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Sludge and Wastewater Reuse for Crop Production and the Impact on Plant Morphology

(Case Study: Sheikh Ejleen Treatment Plant)

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DEDICATION

This research is dedicated to my Father Spirit

With my all love…

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ABSTRACT

Sludge and Wastewater Reuse for Crop Production and the Impact on plant Morphology

The aim of this work is to study and assess the possibility of reusing both the reclaimed wastewater and the sludge (as fertilizer) produced from Gaza Wastewater Treatment Plant (GWWTP). Moreover, the effect of the reuse of the reclaimed wastewater and the sludge on the soil physico-chemical properties especially on its content of heavy elements and the impact on plant morphology (corn crop). Corn seeds were planting in different pots at different sludge/soil mixtures, the plants were irrigated using treated wastewater from GWWTP, and another similar mixture composition were irrigated using brackish water.

The experiment was conducted at El Zaitoon area in a plot owned by Ishtawi family, and it involving different percentage of sludge/soil mixture as (0%, 10%, 20%, 30%, and 40%).

Results showed that the irrigation with reclaimed wastewater and applications of sewage sludge with soil (30% ratio) contribute to the improvement of the plant yield, and this treatment enhance the soil condition of fertility or nutrients., also the mixture of sludge and soil after cultivation had a concentration of heavy metals which is meet the permissible level for sludge or compost for agriculture use.

The most important parameter is the quality of corn, which include heavy metals content of fruits, and the degree of contamination of the fruits with pathogens. The main finding is that no contamination was observed, and the values of heavy metals meet the recommended limits as total threshold limit concentration for hazardous toxic waste as illustrated by California Department of toxic Substance Control.

The main conclusion of the study is that recommended to use the sludge and reclaimed wastewater which could be advantageous opportunity for agricultural uses.

ملخص الدراسة

إعادة استخدام المياه العادمة المعالجة والحمأة في إنتاج المحاصيل وأثرها على مورفولوجيا النبات

تهدف هذه الدراسة إلى تقييم ودراسة إمكانية إعادة استخدام المياه العادمة المعالجة والحمأة (كسماد)، والناتجة من محطة معالجة الشيخ عجلين. كما وتهدف أيضاً لدراسة تأثير استخدام المياه المعالجة والحمأة على الخواص الكيميائية والفيزيائية للتربة بنسب مختلفة من التربة والحمأة (وخصوصا على محتوى التربة من العناصر الثقيلة)، وتهدف لدراسة تأثيرها على مورفولوجيا النبات (الذرة).

وقد تم تطبيق التجربة عملياً على أرض الواقع في منطقة الزيتون في أرض تابعة لعائلة إشتيوى، وذلك بزراعة النبات في صناديق من الفلين متضمنة نسب مختلفة من التربة والحمأة، وتم استخدام المياه المعالجة الناتجة من محطة الشيخ عجلين، وفى مسارٍ موازٍ تم استخدام المياه الجوفية للمقارنة. واشتملت على اثنى عشر معاملاً من الري ومخاليط من الحمأة والتربة، على النحو التالي (0% – 10% – 20% – 30% –40%).

وأظهرت النتائج أن الري باستخدام المياه العادمة المعالجة مع الحمأة بنسبة (30٪) ساهم في زيادة إنتاج النبات، كذلك فإن هذه النسبة حَسَّنت خصوبة التربة وتزويدها بالمغذيات، وأيضاً حَسَّنَ نمو النبات بشكلٍ ملحوظ. وتم دراسة محتوى المعادن الثقيلة ودرجة التلوث البيولوجي في ثمار الذرة، حيث لوحظ أنه لا وجود للتلوث البيولوجي في ثمار الذرة، وكانت قيمة المعادن الثقيلة ضمن الحدود المُوصى بها من قبل وزارة كاليفورنيا لمراقبة المواد السامة، وأظهرت النتائج أيضاً أن التربة المُعاملة مع الحمأة بنسبة (30٪) قبل وبعد الزراعة، تحتوى على تراكيز من المعادن الثقيلة متوافقة مع المعايير المسموح به للحمأة أو السماد المُعد للاستخدام الزراعي.

وبناءً على النتائج السابقة، فإنه يُوصى باستخدام الحمأة والمياه العادمة المعالجة لأغراض الزراعة لما له من أثر في تحسين ظروف التربة وزيادة الإنتاج.

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LIST OF ABBREVIATIONS

µS/cm	micro Siemens per cm
AOX	Absorbable Organic Halogens
APHA	American Public Health Association
BDL	Below Detection Limit
BLWWTP	Beit Lahia Wastewater Treatment Plant
BOD	Bio-chemical Oxygen Demand
BW	Brackish Water
CEC	Cation Exchange Capacity
CFU	Colony-Forming Unit
Cm	Centimeters
CMWU	Costal Municipalities Water Utility
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical conductivity
EDTA	Ethylene Diamine Tetra Acetic Acid
EQA	Environment Quality Authority
FC	Fecal Coliform
FAO	Food & Agriculture Organization
FW	Fresh Water
g	Gram
GWWTP	Gaza Wastewater Treatment Plant
Ha	Hectare (10,000 square meters)
HM	Heavy Metals
ICP- OES	Inductively Coupled Plasma-Optical Emission Spectroscopy
KfW	German Development Bank
m^3/day	Cubic meters per day
m^3/y	Cubic meters per year
MCM/y	Million Cubic Meters per year
meq/g	Mill equivalents per gram
mm/y	millimeters per year
MoA	Ministry of Agriculture
MOH	Ministry of Health
OM	Organic Matter
PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
ppm	parts per million
PS-742-2003	Palestinian Standard for the Treated Wastewater
PW	Potable Water
PWA	Palestinian Water Authority

RWW	Reclaimed Wastewater
SAR	Sodium Adsorption Ratio
SS	Suspended Solids
TC	Total Coliforms
TDS	Total Dissolved Solids
Tds	Ton dry solids
TKN	Total Kjeldahl Nitrogen
TpW	Tap Water
TSS	Total Suspended Solid
TWW	Treated Wastewater
TWWF	Treated Wastewater with complete Fertilization
TWWF½	Treated Wastewater with half Fertilization
UNDP	United Nations Development Program
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WW	Wastewater
WWR	Wastewater Reuse
WWTPs	Wastewater Treatment Plants

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INTRODUCTION

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Chapter 1

CHAPTER 1: INTRODUCTION

1.1 Introduction:

The arid and semi-arid nature of the region renders it a water scarce region. Population growth and agricultural and industrial development have put more pressure on the existing scarce resources. They are currently being exploited to their maximum capacity to meet the desired development. As a result, a lot of environmental problems have started to arise at many places with different levels. Such problems will be more acute in the near future if the current resource utilization patterns continue. Therefore, there is an essential need to start looking at the different options and mechanisms that will help overcome these escalating environmental problems.

The Gaza strip is located in a semi-arid region, with a tight area of 365 km^2. The coastal aquifer is the main water resource in the Gaza strip. The depth of water level of the aquifer varies between few meters in the low land area along the shoreline and about 70 m along the eastern border (PWA, 2012).

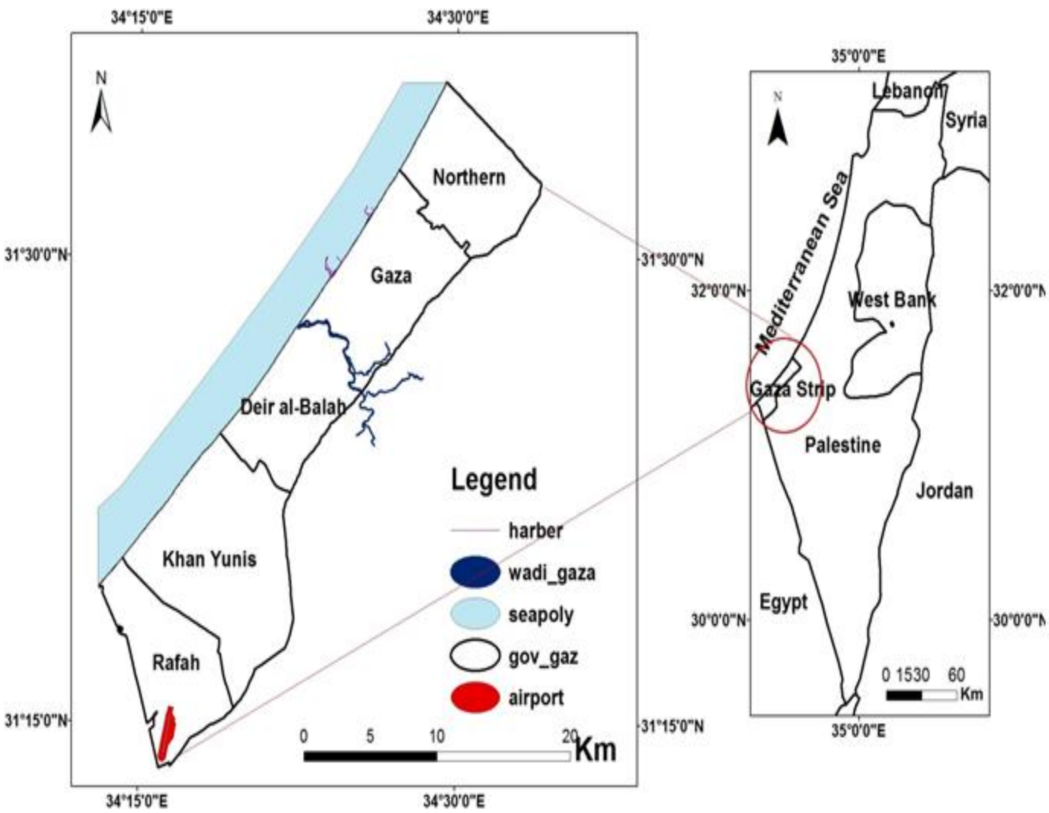

Figure 1.1 :Location map of the Gaza Strip (prepared by Researcher)

The rainfall is falling in the winter season from September to April, the rate of rainfall varies in the Gaza Strip and ranges between 200 mm/year in the south, to about 400 mm/year in the north, while the long term average rainfall rate in all over the Gaza Strip is about 317 mm/year (PWA, 2012).

1.2 Problem Statement:

The Gaza Strip is in critical situation that requires immediate efforts to improve the water situation in terms of quality and quantity. Demand greatly exceeds water supply. In addition water quality is very poor and the aquifer is being over pumped. Very limited water supplied for domestic use is potable. More than 70% of the aquifer are brackish or saline water and less than 30% are fresh water. About 65% of the total pumped water are used for agricultural purposes. If uncontrolled pumping is allowed to continue, the aquifer which is the primary source for the Gaza Strip will become unusable as a source of fresh municipal water and most agricultural extraction will be too saline for crop irrigation. (Al-Yaqubi, 2006)

Sewage sludge / bio-solids represents an increasing challenge all over the world. Gaza's wastewater treatment facilities are still vastly inadequate, with a large amount of sewage being discharged into the environment without any treatments and without any control as sludge treatment is so expensive (Nassar e*t al*., 2003) , In other words, none of the bio-solids is being reused in proper manner.

In Gaza, large amounts of sludge are being produced from Gaza wastewater treatment plants (GWWTP). It is accumulated in the closest sandy dunes surrounding the treatment plant causing serious hazards to the environment and its leachate infiltrates to the ground water causing serious contamination to the groundwater aquifer (possibility of contamination of heavy metals). In addition, the uncontrolled status has faced a deterioration in both quality and quantity for many reasons, e.g. low rainfall, which led to a decrease in the recharge quantity of the aquifer, also, increasing the population will deplete the problem (Nassar e*t al*., 2003).

1.3 Justification:

As a result of all current and expected problems, there is an urgent need to adopt solutions to achieve conservation of water quantity, improve water quality, and achieve sustainability. Selected solution may be one or more of the following:

i) Water use conservation.
ii) Desalination of sea water.
iii) Storm water collection.
iv) Treated wastewater (TWW) for agricultural uses.

Reuse of wastewater could be one of the main options to develop the water resource in the region.

