Wastewater Analysis

Parameter	Instrument	Method	Reference
Temperature, pH, EC and TDS	Hanah HI-98129	As manufacturer procedure	**(APHA 2005)**
TDS, TSS	Evaporation, Filtration	2540-C, D	**(APHA 2005)**
DO	DO meter – Oxi 197	5220-D	**(APHA 2005)**
Turbidity	Hach 2100P turbidity meter	As manufacturer procedure	**(APHA 2005)**
Total and Fecal Coliforms		9222-B 9221-E	**(APHA 2005)**
Na, K, Ca, Mg, Fe, Mn, Ag, Al, As, Ba, Cd, Co, Br, Sr Cr, Cu, Ni, Pb, Zn	ICP/OES (VISTA-MPX, VARIAN)		
NH4	Nesselarization Method	4500D	**(APHA 2005)**
Cl	Ion Chromatography (IC DIONEX DX120)		
F	Ion Chromatography (IC DIONEX DX120)		
NO3	UV 300/ UV-Visible spectrophotometer/ UNICAM (λ=22 0 nm)	4500- NO_3^-	**(APHA 2005)**
HCO3		2320B	**(APHA 2005)**
PO4	Ion Chromatography (IC DIONEX DX120)		
SO4	Ion Chromatography (IC DIONEX DX120)		
COD	Hach COD reactor	5210-B	**(APHA 2005)**
BOD_5	DO meter – Oxi 197	5220-D	**(APHA 2005)**

Soil Analysis

Parameter	Instrument	Method	Reference
Texture	Hydrometer	Bouyoucos Method	**(Ryan, George and Abdul Rashid 2001)**
pH (0.01 M CaCl2).	Metrohm-827 pH meter	0.01 M CaCl solution	**(Carter and Gregorich 2008)**
EC	Jenway 4010	Fixed ratio extract	**(Carter and Gregorich 2008)**
CEC	Car-50 Varian Spectrophotometer	CEC at pH 7 with Ammonium acetate	**(Donald 1995)**
Total N		Kjeldahl method	**(Carter and Gregorich 2008)**
Exchangeable K	Flame Photometer 4110 (Sherwood)	extraction with 1N ammonium acetate buffer	**(Ryan, George and Abdul Rashid 2001)**
Available P	Flame Photometer 4110 (Sherwood)	Olsen’s Method	**(Bashour and Sayegh 2007)**

Plants analysis			
Parameter	**Instrument**	**Method**	**Reference**
Plant high	Meter	--	--
Number of leaves	Manual	--	--
Number of fruits	Manual	--	--
Fruit Dry weight	Sartorius Balance (GE1302)	--	--
Leaf Chlorophyll	UV-Vis spectrophotometer (varian Cary-50)	Extraction	**(Sadasivam and Manickam 1996)**
Leaf Proline	UV-Vis spectrophotometer (varian Cary-50)	Colorimetric assay	**(Ábrahám, et al. 2010)**
Grains elements	ICP/OES (VISTA-MPX, VARIAN)		
Grains pathogenic *E-coli*		ISO 16649-2:2001	Microbiology of food and animal feeding stuffs