And there is a large demand for organic fertilizers in the Gaza Strip that is unsatisfied due to the costs and restrictions of supplies that have to be imported from Israel, it is estimated as 137590 liter of liquid fertilizer, and 2205 tons of solid fertilizer for the year 2013 (Ministry of Agriculture Report for Marketing, 2013).

There is little experience of sludge use in Gaza, and as with any new product, it will take time to become established but a high take-up may be anticipated if the produce is suitable.

1.4 Objective:

1.4.1 The main objective:

The general objective of this project is to investigate the feasibility of using Sludge and treated effluent produced from Gaza Wastewater Treatment Plant (GWWTP) for improving soil fertility and crop production. Moreover, the effect of the reuse of the reclaimed wastewater and the sludge on the soil physico-chemical properties (soil and different mixtures with different percentages of sludge/ soil mixtures) and the impact on plant morphology (corn crop as animal feed).

1.4.2 The Sub objectives:

Based on the above main objective, the following sub-objectives aimed to be achieved:

1.4.2.1 *Study the physico-chemical characteristics of all components used in the reuse research including:*

a. Treated wastewater (effluent) of GWWTP-Sheikh Ejleen proposed to be used for irrigation.
b. The sludge produced in GWWTP proposed to be used as fertilizer (the accumulated sludge).

c. The soil for the crop planting.
d. The different mixtures of sludge/soil of different percentages.
e. The fresh water proposed for irrigation as control samples.

1.4.2.2 *Study the impact of the reuse on the morphology of the crop (corn), this is include:*

1. Plant growth rate.
2. Fruit yields.
3. Crop height.
4. Number of leaves.
5. Protein content.
6. Appearance.
7. Chlorophyll content.

1.4.2.3 *Study the effect of irrigation and sludge using on the physical and chemical properties of soil.*

1.5 Research Questions:

The goal of this research is to study and if possible, to answer the following question conveniently:

1) Do the current practices of reusing the treated wastewater and the sludge (as fertilizer) produced from the GWWTP have a noticeable impact on soil physico-chemical properties (soil and different mixtures with different percentages of sludge/soil mixtures)?

2) Do the current practices of reusing the treated wastewater and the sludge have a noticeable impact on plant morphology (corn crop as animal feed)?

3) Do the current practices of reusing the treated wastewater and the sludge have opportunity for agricultural uses?

CHAPTER 2

Literature Review

- **Water in the Gaza strip: supply and demand**
- **Wastewater in the Gaza strip: quantity and quality**
- **Treated wastewater reuse for irrigation**
- **Benefits and Difficulties of irrigation with treated wastewater.**
- **Guidelines for Wastewater Reuse in Agriculture**
- **Wastewater reuse**
  - **In the West Bank**
  - **In The Gaza Strip**
- **Sludge reuse**
  - **In the world**
  - **In the Gaza Strip**

CHAPTER 2: LITERATURE REVIEW

2.1 Water in the Gaza strip: supply and demand

Groundwater is the most important water sources in the Gaza Strip. The Gaza strip suffers from the arid and semi-arid climate conditions and rainfall variability, and suffers from a high population density and a lack of natural resources. The population in the Gaza Strip is nearly 1,701,437, and population density was estimated 4661 person/km^2 in the same year, which are not served by water services (PCBS, 2013).

Groundwater aquifer is considered the main water supply source for all kind of human usage in the Gaza Strip (domestic, agricultural and industrial). The water situation in the Gaza is very bad in terms of quantity and quality, where the Coastal Aquifer in the Gaza Strip receives an annual average recharge of 55 -60 MCM/y mainly from rainfall, while the annual extraction rates from the aquifer is about 200 MCM (PWA, 2014).

Total water supplied to the Gaza people for domestic and drinking use is 103.34 MCM/y, categorized as follows; 94.1 MCM from municipal groundwater wells, 2.44 MCM from UN groundwater wells, 2.8 MCM from private groundwater desalination vendors resulting from 4.80 MCM abstracted from the aquifer and 4.00 MCM from Mekorot. Assuming the network efficiency of 54% according to CMWU, the total water consumption is about 56 MCM/y resulting in water per capita consumption of 90.2 l/c/d. (PWA, 2014).

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 & 2010). In the Gaza strip about 81.0 Million m^3 is for agriculture usage (PCBS, 2013).

The total crop area has been increased from 189 thousand Dunoms in 2012 to 201 thousand Dunoms in 2013/2014 and the estimated water quantities for agriculture use including the livestock are about 95.3 MCM/y, 92.7 for agriculture and 2.64 for livestock according to MOA. It is clear that there is an annual increase in the agricultural water consumption of about 9.5 % compared to 2012 (PWA, 2014).

If the demand for irrigation is calculated on the basis of the food requirements of the growing population, it appears that it will increase from the present usage to 185 MCM/y by 2020 (PHG, 2006). However, this figure is not a realistic projection for Gaza, because neither the water nor the land to support an increase in agricultural activity exists. Therefore, the estimated future demands for agriculture are based on the actual water amounts of today. Generally, the overall water demand in the Gaza Strip is estimated to increase from the present value to about 260 MCM/y in 2020 (PHG, 2006).

The present net aquifer balance is negative, that is, there is a water deficit. Under defined average climatic conditions and total abstraction and return flows, the net deficit was about 70-80 MCM/y and will reach to about 180 MCM/y in the year 2035 if there is no management actions taken (PWA, 2011).

This unsustainable high rates of extraction has led to lowering the groundwater level, the gradual intrusion of seawater and up conning of the underneath saline groundwater. And this creates major water quality problems, which mainly causes high salinity in the aquifer. The Gaza Aquifer needs to be regenerated before it can be sustainably used again (PWA, 2014).

2.2 Wastewater in the Gaza strip: quantity and quality

Wastewater is the next problem in the Gaza Strip after the water scarcity and it is one of the biggest polluting sources of the Palestinian environment including water resources. Sewerage system in the Gaza Strip is extremely critical, as people suffer from great weakness in their water and sanitary system infrastructures. Only 83.1 percentage of the population is connected to sewerage networks in the Gaza Strip, while cesspits and septic tanks receive the rest (PCBS, 2013).

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 (MEDAWARE, 2003).

In the Gaza Strip, there are four main treatment plants and one of them is temporary plant for collecting and treating wastewater to treat it to the level allowed to be dumped to the sea and to not pollute the aquifer in case of infiltration Except for the north WWTP which infiltrates to the eastern lagoons. These treatment plants are placed along the Gaza Strip (North, Gaza, Khanyounis and Rafah) as shown in figure 2.1 (CMWU, 2011).

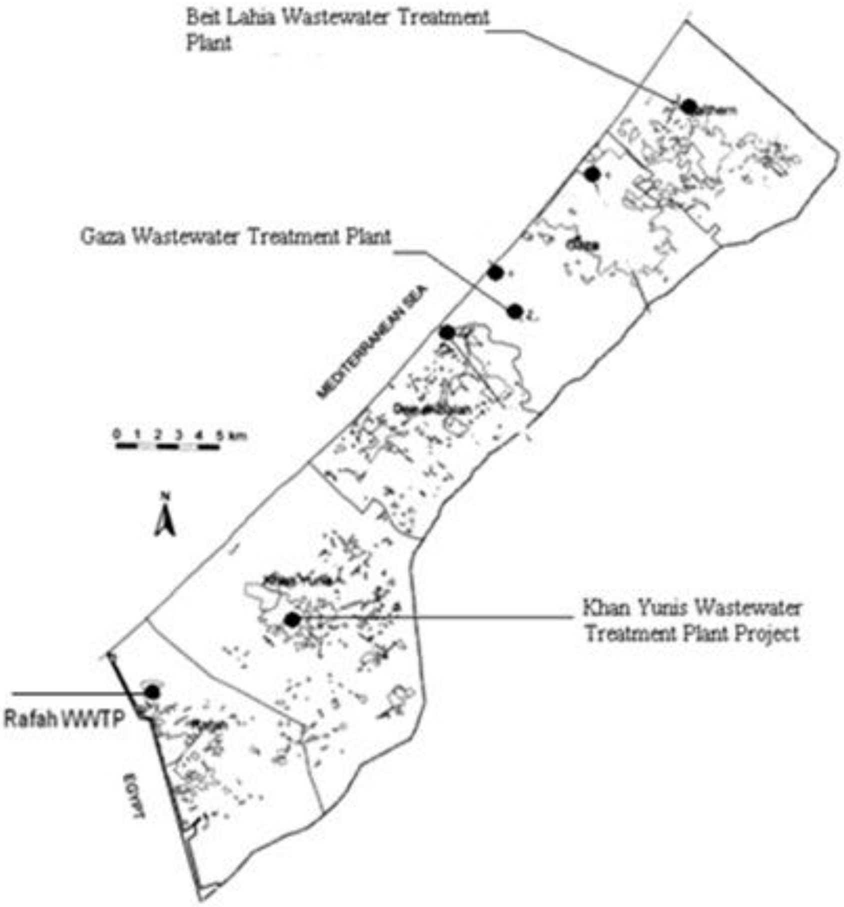

Figure 2.1: Location of WWTP in the Gaza strip

The locations of these treatment plants were chosen during the times of the Israeli occupation of the Gaza Strip; however, the regional contour of Ministry of Planning suggests establishing three central treatment plants near the eastern armistice line. The current treatment plants still do not meet the standards of treating wastewater in the Gaza and this is due to the frequent closure of Gaza crossings that hinder the required periodical maintenance. Moreover, the population growth without a proper expansion of the treatment plants has caused a problem since the wastewater production rate is increasing (CMWU, 2011).

Generally, in the Gaza Strip the WWTPs are inadequate to serve the volume of wastewater being discharged (EQA, 2002). And Table 2.1 describes Efficiency history of GWWTP in the Gaza strip.

Table 2.1: Efficiency history of GWWTP in the Gaza strip

Period	*Flow*	*BOD_5 Removal*		*COD Removal*		*TSS Removal*	
	(m3/d)	**mg/l residual**	*%*	**mg/l residual**	*%*	**mg/l residual**	*%*
1998-2001	42,000	20	96	96	83	20	96
2001-2005	55,000	30	94	132	89	40	92
2005-2007	60,000	50	90	200	83	60	88
2007-2011	65,000	100	80	320	72	165	67

SOURCE: (CMWU, 2011)

Influent wastewater contains considerable amounts of heavy metals, and the partially functional treatment plants of Gaza are able to remove 40–70% of most metals during the treatment process. Heavy metals in 31 industrial wastewater effluents are within the ranges of international standards. All industries of Gaza are light; although they have no treatment facilities, their effluents are being discharged to municipal sewerage system and the existing treatment plants are capable of absorbing the industrial effluents with no significant impact on treatment bioprocesses. Although there are no treatment facilities for sludge within the treatment plants, the results indicated that sludge in general is clean of heavy metals (Shomar, 2004).

2.2.1 Sheikh Ejleen Treatment Plant

The plant was established in 1979 with an infiltration basin next to it and by the year 1986 the United Nations Development Program (UNDP) established another two infiltration basin to develop the plant. The plant also was developed in 1996 by the Municipality of Gaza and UNRWA in order to recharge 12,000 cubic meters per day. In 1998, the plant was rehabilitated and its capacity was enlarged to recharge 35,000 cubic meters per day in order to accommodate population growth till the year 2005, this was done by USAID in collaboration with PWA. A part of the treated WW was pumped to the infiltration basins and another part was pumped to the sea. In 2009, the water pumped to the plant increased to 60,000 cubic meters per day and this exceeds the plant capacity.

After the year 2005, many people seized the plant infiltration basins and turned them into agricultural lands, thus the semi-treated WW was pumped to the sea (without getting treated) as the treatment plant was overloaded (CMWU, 2011).

CMWU, in collaboration with KFW, has drawn the required plans to develop the plant and its pumping stations, and expected to absorb 90,000 cubic meters of wastewater in order to be treated according to the international standards (CMWU, 2011).

The project is big enough to have a lot of goals about the plant and the wastewater system, what we concern about is its specific aims about the plant which is funding the following:

1. Three bar screens: Two of them are mechanical, and the last one is manual.
2. Two grit removal channels.
3. Anaerobic pond (No. 4).
4. Four trickling filters.
5. One settling channel.
6. Two sludge holding ponds.
7. Seven drying beds.
8. Other equipment's such as trucks, loaders, needed laboratory improvement equipment, power generator and change pipes in the plant.
9. Pump station (No. 11).

Until end of 2013 only the bar screens, the grit removal channels, anaerobic pond (No.4), the sludge holding ponds and the drying beds of project are constructed, as shown in figure 2.2.

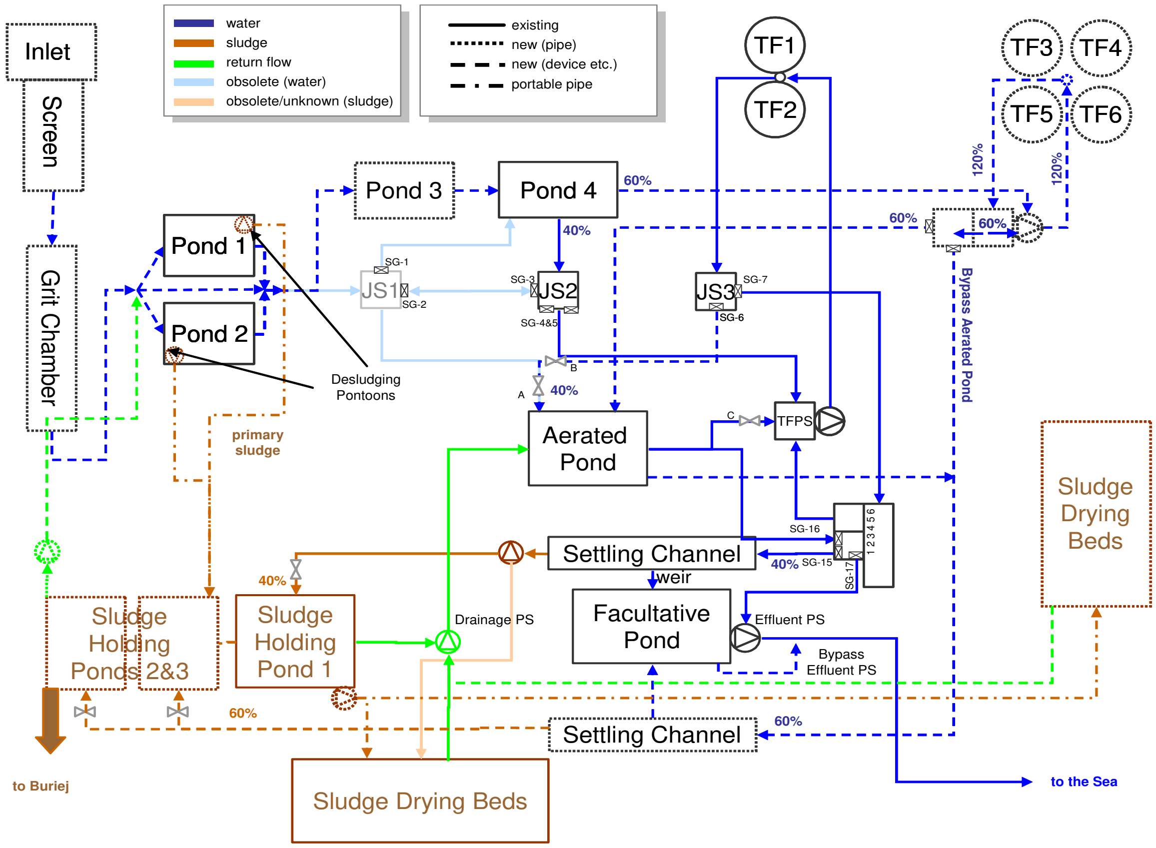

Figure 2.2: Schematic diagram of Upgrading GWWTP
(SOURCE: CMWU)

2.2.2 Treated wastewater reuse for irrigation

Re-using reclaimed wastewater or non-potable water is typically require conventional water and wastewater treatment technologies that are already widely practiced and readily available in many countries throughout the world (USEPA, 2004).

Agriculture is a major user of water and can accept lower quality water than domestic and industrial users. It is therefore inevitable that there will be a growing tendency to look toward irrigated agriculture for solutions to the overall effluent disposal problem. Because wastewater contains impurities, careful consideration must be given to the possible long-term effects on soils and plants from salinity, sodicity, nutrients and trace elements that occur normally manageable if associated problems with these impurities are understood and allowances made for them. (Ayer & Wescot, 1985).

Reclaiming municipal wastewater for agriculture reuse is increasingly recognized as an essential management stately in areas of the world where water is in short supply. Irrigation with wastewater would permit a more efficient use of water resources and considerably limits environmental damage due to the direct introduction into surface bodies (World Commission on Environmental Development, 1987).

Using reclaimed wastewater (RWW) for agricultural, which is less expensive and considered an attractive source of irrigation water. Moreover, irrigation with treated wastewater is considered a promising practice that helps in minimizing the pollution of the ecosystem subjected to contamination by direct disposal of Wastewater into surface or ground water (Kiziloglu *et al*., 2008). In addition, sludge is a valuable source for plant nutrients and organic matter needed for maintaining fertility and productivity of arid soils. However, reuse of wastewater for irrigation and sludge as fertilizer may potentially create environmental problems if not properly treated and managed.

Despite a long history of wastewater reuse in many parts of the world, and sludge was used at the recent decades, the question of safety of wastewater reuse and sludge still remains an enigma mainly because of the quality of reuse water and sludge. There always have been controversies among the researchers and proponents of extensive wastewater reuse and sludge, on the quality the wastewater is to meet. In general, public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilization, especially long term impact of reuse practices. It is difficult to delineate acceptable health risks and is a matter that is still hotly debated (Vigneswaran and Sundarvadivel, n.d).

The experience of Palestinians in the reuse of wastewater is young, but there were many attempts and studies to reuse wastewater in the West Bank and the Gaza Strip, there are very limited activities in the Palestinian territories for using reclaimed wastewater due to many reasons, there is a great potential for the reuse of this water resource to meet increasing agricultural water demand as a main objective of the Palestinian water sector.

2.2.3 Benefits and Difficulties of irrigation with treated wastewater

The use of urban wastewater in agriculture is a century old practice that is receiving renewed attention with the increasing scarcity of fresh water resources in many arid and semi-arid regions. Driven by rapid urbanization and growing wastewater volumes, wastewater is widely used as a low cost alternative to conventional irrigation water, it supports livelihoods and generates considerable value in urban agriculture despite the health and environmental risks associated with this practice (Kamoun, 2006).

Though this practice is largely unregulated in low income countries and costs and benefits are poorly understood. Wastewater from industries and municipalities, organic sludge and animal manures should be considered as resources rather than wastes that need to be put out of sight (Omer, 2003).

The treatment and reuse of the wastewater can improve a potential cause of environment, ground and surface water pollution and at the same time can help in solving the expected water scarcity (Eltoum, 2002), as irrigated agriculture is the largest consumer of water in the world.

In areas with dry climates, irrigation water use is 50-85% of total water use (Hamdy, 2001). Where it is more difficult to meet the agricultural water demand with conventional water resources, wastewater reuse represents a viable option (Capra & Scicolone, 2004). Reuse of wastewater for irrigation is increasingly gaining popularity worldwide as one of the non–conventional water resources targeted to overcome the envisaged international water crises.

Water reuse for irrigation has been largely applied to agriculture due to the advantages related to nutrient recovery possibilities, socio-economic implications, reduction of fertilizer application and effluent disposal, and increase the productivity (World Commission on Environmental Development, 1987).

Irrigation by wastewater should be considered not only for agricultural purpose, it may also be the preferred disposal alternative because it provides public health and environmental benefits that is not achievable by modern treatment and disinfection alone. Reuse has potential to reduce the cost of both wastewater disposal and the provision of irrigation water mainly around cities and towns with sewers (World Commission on Environmental Development, 1987).

Wastewater reuse could free large amount of fresh water currently used for irrigation and make this resource available to meet the growing needs for fresh water of cities and towns in developing countries (Pescod, 1992). Reported that use of Wastewater in agriculture could be an important consideration when its disposal is being planned in arid and semi-arid regions. Wastewater and sludge have both positive and negative impacts on agriculture as it is loaded with high levels of toxic heavy metals and pesticides, but also enriched with several useful ingredients such as Nitrogen, phosphorus, and potassium.

Although there are many benefits of the use of untreated domestic wastewater, there are drawbacks of the use of untreated domestic wastewater for irrigation: The wastewater constituents are organic matter, pathogens, nutrients, toxic contaminants and dissolved minerals (Pescod, 1992). Which can induce health risks for workers and consumers, exposed via direct or indirect contact with such waters during field work and ingestion of fresh and processed food, Health risk such as water-borne disease and skin irritations may occur for irrigators and communities. Also Reuse of wastewater may be seasonal in nature, this will resulting in the overloading of treatment and disposal facilities during the rainy season.

The long term use of untreated wastewater for irrigation has an impact on the soil composition (Surdyka *et.al*, 2010). Application of improper treated wastewater as irrigation water may result in groundwater contamination and buildup of chemical pollutants in the soil. The effluents may contain toxic substances and may increase contents of heavy metals that originated mainly from industrial discharges to sewers and agricultural runoff.

2.2.4 Guidelines for Wastewater Reuse in Agriculture

Considering the wide-ranging potential for wastewater reuse, it may be difficult to set some common quality standards for all types of reuses. Many countries in the world do not have detailed standards or guidelines for recycle and reuse of wastewater. For many countries in Europe, either the guidelines of World Health Organization (WHO) or the US Environmental Protection Agency (USEPA) standards form the basis for any decision or for granting permission to any kind of reuse. Some countries have developed their own standards for reuse. Standards or guidelines for other possible reuses such as groundwater recharge, industrial uses etc., are not common, mainly because such types of reuses are not widespread (USEPA, 2004).

Wastewater contains microbes and chemicals that pose risk to human and environmental health. Wastewater governance refers to the guidelines, regulations, policies and laws that have been developed to guide wastewater use for agricultural and other uses, and to minimize the risk to public health and the environment. All of it was initiated based on experimental data and results.

2.2.4.1 WHO Standard

First water quality criteria for reuse of wastewater in irrigation were set in 1933, by the California State Health Department (CSHD). These standards are for microbiological parameters that indicated the presence of pathogenic organisms in wastewater. In 1971, the WHO meeting of experts on reuse of wastewater recognized that mere presence of pathogens is not sufficient to declare water for reuse as unsafe, and considered that the California standards were overly strict and hindered widespread reuse practice, and recommended a much relaxed microbiological standard for wastewater irrigation (Vigneswaran and Sundarvadivel, n.d).

WHO has recognized both the potential and risk of untreated wastewater use and so has developed guidelines for policy makers attempting to legislate permission for the safe use of wastewater. The WHO acknowledged that most previous standards were unnecessarily high for public health protection and do not reflect reality of wastewater use on the ground.

The main features of WHO guidelines for wastewater reuse in agriculture are as the following:

- Wastewater is considered as a resource to be used safely.
- The aim of the guidelines is to protect against excess infection in exposed populations (consumers, farmworkers, populations living near irrigated fields).
- Faecal coliforms and intestinal nematode eggs are used as pathogen indicators.
- Measures comprising good reuse management practice are proposed alongside wastewater quality and treatment goals; restrictions on crops to be irrigated with wastewater; selection of irrigation methods providing increased health protection, and observation of good personal hygiene (including the use of protective clothing).
- The feasibility of achieving the guidelines is considered alongside desirable standards of health protection (WHO, 1989).

Many countries have welcomed the guidance from WHO standards and guidelines. France, for example, used a similar approach in setting guidelines, which were published in 1991. These are similar to those of WHO in defining analogous water categories called (A, B and C in the WHO guidelines) as obtained in table 2.2 and microbiological limits, but complement them with strict rules of application. For example, for category A in the

French guidelines, the quality requirement must be complemented by the use of irrigation techniques that avoid wetting fruit and vegetables, and for irrigation of golf courses and open landscaped areas, spray irrigation must be performed outside public opening hours (WHO, 1989).