APPENDIX D

Detailed results of analysis for all samples

Tap water results							
Parameters	Analyzed in	Day 1	Day 2	Day 3	Day 4	Avg.	SD
		Sample 1	Sample 2	Sample 3	Sample 4		
T (^oC)	BZU	17	18	19	18	18	1
pH	BZU	8	7.6	8.03	7.79	7.9	0.2
EC (µS/Cm)	BZU	640	637	629	630	634.0	5.4
TDS (mg/L)	BZU	307	324	290	314	308.8	14.3
DO (mgO$_2$/L)	BZU	5.02	5.5	5.11	5.47	5.28	0.25
SAR	BZU	2.07	2.13	2.13	2.13	2.11	0.03
Turbidity (NTU)	BZU	4.74	4.01	4.34	4.15	4.3	0.3
TC (CFU/100mL)	BZU	0	0	0	0	0	0
FC (CFU/100mL)	BZU	0	0	0	0	0	0
Na (mg/L)	BZU	78.7	83.46	83.67	83.77	82.4	2.5
K (mg/L)	BZU	3.99	4.17	4.21	4.23	4.15	0.11
Ca (mg/L)	BZU	62.63	66.88	67.18	67.08	65.9	2.2
Mg (mg/L)	BZU	28.45	30.25	30.47	30.36	29.9	1.0
NH$_4$ (mg/L)	BZU	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fe (μg/L)	HD	13.6	34.4	76.4	28.3	38.18	26.94
Mn (μg/L)	HD	0.833	1.8	0.533	0.543	0.93	0.60
Cl (mg/L)	BZU	242	246	257	259	251.0	8.3
F (mg/L)	BZU	0.61	0.69	0.7	0.74	0.69	0.05
NO$_3$ (mg/L)	BZU	6.8	6.14	6.63	6.37	6.5	0.3
HCO$_3$ (mg/L)	BZU	252	255	204	204	228.8	28.6
PO$_4$ (mg/L)	BZU	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SO$_4$ (mg/L)	HD	40	40	40	40	40.0	0.0
Br (mg/L)	HD	0.55	0.64	0.56	0.62	0.59	0.04
Ag (μg/L)	HD	0.202	BDL	BDL	BDL	BDL	
Al (μg/L)	HD	28.7	16.7	34.5	14.5	23.6	9.6
As (μg/L)	HD	5.72	4.32	6,39	7.25	5.8	1.5
Ba (μg/L)	HD	57.7	56.7	55.6	56.4	56.6	0.9
Cd (μg/L)	HD	0.146	0.242	0,048	0.103	0.16	0.07
Co (μg/L)	HD	BDL	0.1	BDL	BDL	BDL	
Cr (μg/L)	HD	0.283	0.419	0.33	0.297	0.33	0.06
Cu (μg/L)	HD	13.7	10.6	16.9	14.4	13.90	2.59
Ni (μg/L)	HD	0.923	1.51	BDL	3.69	2.04	1.46
Pb (μg/L)	HD	3.07	1.14	2.45	2.54	2.3	0.8
Sr (μg/L)	HD	656	652	652	667	656.8	7.1
Zn (μg/L)	HD	482	578	94.7	642	449.2	245.3

Treated wastewater							
Parameters	Analyzed in	Day 1	Day 2	Day 3	Day 4	Avg.	SD
		Sample 1	Sample 2	Sample 3	Sample 4		
T (^{o}C)	BZU	17	20	19	17	18	2
pH	BZU	8.3	7.7	7.7	7.5	7.8	0.3
EC (µS/Cm)	BZU	1285	1388	1356	1409	1359.5	54.2
TDS (mg/L)	BZU	629	677	663	684	663.3	24.4
DO (mgO$_2$/L)	BZU	6.2	9	6.8	6	7.0	1.4
SAR	BZU	4.96	5.10	5.30	5.08	5.11	0.14
Turbidity (NTU)	BZU	8.3	4.99	4.91	5.82	6.0	1.6
TC (CFU/100mL)	BZU	6.20E+09	9.00E+09	2.20E+09	4.30E+09	5.4E+9	2.9E+9
FC (CFU/100mL)	BZU	3.20E+04	4.50E+04	3.70E+04	1.20E+04	31.5E+3	14.1E+3
Na (mg/L)	BZU	201.54	198.33	207.32	204.15	202.8	3.8
K (mg/L)	BZU	30.41	30.34	29.69	30.28	30.2	0.3
Ca (mg/L)	HD	66.5	69.9	67.9	67.2	67.9	1.5
Mg (mg/L)	BZU	33.87	29.78	32.38	32.11	32.0	1.7
NH$_4$ (mg/L)	BZU	<0.5	<0.5	<0.5	<0.5	<0.5	
Fe (μg/L)	HD	109	75.2	98.3	38.4	80.23	31.25
Mn (μg/L)	HD	49.9	44.4	40.3	21.2	38.95	12.47
Cl (mg/L)	HD	205	199	219	187	202.5	13.3
F (mg/L)	BZU	0.61	0.6	0.61	0.65	0.62	0.02
NO$_3$ (mg/L)	BZU	7.99	3.1	6.32	5.81	5.8	2.0
HCO$_3$ (mg/L)	BZU	275	223	278	247	255.8	25.9
PO$_4$ (mg/L)	BZU	6.6	6.2	5.8	6.5	6.3	0.4
SO$_4$ (mg/L)	HD	67.04	55.9	69.7	71.11	65.9	6.9
Br (mg/L)	HD	BDL	BDL	BDL	BDL	BDL	
Ag (μg/L)	HD	0.328	0.224	0.254	0.138	0.24	0.08
Al (μg/L)	HD	39.7	26.1	31.7	18.1	28.9	9.1
As (μg/L)	HD	11.2	3,74	7.45	8.44	9.0	1.9
Ba (μg/L)	HD	45.9	45.2	41.8	39.3	43.1	3.1
Cd (μg/L)	HD	0.225	0.124	0.142	0.122	0.15	0.05
Co (μg/L)	HD	0.633	0.493	0.652	0.646	0.61	0.08
Cr (μg/L)	HD	2.41	7.12	1.49	0.796	2.95	2.85
Cu (μg/L)	HD	0	1.34	0	2.22	0.89	1.09
Ni (μg/L)	HD	22.2	18.1	13.4	1.35	13.76	9.02
Pb (μg/L)	HD	1.94	2.91	1.97	2.07	2.2	0.5
Sr (μg/L)	HD	579	582	564	577	575.5	7.9
Zn (μg/L)	HD	27.4	32.4	29.8	79.9	42.4	25.1
COD	BZU	56.3	62.9	64.9	68.8	63.2	5.2
BOD	BZU	15.2	17.6	18.1	19.4	17.6	1.8
TKN	BZU	12	17.9	21.5	16.7	17	3.9
TSS	BZU	30.9	28.9	33.5	30.0	30.8	2.0