As noted above, the WHO guidelines continue to be the benchmark target for decision makers in developing the wastewater recycling sector, however, as demonstrated, goals need to be in line with the capabilities of the country in question. Some countries have modified the microbiological criteria to suit local epidemiological and economic circumstances, as for example: Mexico (WHO, 1989).

2.2.4.2 Palestinian Standard

Standards for RWW quality for various uses have been established by the Palestinian Standard Institute in cooperation with all concerned Ministries including the Palestinian Water Authority (PS742/2003) since 2004, but they are often not enforced (McNeill *et al*., 2010).

These set conditions on a range of reuse options, aquifer recharge and sea discharge, with associated limit values for physical, chemical and microbiological parameters, although discharge to Wadi is not mentioned.

The approach and limit values are broadly consistent with the precautionary approach adopted in neighboring countries, but some parameters are significantly more stringent than the well-established WHO and FAO guidelines. The major difference in approach in the Palestinian standard to others in the region is how barriers on reuse are applied in relation to effluent quality (i.e. lower quality effluent requires more barriers). Standards for RWW quality for various uses have been established by the Palestinian Ministry of the Environment, but they are often not enforced (McNeill *et al*., 2010).

The regulations establish four classes of water from Class A “high quality” to Class D “low quality”. Four classes of effluent quality are recognized and classified by BOD, TSS and fecal coliform concentrations as shown in table 2.2. For each effluent class, a number of additional barriers are required for reuse, the number of barriers required depending on the type of crop. For Class A effluent, no additional barriers are required and Class D requires up to four barriers depending on crop type. Vegetables are specifically excluded. Furthermore, limit values are given for an additional 35 parameters for eight categories of reuse and disposal.

Table 2.2: Classification of Effluent Quality (EQA, 2003)

Class	Quality	BOD (mg/l)	TSS (mg/l)	Faecal coliform (MPN/100ml)
A	High	20	30	200
B	Good	20	30	1,000
C	Medium	40	50	1,000
D	Low	60	90	1,000

Also Palestinian recommend Standards guidelines for Treated Wastewater Characteristics according to different applications as shown in Table 2.3.

Table 2.3: Recommended Guidelines by the Palestinian Standards Institute for Treated Wastewater Characteristics according to different applications (WSI, 2005).

Quality Parameter	Fodder Irrigation		Gardens, Playground Recreation	Industrial Crops	GW Recharge	Land-scapes	Trees	
	Dry	Wet					Citrus	Olive
BOD_5 as (mgO_2/L)	60	45	40	60	40	60	45	45
COD as (mgO_2/L)	200	150	150	200	150	200	150	150
DO (mgO_2/L)	> 0.5	> 0.5	> 0.5	> 0.5	> 1.0	> 0.5	> 0.5	> 0.5
TDS (mg/L)	1500	1500	1200	1500	1500	1500	1500	500
TSS (mg/L)	50	40	30	50	50	50	40	40
pH	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9
Color (PCU)	Free	Free	Free	Free	Free	Free	Free	Free
FOG	5	5	5	5	0	5	5	5
Phenol (mg/L)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
MBAS (mg/L)	15	15	15	15	5	15	15	15
NO_3-N (mg/L)	50	50	50	50	15	50	50	50
NH_4-N (mg/L)	-	-	50	-	10	-	-	-
O.Kj-N (mg/L)	50	50	50	50	10	50	50	50

Quality Parameter	Fodder Irrigation		Gardens, Playground Recreation	Industrial Crops	GW Recharge	Land-scapes	Trees	
	Dry	Wet					Citrus	Olive
PO_4-P (mg/L)	30	30	30	30	15	30	30	30
Cl (mg/L)	500	500	350	500	600	500	400	400
SO_4 (mg/L)	500	500	500	500	1000	500	500	500
Na (mg/L)	200	200	200	200	230	200	200	200
Mg (mg/L)	60	60	60	60	150	60	60	60
Ca (mg/L)	400	400	400	400	400	400	400	400
SAR	9	9	10	9	9	9	9	9
Residual Cl_2	-	-	-	-	-	-	-	-
Al (mg/L)	5	5	5	5	1	5	5	5
Ar (mg/L)	0.1	0.1	0.1	0.1	0.05	0.01	0.01	0.01
Cu (mg/L)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
F (mg/L)	1	1	1	1	1.5	1	1	1
Fe (mg/L)	5	5	5	5	2	5	5	5
Mn (mg/L)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ni (mg/L)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pb (mg/L)	1	1	0.1	1	0.1	1	1	1
Se (mg/L)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cd (mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn (mg/L)	2.0	2.0	2.0	2.0	5.0	2.0	2.0	2.0
CN (mg/L)	0.05	0.05	0.05	0.05	0.1	0.05	0.05	0.05
Cr (mg/L)	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.1
Hg (mg/L)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Co (mg/L)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
B (mg/L)	0.7	0.7	0.7	0.7	1.0	0.7	0.7	0.7
FC (CFU/100 ml)	1000	1000	200	1000	1000	1000	1000	1000
Pathogens	Free	Free	Free	Free	Free	Free	Free	Free
Amoeba & Guardia (Cyst/L)	-	-	Free	-	Free	-	-	-
Nematodes (Eggs/L)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

(-) Undefined

There are some Criteria Recommended by PWA for Effluent Standards in the Gaza Strip as shown in table 2.4.

Table 2.4: Criteria Recommended by PWA for Effluent Standards in the Gaza Strip

Criteria	Recharge by infiltration	Restricted irrigation	Unrestricted irrigation
BOD (mg/l)	10 – 20	10 – 20	10 – 20
SS (mg/l)	15 – 25	15 – 20	15 – 20
T-N (mg/l)	10 – 15	10 – 15	10 – 15
Helminths (no./l)	-	<1	<1
Faecal coliform (CFU/100 ml)	-	<1,000	<200

Source: (EQA, 2003)

2.3 Wastewater reuse

2.3.1 In the West Bank

Amer (2011): has studied the reuse of reclaimed wastewater to irrigate corns designated for animal feeding. The study was conducted in the research field of Birzeit University (BZU) - Palestine, in order to study the effect of using secondary treated wastewater (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.

The results showed high numbers of coliform bacteria in the TWW, and the use of TWW from Al-Bireh did not result in an increased content of heavy metals in the soil compared to tap water (TpW), The results also 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, also 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. Results indicated also an increase in the chlorophyll and proline content of leaves when using TWW in irrigation, and fertilizer also led to the same result.

Abu-Madi (2008): has studied the perceptions of Deir Debwan farmers and public towards wastewater reuse for agricultural irrigation (treated effluent of Al-Bireh WWTP). The results of his study are over all, participants had good knowledge about the general water crisis, 93% were aware of the water crisis in Palestine, and 90% were aware of water crisis in their village. Interestingly, 73% knew that there are negative impacts from using untreated wastewater in irrigation and 24% knew that there are negative impacts from using treated wastewater. Further, only 40% knew that there are special standards for wastewater reuse and 42% did not know if there should be special standards for wastewater reuse. It was obvious that participants are willing to use treated wastewater 87% and products irrigated with it 85%. However, the situation was opposite concerning untreated wastewater with only 6% are willing to use it and 10% are willing to use products irrigated with it. Health was the main reason followed by environmental and economical reasons for not accepting the reuse of wastewater.

Othman (2004): has studied the use of treated gray water for irrigation of rainfed olives, and he concerned on the effect of different water regimes with different quality on the growth and production of "Nabali" olive cultivars. Thirty year old olive "Nabali" trees were irrigated from April 2000 to July 2002 with the different water treatments, each level was applied for a tree. Irrigation was applied by drip laterals. The experiment was conducted as Beit Doko village close to Jerusalem in the West Bank. Both types of water significantly increased olive yield compared to that obtained in the control. A higher vegetative growth (shoot number and length) was obtained with higher water level 30 cm/tree treated water. The result of his study indicated that this kind of treated wastewater is suitable for application to olive orchards.

2.3.2 In the Gaza Strip

Attaallah (2013): has investigated the short-term effect of irrigation with reclaimed wastewater RWW (from Gaza Wastewater Treatment Plant) on physiochemical properties of soil, groundwater and fruits. Two experimental plots planted with olive and citrus trees were used. The experimental sites were located in Zaiton area, south of Gaza city; the first experimental was irrigated with fresh water (FW). The second experimental was irrigated with RWW. Soil, irrigation water, fruits and olive oil samples were characterized according to standard methods. The electrical conductivity (EC), total dissolve solid (TDS), Nitrite (NO_2), chloride (Cl), alkalinity, potassium (K^+), sodium (Na^+), sodium absorption ratio (SAR), chemical oxygen demand (COD), total coliform and fecal coliform were significantly higher in RWW than FW. However, heavy metal in RWW and FW were found to be below standard limits. At the end of the experiment, soil results exhibited no significant variation in infiltration rate, bulk density, and porosity between the two plots. However, significant difference in EC, TDS, NO_3^-, Cl^-, Mg^{+2}, Ca^{+2}, Na^+ and OM were reported, particular at top soil layer (0-30) cm more than (30-60) cm layer. Piper (Trilinear) diagram indicated that there is no significant changes in the hydro chemical facies of groundwater were observed during the study period. Which indicated that short term irrigation by RWW for citrus and olive trees does not affected clearly on the groundwater. Results also showed no microbial contamination in the olive and citrus fruits in both plots. Additionally, the levels of the heavy metals were reported to be low. Olive oil quality parameters indicated no significant variation in refractive index, free acidity, peroxide value and acid value extracted from olive fruits from both plots.

Idais (2013): has studied the Evaluation of short term using treated wastewater on soil chemical properties and crop productivity in the Gaza Strip, The results indicated that the level of TDS, Na, Cl, TSS, Zn and Fe were higher in the effluent than the fresh water; it was above the recommended Palestinian standard for dry fodder irrigated by treated wastewater. Also, irrigation with wastewater lead to significant increase in O.M, CEC, K, TP, Ca, Mg, Na, and Cl in soil than irrigation with fresh water. In addition, the increases of Zn, Fe, Mn, and Pb in soil and sorghum plant irrigated with treated wastewater were significant in comparison with the plants irrigated with fresh water. Further, treated wastewater increased the plants height, and grain weight of sorghum.

Abu Nada (2009): has studied the impacts of long term use of wastewater irrigation on soil and crop properties in the northern the Gaza strip at “Om Al Nasser” village to the north of Beit Lahia Pilot Project (BLWWTP) where wastewater effluent was used for alfalfa irrigation, and the analysis was done for soil, wastewater and alfalfa samples. Results revealed that BLWWTP effluent is suitable to be used for irrigation as its quality match the local and international standards for wastewater irrigation except Na, Cl and Pb. Long term wastewater irrigation increased salt, organic matter and plant nutrients in both soil layers and soil pH was not consistently affected. Lead was the dominant heavy metal in wastewater and alfalfa crop. Although Pb level was in the acceptable range for soil, it was noticed that Pb has higher levels in alfalfa compared with other metals. Alfalfa yield with wastewater irrigation was higher than alfalfa yield by well water in the first year. The study concluded that regular monitoring of site-specific water and soil and appropriate management are needed to mitigate the negative impacts of sodium and salts accumulations.

Nassar et.al (2009)[a]: has investigated the socio-economical aspects of reuse in the Gaza Strip, the study was conducted by using field investigations and questionnaire analysis, the field investigations concerns about the potential lands for reuse and models to identify the quality of irrigated water, in two agriculture areas in the Gaza Strip, in Beit Hanoun in North Gaza 68% of farmers agreed directly to use the treated wastewater for irrigation purposes, in the Southern area, 91% of farmers accepted direct wastewater reuse schemes. The educational level, living background and the environment played a remarkable role in convincing the farmers about the feasibility of using treated wastewater. The study indicated an economical improvement for farmers switching from groundwater to effluent irrigation, even though full yield potential of citrus and olive.

Nassar et al. (2003): studied the sludge management using reed bed system and they concluded that the wastewater and the sludge in the Gaza Strip is relatively free of contamination of heavy metals and they suggested the application of sludge to agriculture would have minimal risk of heavy metals accumulation. Furthermore in advanced study (Nassar *et al*., 2005), the authors studied the sludge management concept in the Gaza Strip and found that there is little experience of sludge use in Gaza. In addition, they reported that huge quantities of sludge 30,000 tds produced annually and this required a minimum of 30,000 dunums for its use. However, the report mentioned the international standards for sludge use in agriculture whereas the physicochemical properties of sludge produced in Gaza were not reported.

2.4 Sludge in the Gaza strip

Sludge is a bio-product resulting from the ponds of primary and secondary wastewater treatment. It contains different ratios of organic materials and heavy metal elements and pathogens, according to the nature and source of wastewater treatment (Nassar *et al.* 2003)

Sludge is one of the main environmental problems in the Gaza Strip. More than 400 m^3/day of aerobic sludge and 5000 m^3/year of anaerobic sludge are disposed of randomly in the Gaza Strip, creating several environmental and health problems (Nassar *et al.* 2008)

The quantities of sludge estimated by the year 2025 in all the Gaza Strip are 55.74 thousand kilograms of dry solids daily. Table 2.5 summarizes the quantities of Wastewater and sludge in the Gaza strip by 2025.The sludge is expected to consist of 1–2% dry solids which mean that 3,716 m^3 of sludge will be generated daily in the Gaza Strip by the year 2025 (Nassar & Afifi, 2006).

Table 2.5: Wastewater and sludge quantities in the Gaza Strip by 2025

	Northern Area	Gaza and Middle Area	Khan Younis and Rafah	Total
Population	318,892	1,385,860	1,205,676	2,910,428
Wastewater m^3/d	35,716	155,216	135,036	325,968
Sludge kg dry solids/day	6,107	26,542	23,091	55,740

Source: Author calculations based on SOGREAH population forecast (1998)

The sludge produced in Beit Lahia and Rafah treatment plants is kept in the ponds for several years and when desludged, it is kept in the sand dunes around the treatment plant without any treatment. Such dispose could pollute the groundwater in the area through increasing the concentration of contaminants. In Gaza treatment plant, eight drying beds were constructed with a surface area of 430 m^2 each. Sludge drying beds are operated unsatisfactorily and large quantities of sludge are disposed of in the unused areas of the treatment plant. After partial drying, the sludge is transported to solid waste dumpsites within the Gaza Strip. Due to the high cost of transporting and land filling of dry sludge, it is kept in the treatment plants where it mixed with sand or fly due to wind into the adjacent agriculture areas. Sludge treatment facilities are almost absent and the sludge produced is removed from the ponds and left to be dried, partially depending on the season and the available area close to the treatment plant (Nassar *et al.,* 2008).

Currently, Palestine has no sludge management policy and the appropriate organizational setup for monitoring and control has not yet been established, although it is expected that these would be similar to that for effluent reuse. The adoption of appropriate standards for the use of treated sludge in agriculture is an essential step in this regard in order to codify institutional responsibilities. Sludge cannot be regarded as a commercial product that will reliably provide revenue; sludge is essentially a waste product of wastewater treatment.

In this regard, the disposal of sludge and associated treatment and disposal costs is strictly the responsibility of the operator of the WWTP (CMWU), to prevent sludge accumulating on the WWTP and to ensure its use or disposal does not cause adverse effects on the environment and human health. If revenue can be earned from selling sludge to farmers, this will help defray operating costs but this should not be relied upon. Farmers may be expected to pay for the transport of sludge and this represents a cost saving since the operator would otherwise have to cover the costs for alternative disposal, although, essentially there are no other means of disposal.

2.5 Sludge reuse

Sewage sludge has valuable agronomic properties in agriculture. In general , the sludge is rich in organic nutrients to agricultural soil and can be used as fertilizer or soil conditioner with rich organic elements, nitrogen, phosphorus, potassium, and a little of the condition to get rid of pathogens and heavy metals to the limits and provisions for monitoring and environmental monitoring to be used.

Although there are no treatment facilities for sludge within the treatment plants, in the Gaza strip the studies indicated that sludge in general is clean of heavy metals. Only Zinc and Absorbable Organic Halogens (AOX) showed anomalous concentrations; more than 85% of sludge samples showed that averages of zinc and AOX are 2,000 mg/kg and 550 mg/kg, respectively, which exceed the standards of all industrial countries for sludge to be used in land application (Shomar *et al*., 2004).

(El-Nahhal *et al*., 2014) studied the characteristics of the physicochemical properties of sewage sludge collected from Gaza wastewater treatment plant. They studied Sludge density, particle size distribution, water holding capacity, void volume, pH, EC, total organic carbon and hydrophobicity. The results showed that bulk density is about 1.18 g/cm^3 whereas the real density is 2.12 g/cm^3 and void volume is 50%; Particle size distribution showed that the major size of sludge is sand-like size 630 – 200 μm and the minor size is silt-like size 200 - 20 μm and clay-like size is less than 20 μm. Sludge has an acidic pH reaction 6.78 ± 0.02 with an electric conductivity equal to 2.49 ± 0.04 $mS \cdot cm^{-1}$. The hydrophobicity of sludge is very high, water drop penetration time (WDPT) is 114.77 ± 18.78 sec with a radius of 0.44 ± 0.08 cm. In the way around, oil drop penetration time (ODPT) of sludge is 5.05 ± 1.28 sec with a radius of 1.25 ± 0.14 cm. The WDPT/ODPM ration has very high value 22.73 indicating extreme hydrophobicity. High value of hydrophobicity may reduce water filtration in soil when sludge applied for agriculture. These results suggest that sludge application to soil may change the physicochemical properties of soil (El-Nahhal *et al*., 2014).

2.5.1 Sludge reuse in the world

Roig et al. (2012), analyzed the systematic and periodical use, for 16 years, of anaerobically digested sewage sludge as an agricultural fertilizer by assessing the effects on some soil physical–chemical, functional, and eco-toxicological properties. They found that the input of sludge enhances soil properties proportionally to the application doses and/or frequency. The organic amendments increased the organic matter content (and its aromaticity), the soil nitrogen, and the microbial activity, improving carbon and nitrogen mineralization processes and some enzymatic functions. They showed that the maximum dose should be (40 mg ha^{-1} $year^{-1}$) no more.

López-Valdez et al. (2010), investigated how emissions of CO_2, N_2O and N_2, and dynamics of mineral N were affected when different types of N fertilizer, i.e. NH_4^+, NO_3^-, or unsterilized or sterilized wastewater sludge, were added to the Texcoco soil. It was found that microorganisms added with the sludge accelerated organic material decomposition, increased NH_4^+ immobilization, and induced immobilization of NO_3^- (in Texcoco soil). They suggested that wastewater sludge improves soil fertility at Otumba (an agricultural soil) and would favor the vegetation of the Texcoco soil (alkaline saline).

Inderscience Publishers (2009), studied the use of sewage sludge as fertilizer supplement for Abelmoschus esculentus plants: physiological, biochemical and growth responses, This study was conducted to assess the usefulness of sewage sludge amendment (SSA) at 20% & 40% ratios for lady's finger (Abelmoschus esculentus L. var Varsha uphar) by evaluating the morphological, physiological, biochemical and yield responses. Lipid peroxidation, protein and antioxidant levels increased whereas photosynthetic rate, stomatal conductance and variable fluorescence ratio decreased in plants at higher SSA ratio. Biomass, yield and heavy metal concentration increased significantly at both the amendment ratios. The study suggests that SSA ratio below 20% could be an alternative option of fertilizers for good yield of lady's finger and also a useful management option for this solid waste.

Janali et al. (2008), studied the use of sewage sludge on agricultural land provides an alternative for its disposal. Therefore, the aim of the study was to evaluate the feasibility of using industrial sewage sludge produced in Pakistan, as an agricultural fertilizer. The agricultural soil amended with 250 g/kg sewage sludge with or without lime treatment was used for the growth of the common local grain crop, maize (*Zea maize*). The mobility of the trace and toxic metals in the sludge samples was assessed by applying a modified BCR sequential extraction procedure. The single extraction procedure was comprised of the application of a mild extracting ($CaCl_2$) and water, for the estimation of the proportion of easily soluble metal fractions. To check the precision of the analytical results, the concentrations of trace and toxic metals in every step of the sequential extraction procedure were summed up and compared with total metal concentrations. The plant-available metal contents, as indicated by the deionized water and 0.01 mol/L $CaCl_2$ solution extraction fractions and the exchangeable fraction of the sequential extraction, decreased significantly ($P < 0.05$) with lime application because of the reduced metal availability at a higher pH, except in the cases of Cd and Cu, whose mobility was slightly increased. Sludge amendment enhanced the dry weight yield of maize and the increase was more obvious for the soil with lime treatment. Liming the sewage sludge reduced the trace and toxic metal contents in the grain tissues, except Cu and Cd, which were below the permissible limits of these metals. The present experiment demonstrates that liming was an important factor in facilitating the growth of maize in sludge-amended soil.

Casado-Vela et al. (2007), studied the effect of the application of three increasing amounts of composted sewage sludge (3, 6 and 9 kg compost m^{-2}) on the physicochemical properties of a horticultural calcareous soil where two types of plants were grown under two exploitation regimes (one in a greenhouse and the other in open-air). They found out that the (9 kg compost m^{-2}) application promoted the appearance of deleterious effects on the properties of soil, such as salt accumulation, a significant increase in the electrical conductivity and an input of heavy metals (Pb > Cr > Cd). The (6 kg compost m^{-2}) application provided a supply of nutrients necessary to grow peppers plants under both exploitation regimes. The first plant biomass production under greenhouse was almost 60% higher compared to that of the open-air plot.

Al-Zoubi et al. (2004), studied the Effects of Sewage Sludge on Heavy Metal Accumulation in Soil and Plants, and on Crop Productivity in Aleppo Governorate, they said although sewage sludge is a good source of nutrients for plant growth, the presence of heavy metals in sludge can limit its use. The effects were evaluated of soil application of sludge on heavy metal accumulation in soil and plants and on the productivity of wheat, maize and vetch. There were four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to the MAAR-recommended nitrogen application; (iv) application of sludge at double the rate used in (iii).

The experiment was conducted at the Kamari Research Station in Aleppo. Analysis of soil before sludge application and after harvest reveals significant buildup of some heavy metals. Similarly in crops, heavy metal content increased with the increased application rate of sludge. In terms of other parameters, there was significant increase in organic matter and plant-available soil P levels in sludge-fertilized treatment. There were no significant differences for wheat yield between the sludge-fertilized treatments (2.66 and 2.86 t ha^{-1}) and mineral fertilized treatment (2.93 t ha^{-1}). Maize yield increased significantly in sludge fertilized treatments compared to the control (3.88 t ha^{-1}); the highest yield (6.34 t ha^{-1}) was in the treatment fertilized with double the amount of sludge. Vetch production also followed a similar pattern. Based on the results of this study.

It is concluded that sludge application to the soil is effective in improving crop yield. It is unlikely that a single factor in sludge was responsible for the yield improvement rather a combination of macro and micronutrients and organic matter supplied by the sludge. The addition of heavy metals to the soil with the application of sludge was minimal.

Arslan et al. (2004), studied the effect of mixing sludge with surface soil on soil physical properties and cotton yield, by using four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to MAAR-recommended nitrogen application rate; (iv) application of sludge at double the rate used in (iii). The experiment was conducted in the 2004 season at the Kamari Research Station in Aleppo-Syria. Organic matter in the top soil of the sludge treatments was significantly higher than in the control and mineral fertilizer treatments. Application of sewage sludge clearly improved the infiltration rate and soil water holding capacity because of the high water holding capacity of the applied sewage sludge compared the soil. Cotton yield increased with increasing sewage sludge application, and the highest yield (5400 kg cotton/ha) was obtained from treatment received sludge double crop N needs.

Tamrabet and Golia (2003), carried out two experimentations under semi-controlled environment to investigate the effect of wastewater and sewage sludge applications on growth of barley and soil properties. For the first study, Wastewater applications were carried out according to three modalities; application with 100% wastewater, 100% plate water and 50% / 50% wastewater to plate water. The second study was similar to the first one, except that sewage sludge doses applied were (zero, 30 and 60 t/ha). Results showed that the irrigation with wastewater and applications of sewage sludge contribute to the improvement of the plant yield with increases ranging from 100% to 250%. Irrigation with wastewater and particularly applications of sewage sludge improve effectively crop water use efficiency and reduces the evaporative part of irrigation water.