SAR Calculation

mg/L = meq/L × equivalent weight

$$\boldsymbol{SAR = \frac{Na^{+}\ meq/L}{\sqrt{\frac{(Ca^{++}\ meq/L) + (Mg^{++}\ meq/L)}{2}}}}$$

SAR (Tap water)

Parameter	Unit	Sample 1	Sample 2	Sample 3	Sample 4	Equivalent Weight
Ca	mg/L	62.63	66.88	67.18	67.08	20.04
Mg	mg/L	28.45	30.25	30.47	30.36	12.1525
Na	mg/L	78.7	83.46	83.67	83.77	22.9898
Ca	Meq/L	3.125249501	3.337325349	3.352295409	3.34730539	
Mg	Meq/L	2.341082082	2.489199753	2.507303024	2.49825139	
Na	Meq/L	3.423257271	3.630305614	3.6394401	3.64378985	
SAR		2.07	2.13	2.13	2.13	2.11 ± 0.03

SAR (Treated wastewater)

Parameter	Unit	Sample 1	Sample 2	Sample 3	Sample 4	Equivalent Weight
Ca	mg/L	69.28	65.66	62.63	69.7	20.04
Mg	mg/L	33.87	29.78	32.38	32.11	12.1525
Na	mg/L	201.54	198.33	207.32	204.15	22.9898
Ca	Meq/L	8.766496446	8.626869307	9.017912292	8.880025055	
Mg	Meq/L	3.457085828	3.276447106	3.125249501	3.478043912	
Na	Meq/L	2.787080848	2.450524583	2.664472331	2.64225468	
SAR		4.96	5.10	5.30	5.08	5.11±0.14

The results of Soil pH before and after the project

Soil pH at the beginning and at the end of the project						
	After					**Before**
Replicates	**Treatments**					**5-composite samples**
	TpW	**TpWF**	**TWW**	**TWWF**	**TWWF½**	
R1	6.69	6.73	6.9	6.92	7.1	7.54
R2	6.58	6.8	7.1	6.92	7.07	7.68
R3	6.63	6.74	7.03	6.96	7.21	7.73
R4	6.71	6.79	6.84	6.88	7.05	7.49
R5	6.46	6.83	6.97	7.19	7.19	7.72
R6	6.55	6.82	7.11	6.91	7.09	
Avg	6.60	6.79	6.99	6.96	7.12	7.63
S.D	0.09	0.04	0.11	0.11	0.07	0.11
S.E	0.04	0.02	0.04	0.05	0.03	0.05