Yarilga (2003), investigated the effects of various sewage sludge (bio-solids) rates and a single dose barnyard manure application on the fruit yield, growth, nutrition and heavy metal accumulation of apple trees. The experiment was conducted using a completely randomized design with four replicates in 2000 and 2001. Two years data showed that the addition of sewage sludge to soil significantly increased fruit yield, accumulative yield efficiency, shoot growth and leaf N, Mg, Fe, Mn and Zn concentrations. These increases were generally lower with barnyard manure applications. The sewage sludge and manure applications did not cause any significant increase in tree trunk girth and P, K, Ca, Ni, Cr and Cd concentrations in leaf samples. Leaf Fe, Mn and Zn concentrations increased at the highest sludge application rate. The two-year results of this study demonstrated that sewage sludge applied to apple trees did not cause toxicity in the leaves.

Erdem & Ok (2002), evaluated the changes in chemical properties of an acid soil amended with (0, 15, 30, 60 and 120 t ha^{-1}) of brewery sludge (BS) for an incubation period of 120 days. And they found that by increasing BS rates and incubation time, the soluble salts of the soil increased from (0.11 to 0.80 dS m^{-1}), and the organic C, exchangeable cations, soluble cations and anions, NH_4–N and NO_3–N contents of the amended soil increased while the pH of the soil decreased by (0.3–0.5) unit with respect to the control. Furthermore cation exchange capacity (CEC) increased slightly whereas the exchangeable acidity decreased slightly.

Banerjee et al. (1997), studied the effect of sewage sludge application on biological and biochemical properties of soil in the plots maintained by the City of Winnipeg at Oak Hammock Marsh, Manitoba. They found that the sludge application significantly increased the amount of microbial biomass present in the soils. Also the biomass N content was uncharacteristically low resulting in a mean microbial biomass C:N ratio of 36:1. And despite the low C:N ratio of the biomass, sludge application enhanced the N mineralization potential of the soil. Additionally they found that the sludge application somewhat increased soil enzyme activities.

Sterritt & Lester (1980), studied the effects of organic matter, nitrogen, phosphorus and toxic elements in sewage sludge applied to agricultural land, and they found that the organic matter may improve the structure and water holding capacity of poor soils and the nitrogen and phosphorus in sludge have fertilizer value, and the crops can accumulate toxic elements from sludge-amended soils. Also the extent of accumulation varies considerably with plant species and cultivar; cereals and legumes accumulating lower concentrations than leafy plants.

2.5.2 Sludge reuse in the Gaza strip

There is lack of published works that describe the reuse of sludge and its physico-chemical impact and/or biological characteristics in Palestine especially in the Gaza Strip, and there are many farmers in Gaza use partially treated sludge such illegal and unmonitored use, and this action of contaminated sludge could create environmental and health problems.

Nassar et al. (2009)[b], studied Attitudes of farmers toward sludge use in the Gaza Strip, they said that the local production of organic fertilizer in the Gaza Strip is 66,800 m^3/year, which represents only 8.5% of the required quantities. This means that farmers have to import 728,000 m^3 of organic fertilizer per year, which costs around 10.2 Million US$. The social survey carried out for more than 300 farmers in the Gaza Strip shows that the scarcity of organic fertilizers and their high prices could encourage farmers to use treated sludge instead of importing organic fertilizers. The farmers who have not used sludge before are willing to use it if it is well treated and shows good results after application. Also sludge can be used as soil conditioner if it is composted as imported compost materials used in the Gaza Strip.

CHAPTER 3

MATERIALS AND METHODS

- **Data Collection**
- **Materials**
- **Methods**

CHAPTER 3: MATERIALS AND METHODS

3.1 Data Collection

The study was initiated with collecting baseline information from several sources that include previous reports, municipalities, interviews, field visits and governmental authorities addressing assessment of wastewater resources in Gaza, experiences of wastewater reuse in the world, guidelines for using treated wastewater for irrigation and characteristics of the sludge produced in GWWTP.

3.2 Materials

3.2.1 Study Site

The experiment was carried out in a farm owned by Ishtawi family, located in el Zaitoon area eastern to GWWTP, the assigned area is provided by treated wastewater from GWWTP. The site divided into two main parts, the first part was irrigated with effluent from GWWTP and the second part was irrigated with brackish water.

3.2.2 Soil Source

The soil used in the project was from agricultural area that has not been irrigated with wastewater before, the seed was covered well with mixing soil and sludge to aid germination.

Auger method was used to collect samples from 0-30 depth , Random soil sampling technique was used, the technique was used according to the standard method of International Center for Agriculture Research in Dry Areas (ICARDA, 2001).

3.2.3 Sludge source

The source of the sludge was from Gaza Wastewater Treatment plant, as from both primary and secondary sludge produced in the treatment plant. The sludge was processed to reach appropriate quality, such as drying at sun light, and grinding to reach appropriate size (0.0117 inches). Figure 3.1 & Figure 3.2 show GWWTP and the drying beds of sludge at GWWTP.

The sludge used in the experiment was from the accumulated one stated in the collection lagoons for a period of time more than six months.

Figure 3.1: Gaza Wastewater Treatment plant (GWWTP)

Figure 3.2: The drying beds of the sludge at GWWTP

3.2.4 Major features of corn seeds

Certified corn seeds was obtained from a certified source with the recommendations of ministry of agriculture specialists. Corn seeds are shown in Figure 3.3.

Corn was planted manually using three seeds per hole in March 2014, then after the growth of these seeds, the best one was selected for the study by sight, and the others were removed from the pots, and the plants were harvested in June 2014.

Figure 3.3: Maize (Zea mays) seeds

3.2.5 Planting Pots

Planting the crop was implemented using locally produced Flynn pots 27 liter in size (47,32,18 cm), 30 pots are needed to cover the trials and replicates of the experimental part. The 30 pots were filled with the assigned amount of sludge/soil mixtures as designed in Table 3.1. Flynn pots are shown in Figure 3.4.

Figure 3.4: Flynn pot

3.2.6 Irrigation water

Two types of irrigation water were used in this experiment:

i. Brackish water from ground water at al Zaiton area used for irrigation in the farm contained the study Area .

ii. RWW from GWWTP. The wastewater effluent translocate from GWWTP by pipes to the farm. During the experiment, the effluent was stored in a collection basin, the effluent passed through a sand filter and a Disk filter then to the field.

3.3 Methods

3.3.1 Experimental Design

The treatments were used illustrated below as shown in Table 3.1:

Table 3.1: Experimental Design were used

Trial	sludge/soil percentage mixture	Replicates
T_{1a}	Soil with 0% of sludge, irrigation with brackish water (Control)	R_1, R_2, R_3
T_{1b}	Soil with 0% of sludge, irrigation with reclaimed wastewater	R_1, R_2, R_3
T_{2a}	Soil with 10% sludge, irrigation with brackish water	R_1, R_2, R_3
T_{2b}	Soil with 10% sludge, irrigation with reclaimed wastewater	R_1, R_2, R_3
T_{3a}	Soil with 20% sludge, irrigation with brackish water	R_1, R_2, R_3
T_{3b}	Soil with 20% sludge, irrigation with reclaimed wastewater	R_1, R_2, R_3
T_{4a}	Soil with 30% sludge, irrigation with brackish water	R_1, R_2, R_3
T_{4b}	Soil with 30% sludge, irrigation with reclaimed wastewater	R_1, R_2, R_3
T_{5a}	Soil with 40% sludge, irrigation with brackish water	R_1, R_2, R_3
T_{5b}	Soil with 40% sludge, irrigation with reclaimed wastewater	R_1, R_2, R_3

3.3.2 Sludge Processing

The sludge used in the experiment was drying by air for three months to ensure stabilizing. Sludge was cleaned off plant tissues, and stones. Sludge was grinded manually by mortar pestle, then sludge passed through a 2mm sieve. The sieved soil were collected ~500 g, and stored in plastic bags, labeled and stored for the next step for cultivation. Sludge sample was divided into two parts; one for analysis at *BZU* and the other one for analysis at *Heidelberg laboratory*.

3.3.3 Irrigation system

Two irrigation networks were installed and connected to the pots, one for irrigation using brackish water as control, and one for irrigation using treated wastewater. Drip irrigation system was applied in the field. The adopted type of irrigation pipes is 1.6 cm in diameter, and each emitter is able to discharge 3 liters per hour when the pressure head is 1 bar at the emitter. Figure 3.5 shows a schematic diagram for the pots connected to irrigation networks and sources of feeding water.

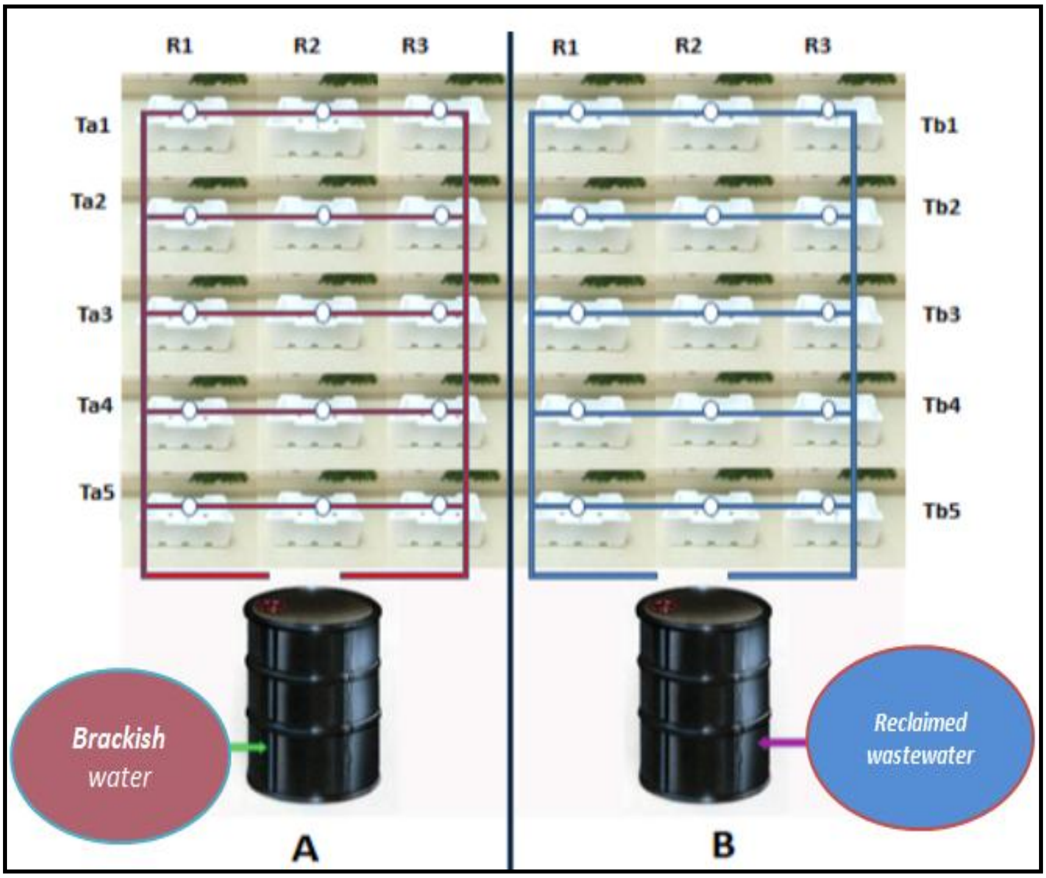

Figure 3.5: Schematic diagram for Irrigation system
A) Dripping with brackish Water, B) dripping with Reclaimed Wastewater

3.3.4 Planting and Harvesting

Pots were filled with soil and sludge as assigned in table 3.1, soil samples (2-3 Kg) were taken from each pot for analysis use. Corn was planted on March 26th, 2014; three seeds were planted in each pot. Drip irrigation was used in this experiment. The pots were irrigated regularly with brackish water for ten days. Then, RWW was connected as discussed before. During the growing process, several parameters related to plant morphology were monitored especially the ones related to plant height, number of leaves, number of fruits, etc.

At the final growth stage, leaves were obtained to direct analysis. Upon harvest (June 22nd, 2014), samples were taken from plants and fruits for analysis. 2-3 Kg soil samples were collected from each pot for analysis purposes. After harvesting, the samples were collected and prepared according to the methods for the intended parameter to be analyzed.

3.3.5 Sampling Action and Analysis

The following matrices were analyzed (samples for each matrix were analyzed for duplicate or triplicate) :

a- Water and wastewater sampling and analysis

The brackish water samples were collected from groundwater source at al Zaiton used for irrigation in the farm contained the study Area. Samples were collected in clean labeled bottles, transported in an ice chest with ice to the laboratory and treated according to the standard methods of American Public Health Association (APHA, 2005), (MERCK, 2009) and (USEPA, 1979).

Physical parameters (Temp, Turbidity, pH, EC and TDS) were taken during the sampling action for both type of irrigation water. The measurements were done by using portable instruments by using multifunctional meter in the field, while the turbidity was measured by turbidity meter. Table 3.2 summarizes the instruments and the methods of analysis used in irrigation water analysis.

Sample was divided into appropriate sub samples; one for the analysis at *BZU* laboratory and the other portion was assigned for the analysis at *Heidelberg* laboratory in Germany (Metals & Heavy metals), the samples were preserved by using concentrated Aristar nitric acid (HNO_3, Merck, ultra-pure) for the determination of metals & heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Si, Sr, Zn) by using Agilent Technologies 700 series (ICP/OES). The second was kept for the determination of anions (Cl, NO_3, PO_4-p, HCO_3 and SO_4) and cations (Na, K, Ca, Mg and NH_4-N) which measured according to (APHA, 2005). 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 for 24 h at 37^o C for TC and 44.5^o C for 24 h for FC.

Composite wastewater samples were collected from the outlet chamber of GWWTP, the physical parameters were measured onsite using same instruments as with brackish water samples. The effluent samples were transported directly in an ice box to the laboratories of *BZU*, and divided into two parts for analysis at BZU and *Heidelberg* Laboratory, and treated as brackish water samples in the previous section. COD, BOD, and TSS were determined according to standard method of analysis for water and wastewater (APHA, 2005).

Table 3.2: Parameters analyzed for brackish water and reclaimed wastewater

Parameters	Method	Summary of the analytical method
Turbidity	2130B. Nephelometric method	The turbidity was measured by turbidity meter.
pH	4500-H^+ B. Electrical method	The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode.
Conductivity (EC)	2510B. Laboratory method	TDS, EC and pH were measured in situ by a multipurpose EC pH meter.
TSS	2540D.	Total suspended solids were measured according to Standard Methods (APHA, 1995) by oven drying at 103-105 ºC of filtered samples using filter paper of glass microfiber filters (GF/C 125 mm f, CATNO 1822 122 Whatman). The difference in the filtered residue on the filter paper is gravimetrically evaluated as TSS.
HCO_3	2320B. Titration method	Bicarbonate was measured by using Bromocresol green indicator, and titrate against standard HCl, the end point is reached when blue color is change to greenish yellow, and finally the concentration of the Bicarbonate in the sample is calculated.
SO_4	4500-SO_4^{-2} E. Turbidimetric method	Sulfate was measured by using SO_4 Buffer solution and $BaCl_2$and then measured spectrophotometrically at 420 nm.
NO_3 (1)	Photometrically by means of sodium salicylate method	The sample of water is dried in oven at 150 ^oC after addition of sodium salicylate solution, and then continue drying for 2 hours. Then the sample is acidified with conc H_2SO_4, and after the addition of potassium sodium tartarate solution, the yellow color is red at 420nm for evaluation of nitrate content in the original sample..

Parameters	Method	Summary of the analytical method
Cl	4500-Cl- B. Argentometric method	An appropriate amount of the sample is titrated using standard solution of silver nitrate. An indicator used is a solution of potassium chromate, the end point is reached when a brown bluish precipitate is formed, and finally the concentration of the chloride in the sample is calculated.
PO_4-P	4500-P C. Vanadomolybdophosphoric acid colorimetric method	Spectrophotometer at absorbance of 400 nm wavelengths was used to determine the amount of PO_4-P by adding Vanadomolybdophosphoric acid to An appropriate amount of the sample.
K^+	3500-K B. Flame photometric method	A calibration curve is prepared from different standards of K concentrations. The intensity of absorbance of the sample and the standards are measured at k-filter using flame photometer.
Na^+	3500-Na B. Flame Emission photometric method	A calibration curve is prepared from different standards of Na concentrations. The intensity of absorbance of the sample and the standards are measured at Na-filter using flame photometer
Mg^{+2}	3500-Mg B. Calculation method	Mg^{+2} conc. is Calculated from Hardness and Ca^{+2}
Ca^{+2}	3500-Ca B. EDTA Titrimetric method	The sample was titrated against EDTA in the presence of murexide indicator , the end point is reached when wine red color is change to violet, and finally the concentration of the Ca^{+2} in the sample is calculated.
NH_4-N(2)	Nesslerization method	NH_4 was measured by adding Nessler reagent and K-Na Tartarate and then measured spectrophotometrically at 450 nm.
Metals & Heavy metals (3) (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Si, Sr, Zn)	3120B. Inductivity coupled plasma (ICP) method	Samples was filtered through a 0.45 µm Millipore membrane filters and the filters were preserved by adding Conc. HNO_3 and kept in 100-ml polyethylene bottles for analysis. Samples were analyzed by Agilent Technologies 700 series (ICP/OES) for the heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Si, Sr, Zn)

Parameters	Method	Summary of the analytical method
COD	5220D. Closed reflux colorimetric method	Sample, blanks and standards in sealed tubes are heated in an oven or block digester in the presence of dichromate at 150°C. After two hours, the tubes are removed from the oven or digester, cooled and measured spectrophotometrically at 600 nm.
BOD_5	5210B. 5-Days BOD test	The sample of waste, or an appropriate dilution, is incubated for 5 days at 20°C in the dark. The reduction in dissolved oxygen concentration during the incubation period yields a measure of the biochemical oxygen demand.
Surfactants	5540C. Anionic surfactants as MBAS	The dye, methylene blue, in aqueous solution reacts with anionic-type surface active materials to form a blue colored salt. The salt is extractable with chloroform and the intensity of color produced is proportional to the concentration of MBAS. The intensity of the produced color is spectrophotometrically measured as absorbance at 652nm.
TC,FC	9222B. E Standard total coliform membrane filter procedure	The several dilutions of the sample were filtered using 0.45 micrometer membrane filter, then the filters were incubated at the appropriate temperature using MFC agar media.

Ref: APHA AWWA 2005

(1) Ref: MERCK 2009 (2) Ref: USEPA 1979 (3) Analysis of Heavy metals at Heidelberg laboratory in Germany

b- Soil and sludge sampling and analysis

Soil sample from each pot was collected at the beginning of the experiment (March 2014), and at the end of the experiment (June 2014). Samples were cleaned off plant tissues and stones manually and air dried. 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 pockets, labeled and divided into two parts; one for analysis at *BZU* and the other one for analysis at *Heidelberg laboratory*.

Table 3.3 summarizes the instruments and the methods of analysis for soil and sludge.

Table 3.3: Parameters analyzed for soil and sludge

Parameters	Method	Summary of the analytical method
Soil Texture	ASTM (ADJD0422) by Hydrometer	The amount of soil is washed several times, then using a dispersion solution to disperse the soil particles and passing them through sieve and using a hydrometer, the percentages of the soil composition is classified.
pH soil-water suspension.	pH meter	Equivalent amounts of the soil sample and de ionized water are mixed and shaken, then, the pH of the solution is measured using pH meter.
EC	Laboratory method	Equivalent amounts of the soil sample and de-ionized water are mixed and shaken, then, the EC of the solution is measured using EC meter.
CEC	Cation exchange capacity	The soil sample is washed by deionized water or alcoholic deionized water, then the cations are extracted by sort of ammonium acetate, the equivalence of the replaced ammonium is equal the CEC of the sample in 100g. The ammonium is evaluated by TKN instrument[(1)].
TKN	Kjeldahl method	The Kjeldahl method (digestion, distillation and titration) was used to determine the amount of organic and ammonium nitrogen. The organic nitrogen in the sample is converted to ammonium nitrogen by digestion in acidic media, then the original ammonium nitrogen and the converted ammonium nitrogen is distilled in a basic media and collected. Then the ammonium nitrogen is measured by Nesslerization method.
Na	Flame Emission photometric method	10g of the soil sample is mixed with appropriate volume (50ml) of ammonium acetate solution, the desired metals are extracted, after filtration, the filter is used for the evaluation of the desired metal (Here Na by flame photometer)
Ca	Replacement of Exchangeable cations	10g of the soil sample is mixed with appropriate volume (50ml) of ammonium acetate solution, the desired metals are extracted, after filtration, the filter is used for the evaluation of the desired metal (Here, Ca by EDTA titration method)

Parameters	Method	Summary of the analytical method
K	Flame Emission photometric method	10g of the soil sample is mixed with appropriate volume (50ml) of ammonium acetate solution, the desired metals are extracted, after filtration, the filter is used for the evaluation of the desired metal (Here, K by flame photometer)
Mg	Replacement of Exchangeable cations	10g of the soil sample is mixed with appropriate volume (50ml) of ammonium acetate solution, the desired metals are extracted, after filtration, the filter is used for the evaluation of the desired metal (Here, EDTA titration for sodium and then Mg-Calculations)
PO_4-P	Vanadomolybdophosphoric method	A 2.5 gram scoop of soil and 50 milliliters of 0.5 M sodium bicarbonate (pH 8.5) solution are shaken for 30 minutes. The mixture is then filtered through Whatman filter paper and the ortho-phosphate in the filtered extract is determined colorimetrically (at 400 nm by adding Vanadomolybdophosphoric. Results are reported as parts per million (ppm) phosphorus (P) in the soil.
$CaCO_3$	Calcimeter	2g of the soil sample is taken and reacted with a standard concentrated HCl acid in a closed small bottle instrument. The carbon dioxide released is a measure of the calcium carbonate in the sample
NO_3	Nitrate by colometric method	10g The sample of the soil is extracted using 2M KCl solution, then the nitrate nitrogen is determined photochemically by means of sodium salicylate method (The testing of water, Merk, Darmstadt)
OM	Organic matter	Carbon in soil is determined by the reaction with acidic dichromate ($Cr_2O_7^2$). The oxidation step is then followed by titration of the excess dichromate solution with ferrous sulfate. The OM in the Soil is calculated using the difference between the total volume of dichromate added and the amount of unreacted dichromate determined through titration with ferrous sulfate after the reaction..

Parameters	Method	Summary of the analytical method
Metals & Heavy metals [(2)] Ag, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, and Zn.	Inductivity coupled plasma (ICP)method	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 HNO3 (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). Then 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 Agilent Technologies 700 series (ICP/OES) for the metals and heavy metals Ag, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, and Zn.

Ref: Miller and Keeney (1982) ,
(1) Yosef (1999) , (2) Analysis of metals and Heavy metals at Heidelberg laboratory in Germany

c- Plant sampling and analysis

i. Leaves sampling and analysis

Three leaves from the top was taken during the final stage of the growing season to measure both chlorophyll content in the leaves. The chlorophyll contents were determined according to (Sadasivam & Manickam, 1996). Shortly, total chlorophyll were extracted with 90% acetone and the absorbance of the extract was read at (645, 663 and 652) nm using UV-VIS spectrophotometer and chlorophyll was determined as mg/kg fresh weight.

ii. Fruit sampling and analysis

Samples of corn grains were collected from all plants in June 2014. Each sample was placed separately in plastic bag and taken immediately to the laboratory for analysis. At the end of the experiment, corn cobs were reaped and the husk was removed from the cobs Fruits from each plant, then dried in oven at 50 ^{o}C for three days. After drying, corn grains were removed from the cobs by hand, some measurements were determined as Plant high, Fresh and dry weight, Thickness. Then grinded by mortar into powder, filled in Poly Ethylene (PE) plastic cup, and stored for analysis. Trace elements were analyzed in each sample by ICP/OES. Table 3.4 summarizes the instruments and the methods of analysis for plant.