The results of Soil EC before and after the project

Soil EC (µS/cm) at the beginning and at the end of the project						
After						**Before**
Replicates	**Treatments**					**5-composite samples**
	TpW	**TpWF**	**TWW**	**TWWF**	**TWWF½**	
R1	771	1085	915	1210	1051	326
R2	780	1063	923	1245	1073	322
R3	769	1103	913	1222	1060	316
R4	774	1071	925	1231	1077	329
R5	788	1065	919	1217	1064	338
R6	774	1060	929	1251	1085	
Avg	776.00	1074.50	920.67	1229.33	1068.33	326.20
S.D	6.96	16.54	6.12	16.11	12.36	8.20
S.E	2.84	6.75	2.50	6.58	5.04	3.67

Soil texture at the beginning and at the end of the project

Soil Texture Before & After								
	Before Plantation				**After Plantation**			
Treatment	**% Sand**	**% Silt**	**% Clay**	**Texture**	**% Sand**	**% Silt**	**% Clay**	**Texture**
T1R1	93.6	4.9	1.2	Sandy	93.8	5.0	1.2	Sandy
T1R2	93.9	4.9	1.2	Sandy	94.0	5.0	1.2	Sandy
T1R3	94.6	5.0	1.2	Sandy	94.3	5.0	1.2	Sandy
T1R4	----	----	----	----	94.0	5.0	1.2	Sandy
T1R5	----	----	----	----	94.3	5.0	1.2	Sandy
T1R6	----	----	----	----	94.1	5.0	1.2	Sandy
T2R1	93.1	4.9	1.2	Sandy	93.6	5.0	1.2	Sandy
T2R2	94.9	5.0	1.2	Sandy	93.0	5.0	1.2	Sandy
T2R3	94.3	5.0	1.2	Sandy	94.5	5.0	1.2	Sandy
T2R4	----	----	----	----	93.3	5.0	1.2	Sandy
T2R5	----	----	----	----	94.5	5.0	1.2	Sandy
T2R6	----	----	----	----	93.9	5.0	1.2	Sandy
T3R1	94.7	5.0	1.2	Sandy	93.7	5.0	1.2	Sandy
T3R2	94.6	5.0	1.2	Sandy	94.1	5.0	1.2	Sandy
T3R3	94.9	5.0	1.2	Sandy	93.1	5.0	1.2	Sandy
T3R4	----	----	----	----	93.5	5.0	1.2	Sandy
T3R5	----	----	----	----	94.0	5.0	1.3	Sandy
T3R6	----	----	----	----	94.6	5.0	1.2	Sandy
T4R1	94.3	5.0	1.2	Sandy	93.3	5.0	1.2	Sandy
T4R2	94.6	5.0	1.2	Sandy	94.6	5.0	1.2	Sandy
T4R3	94.6	5.0	1.2	Sandy	94.8	5.0	1.2	Sandy
T4R4	----	----	----	----	93.6	5.0	1.2	Sandy
T4R5	----	----	----	----	93.8	5.0	1.2	Sandy
T4R6	----	----	----	----	94.3	5.0	1.2	Sandy
T5R1	94.5	5.0	1.2	Sandy	94.5	5.0	1.2	Sandy
T5R2	94.2	5.0	1.3	Sandy	94.5	5.0	1.2	Sandy
T5R3	95.1	4.9	1.2	Sandy	94.8	5.0	1.2	Sandy
T5R4	----	----	----	----	94.0	5.0	1.2	Sandy
T5R5	----	----	----	----	93.4	5.0	1.2	Sandy
T5R6	----	----	----	----	94.3	5.0	1.2	Sandy

Soil CEC (cmol/kg) at the beginning and at the end of the project

Treatments		R1	R2	R3	R4	R5	R6	Avg.	S.D	S.E
T1	**Before**	12.58	13.42	12.57	12.51	13.16	12.02	***12.71***	***0.50***	***0.20***
	After	13.48	13.16	13.12	12.77	12.22	13.06	***12.97***	***0.43***	***0.18***
T2	**Before**	12.56	12.54	12.54	13.10	12.69	12.56	***12.67***	***0.22***	***0.09***
	After	13.42	13.00	13.41	13.49	13.72	12.96	***13.33***	***0.29***	***0.12***
T3	**Before**	13.05	12.55	12.01	12.63	12.50	13.35	***12.68***	***0.47***	***0.19***
	After	13.50	13.41	13.72	13.41	12.96	13.37	***13.40***	***0.25***	***0.10***
T4	**Before**	12.64	12.62	13.18	13.19	12.09	12.55	***12.71***	***0.42***	***0.17***
	After	14.43	14.11	13.67	14.20	13.91	13.97	***14.05***	***0.26***	***0.11***
T5	**Before**	12.06	12.71	12.68	13.16	12.65	12.14	***12.57***	***0.41***	***0.17***
	After	13.83	13.45	13.26	13.24	13.19	13.58	***13.43***	***0.25***	***0.10***

Soil N, P & K at the beginning and at the end of the project

Soil TKN at the beginning and at the end of the project

Treatments		R1	R2	R3	R4	Avg.	S.D	S.E
T1	**Before**	0.307	0.291	0.307	0.324	***0.307***	***0.013***	***0.005***
	After	0.324	0.307	0.307	0.307	0.311	0.008	0.003
T2	**Before**	0.307	0.291	0.307	0.307	0.303	0.008	0.003
	After	0.307	0.291	0.307	0.307	0.303	0.008	0.003
T3	**Before**	0.307	0.307	0.307	0.307	0.307	0.000	0.000
	After	0.324	0.291	0.307	0.307	0.307	0.013	0.005
T4	**Before**	0.307	0.307	0.324	0.307	0.311	0.008	0.003
	After	0.307	0.291	0.291	0.324	0.303	0.015	0.006
T5	**Before**	0.324	0.291	0.291	0.291	0.299	0.016	0.007
	After	0.324	0.291	0.307	0.291	0.303	0.015	0.006

Soil P at the beginning and at the end of the project

Replicates		R1	R2	R3	R4	R5	R6	Avg.	S.D	S.E
T1	**Before**	8.80	8.94	9.31	9.37	9.35	9.17	***9.16***	***0.23***	***0.10***
	After	0.67	0.53	0.63	0.55	0.49	0.59	***0.57***	***0.07***	***0.03***
T2	**Before**	8.88	8.84	9.35	9.13	9.47	9.31	***9.16***	***0.26***	***0.11***
	After	30.13	30.15	29.95	30.47	30.07	30.51	***30.21***	***0.23***	***0.09***
T3	**Before**	9.21	9.45	9.27	9.37	9.49	9.27	***9.34***	***0.11***	***0.05***
	After	39.56	39.56	39.32	39.72	39.84	39.62	***39.60***	***0.18***	***0.07***
T4	**Before**	9.43	9.39	9.43	9.53	9.09	8.96	***9.30***	***0.23***	***0.09***
	After	33.71	33.14	33.25	33.10	33.39	33.31	***33.32***	***0.22***	***0.09***
T5	**Before**	9.59	9.41	9.39	9.17	9.41	9.55	***9.42***	***0.15***	***0.06***
	After	68.27	67.79	68.07	67.85	68.80	68.39	***68.19***	***0.38***	***0.15***

Soil TKN at the beginning and at the end of the project

Replicates		R1	R2	R3	R4	R5	R6	Avg.	S.D	S.E
T1	**Before**	54.60	54.20	75.50	60.94	66.74	52.58	***60.8***	***8.95***	***3.66***
	After	113.39	100.31	117.84	95.05	118.51	113.52	***109.8***	***9.74***	***3.98***
T2	**Before**	52.58	58.38	50.29	82.92	51.77	82.78	***63.1***	***15.53***	***6.34***
	After	167.72	170.28	156.94	156.40	165.84	163.41	***163.4***	***5.71***	***2.33***
T3	**Before**	59.19	52.72	79.82	65.79	76.99	55.55	***65.0***	***11.29***	***4.61***
	After	124.17	121.48	135.90	131.05	109.61	118.38	***123.4***	***9.32***	***3.81***
T4	**Before**	50.02	65.19	62.02	68.69	70.85	60.40	***62.9***	***7.41***	***3.03***
	After	166.64	181.74	185.52	179.05	181.88	172.04	***177.8***	***7.09***	***2.89***
T5	**Before**	67.68	64.38	54.87	94.11	76.72	77.79	***72.6***	***13.51***	***5.52***
	After	181.61	178.24	171.50	172.17	197.65	181.07	***180.4***	***9.50***	***3.88***

APPENDIX E

Plants growth parameters and results

Plant hieght (cm)

Replicates	Treatments				
	TpW	TpWF	TWW	TWWF	TWWF½
R1	141	183	162	196	203
R2	210	183	160	185	192
R3	130	187	182	196	185
R4	136	206	183	185	181
R5	144	193	176	183	194
R6	183	181	161	197	178
Avg.	157.3	188.8	170.7	190.3	188.8
S.D	31.87	9.43	10.88	6.62	9.28
S.E	13.01	3.85	4.44	2.70	3.79

Number of leaves per plant

Replicates	Treatments				
	TpW	TpWF	TWW	TWWF	TWWF½
R1	9	10	10	10	11
R2	10	10	10	10	10
R3	9	9	9	11	10
R4	8	11	10	10	11
R5	9	10	10	10	10
R6	8	10	9	10	10
Avg.	8.8	10.0	9.7	10.2	10.3
S.D	0.75	0.63	0.52	0.41	0.52
S.E	0.31	0.26	0.21	0.17	0.21

Number of fruits per plant

Replicates	Treatments				
	TpW	TpWF	TWW	TWWF	TWWF½
R1	2	2	1	3	2
R2	2	2	1	3	3
R3	1	2	2	4	4
R4	1	3	2	4	4
R5	2	3	2	3	4
R6	2	3	1	4	4
Avg.	1.7	2.5	1.5	3.5	3.5
S.D	0.52	0.55	0.55	0.55	0.84
S.E	0.21	0.22	0.22	0.22	0.34

Fruits dry weight (g) per plant

Replicates	Treatments				
	TpW	TpWF	TWW	TWWF	TWWF½
R1	0	0	0	0	0
R2	124.2	124.2	124.2	124.2	124.2
R3	20.8	20.8	20.8	20.8	20.8
R4	10.6	10.6	10.6	10.6	10.6
R5	0	0	0	0	0
R6	101.4	101.4	101.4	101.4	101.4
Avg.	42.8	103.4	74.5	116.8	110.7
S.D	55.22	14.50	20.61	24.62	11.95
S.E	22.54	5.92	8.41	10.05	4.88

Leaves Chlorophyll content

Instrument : Cary 50					
Sample ID	**Abs(645)**	**Abs(663)**	**Chlorophyll a (mg/g tissue)**	**Chlorophyll b (mg/g tissue)**	**Total Chlorophyll (mg/g tissue)**
TpW Sample 1	0.2602	0.7859	0.4640	0.1140284	0.5779479
TpW Sample 2	0.2549	0.7851	0.4643	0.1081471	0.5722741
TpW Sample 3	0.25	0.7832	0.4637	0.1029812	0.5665632
TpWF Sample 1	0.6997	2.0331	1.1969	0.3254111	1.5219701
TpWF Sample 2	0.6979	2.0225	1.1904	0.3258305	1.5159015
TpWF Sample 3	0.6938	2.0271	1.1939	0.3200596	1.5136051
TWW Sample 1	0.608	1.8497	1.0928	0.2633302	1.3558097
TWW Sample 2	0.6082	1.8583	1.0982	0.2615468	1.3594603
TWW Sample 3	0.6092	1.8554	1.0962	0.2633704	1.3593074
TWWF Sample 1	1.255	3.3964	1.9879	0.6422174	2.6295064
TWWF Sample 2	1.2537	3.1335	1.8211	0.7022475	2.5227705
TWWF½ Sample 3	1.2577	3.0799	1.7866	0.7193699	2.5053169
TWWF½ Sample 1	0.9202	2.5556	1.4990	0.4556186	1.9541976
TWWF½ Sample 2	0.9218	2.5332	1.4846	0.4626922	1.9468312
TWWF½ Sample 3	0.9253	2.5313	1.4829	0.4671443	1.9496043