Table 3.4: Parameters analyzed for plant

Parameters	Method	Summary of the analytical method
Total N	Kjeldahl method	The Kjeldahl method (digestion, distillation and titration) was used to determine the amount of organic and ammonium nitrogen. The organic nitrogen in the sample is converted to ammonium nitrogen by digestion in acidic media, then the original ammonium nitrogen and the converted ammonium nitrogen is distilled in a basic media and collected. Then the ammonium nitrogen is titrated vs. standard sulfuric acid and evaluated.
Total K	Flame Emission photometric method	5g of each homogenized and grinded corn sample was burning until become ash then digested in few mls of concentrated HNO3 (65% p.a.) in 50-ml retorts (digesting flask). then cooling the solutions were diluted with distilled water in 100-ml volumetric flasks and kept in 100-ml polyethylene bottles for analysis. Samples were analyzed by flame photometer
Total P	Vanadomolybdophosphoric method	5g of each homogenized and grinded corn sample was burning until become ash then digested in few mls of concentrated HNO3 (65% p.a.) in 50-ml retorts (digesting flask). Then cooling the solutions were diluted with distilled water in 100-ml volumetric flasks and kept in 100-ml polyethylene bottles for analysis. Adding Vanadomolybdophosphoric acid Results are reported as parts per kg (mg/kg) phosphorus (P) in the fruit.
Plant high	Manually by meter	Plant high was measured manually by meter every two weeks.
Plant and fruit thickness	Manually by caliber meter	Plant and fruit thickness were measured manually by caliber meter every two weeks.
Number of leaves	By counting	Number of leaves was counted every two weeks
Number of Fruits	By counting	Number of Fruits was counted at the end of panting
Fresh and dry weight	Analytical Weight	Fresh and dry weight were measured by oven drying at 105 ºC of fresh and dry samples using analytical balance.

Parameters	Method	Summary of the analytical method
Metals & Heavy metals(1) (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Si, Sr, Zn)	Inductivity coupled plasma (ICP)method	Approximately, 5g of each homogenized and grinded corn sample was burning until become ash then digested in few mls of concentrated HNO3 (65% p.a.) in 50-ml retorts (digesting flask). Then cooling the solutions were diluted with distilled water in 100-ml volumetric flasks and kept in 100-ml polyethylene bottles for analysis. Samples were analyzed by Agilent Technologies 700 series (ICP/OES) for the metals and heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Si, Sr, Zn)

(1) Analysis of metals and Heavy metals at Heidelberg laboratory in Germany

d. Statistical analyses

All statistical analyses were performed with the SPSS program (Statistical Program for the Social Sciences 18.0), collected data were subjected to the analysis of variance, an ANOVA test was done with the two treatments as the independent variables. The mean values of all parameters were compared using the Tukey test.

CHAPTER 4

RESULTS AND DISCUSSION

- Introduction
- Evaluation of GWWTP efficiency
- Characteristics of Irrigation Water
- Evaluation of the soil used in the experiment
- Evaluation of the sludge from GWWTP
- Plant Morphology
- Physico-Chemical properties for sludge/soil (30% ratio)
- Plant Analysis

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The main objective of this research is the study of the possibility of reusing both of the Reclaimed wastewater and the sludge (as fertilizer) produced from Gaza Wastewater Treatment Plant (GWWTP). Moreover, the effect of the reuse of the reclaimed wastewater and the sludge on the soil physico-chemical properties (soil and different mixtures with different percentages of sludge/soil mixtures) and the impact on plant morphology (corn crop).

4.2 Evaluation of GWWTP Efficiency

In order to evaluate the treatment efficiency of GWWTP, Samples were taken from the influent and from the effluent. Parameters such as BOD, COD, TDS, and TSS are generally used for evaluation of effluent quality (Tchobanoglous *et al*., 2003). The parameters used for the determination of the efficiency of the WWTP were COD, BOD_5, TSS, TKN, FC, TC, pH and TDS. The characteristic parameters were measured according to Standard Methods of Analysis (APHA, 2005), and the results obtained are summarized in Table 4.1.

Table 4.1: The efficiency of GWWTP

Parameter	Inlet from GWWTP	Outlet from GWWTP	Removal %
pH	7.881	7.664	-
EC µS/cm	4860	4360	10.3
TDS mg/l	3020	2700	10.5
TSS mg/l	568	84	85.2
COD mg/l	945	225	76.2
BOD mg/l	444	85	81
TKN mg/l	78	66	15.4
FC (CFU/100ml)	$25*10^6$	$24*10^4$	99
TC (CFU/100ml)	$26*10^7$	$25*10^5$	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 (EQA,2005). Influent from GWWTP considered as high strength domestic sewage with average COD concentration of 945 mg/l, COD was reduced to 225 mg/l (76.2% removal). Also the average BOD_5 was 444 mg/l which reduced to 85 mg/l (81% removal). The average TSS through the treatment plant was reduced from 568 mg/l to 84 mg/l (removal of 85.2%). The average concentration of TKN decreased from 78 mg/l to 66 mg/l . The low efficiency of removal is due to the increase in the hydraulic and organic load that exceeded treatment plant designed capacity, inaccurate design parameters and inadequate operation (Ghannam, 2006).

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 and Palestinian guidelines for irrigation that specify the maximum concentration to be 10^3 fecal coliform colonies per 100 ml.

The main reason of having the high values of the Faecal Coliform and total Coliform in the effluent is due to absence of sorts of disinfections (Ghannam, 2006).

4.3 Characteristics of Irrigation Water

The majority results of physicochemical and biological analyses of irrigation water (RWW and BW) are presented in Table 4.2.The suitability of the two sources of irrigation water used (RWW and BW) were evaluated according to the guidelines and standards of local, regional and international references (FAO, 1992; USEPA, 2003 & PS-742-2003) guidelines.

Table 4.2: Characteristics of irrigation water

Parameters	Unit	RWW Average	BW Average	FAO	USEPA	PS
Turbidity	NTU	0.45	0	-	-	-
pH	-	7.622	6.841	6.5-8	6.5-8	6-9
Conductivity (EC)	µS/cm	4580	2900	0-3000	0-3000	2500
TDS	mg/l	2840	1740	500-2000	0-2000	1500
TSS	mg/l	7.1	0.7	50	40-50	50
HCO_3	mg/l	716	510	610	610	-
SO_4	mg/l	280	170	1920	1920	500
NO_3	mg/l	12.2	48	50	50	50
Cl	mg/l	1040	660	1000	1000	500
PO_4-P	mg/l	6.2	0	30	30	30

Parameters	Unit	RWW Average	BW Average	FAO	USEPA	PS
K^+	mg/l	30	15	-	78	78
Na^+	mg/l	520	320	900	900	460
Mg^{+2}	mg/l	114	84	60	60	60
Ca^{+2}	mg/l	136	107	400	400	400
SAR	meq/100ml	7.92	5.62	0-15	0-15	9
TKN	mg/l	46	14	NA	NA	50
NH_4-N	mg/l	40	9.3	40	40	-
COD	mg/l	170	62	50-60	50-60	150-200
BOD_5	mg/l	15	<10	20-30	20-30	45-60
Surfactants	mg/l	1.3	BDL	-	-	15
TC	CFU/100ml	400	8	<1000/100ml	<1000/100ml	<1000/100ml
FC	CFU/100ml	120	0	<1000/100ml	<1000/100ml	<1000/100ml

BDL: below detection limit

4.3.1 Physical Properties

- **pH Hydrogen Ion Activity (pH)**

pH average values indicated that the applied treated wastewater was slightly basic as it was 7.622 for RWW and it was slightly acidic for brackish water with 6.841 value. According to (USEPA, 2003; FAO, 1992 & PS-742-2003) guidelines these values are in the usual range for wastewater pH 6.5- 8 to be used for irrigation. Almost pH values of wastewater can be affected by the source of water, the season, type of wastewater and the treatment process (Kiziloglu *et al*., 2007).

For GWWTP most of the wastewater source is of domestic origin with almost the same source, therefore, the risks of pH dramatic changes are negligible due to the absence of industrial activities along with the wastewater network.

- **Salinity**

Salinity in applied treated wastewater as average was 2840 mg/l and for brackish water was 1740 mg/l.

Based on (FAO, 1992) guidelines for salinity concentrations current salinity for RWW has severe degree of restriction on use. While salinity for BW has slight to moderate degree of restriction on use and it can be used for irrigation with no severe.

According to (USEPA, 2003) EC values are still in the usual range of salinity where the critical value of applied water should not increase 3000 µs/cm. According (USEPA, 2003) guidelines divided the applied wastewater into five main classes based on EC and TDS values as shown in table 4.3. Current EC and TDS values of RWW and BW within class 4 which indicate that RWW and BW must be applied in excess for leaching, salt tolerant plant should be selected and soil must be permeable.

According to (PS-742-2003) the values of TDS for RWW does not meet the guidelines while values for BW are slightly exceed the maximum allowable value 1500 mg/l of guidelines. But Zea mays which was used in this experiment, is salt tolerant plant.

Table 4.3: Salinity classes of irrigation waters and salt tolerant plants

Class	TDS (mg/l)	EC (µS/cm)	Comments
1	0-175	0-270	Can be used for most crops on most soils with all methods of water application with little likelihood that salinity problem will develop. Some leaching is required and this will occur under the normal irrigation.
2	175-1500	270-780	Used if moderate amount of leaching occur. Plant of moderate salt tolerance can grow. Usually without salinity management. Sprinkler irrigation can cause leaf scorch on salt sensitive crops.
3	500-1500	780-2340	The more saline water in this class should be used with restricted drainage. Even with adequate drainage best practice management controls for salinity may be required and plant salt tolerance must be considered
4	1500-3500	2340-5470	Soil must be permeable. Water must be applied in excess for leaching and salt tolerant plant should be selected.
5	>3500	>5470	Not suitable for irrigation except on well drain soil wider good management especially in relation to leaching. Restricted to salt tolerant crops or emergency use.

Source: USEPA, 2003

4.3.2 Chemical Properties

- **Hardness of Water**

Average of calcium concentration at applied RWW in GWWTP was 136 mg/l for the RWW while it was 107 mg/l for BW. Ca level is still in the acceptable range according to the (USEPA, 2003; FAO, 1992 & PS-742-2003) guidelines as the value recommends of Ca concentration is 0-400 mg/l.

Average of Magnesium concentration at applied RWW at GWWTP was 114 mg/l, while it was 84 mg/l for BW. Values of Mg^{+2} slightly exceed the maximum allowable value 60 mg/l of guidelines according to (USEPA, 2003; FAO, 1992 & PS-742-2003) guidelines. High concentration of Ca^{+2} and Mg^{+2} ions in irrigation water can increase soil pH, resulting in reducing of the availability of phosphorous PO_4^{-3} (Al-Shammiri, 2005). But they are also essential plant nutrients.

- **Sodium (Na)**

Results showed that sodium Na^+ level for the applied water concentration of RWW exceeded the maximum level assigned according to the (USEPA, 2003; FAO, 1992 & PS-742-2003) guidelines which is 200 mg/l in (PS-742-2003) and 920 mg/l in (USEPA, 2003 & FAO, 1992). The average concentration of Na^+ for RWW was 520 mg/l, and for BW was 320 mg/l, this high concentration for RWW may refer to the original water quality which is the main source of wastewater due to household products for laundry, kitchen, bath and cleaning (Shomar *et al.,* 2005). Also sodium concentration is associated with chloride concentration which is originally high in the Gaza strip ground water due to sea water intrusion (Shomar *et al*., 2010).

- **Sodium Adsorption Ratio (SAR)**

The most important index of the sodium hazard for the determination of the suitability of irrigation water is the sodium adsorption ration, SAR, which can pose soil infiltration problems. High SAR values above 10 may result in reduction of soil permeability and aeration and a general degradation of soil structure.

SAR is the relative concentration of Na^+ to Ca^{++} and Mg^{++} levels. Calculated SAR values of RWW of GWWTP applied water was 7.92, while for brackish water was 5.62. This means that the applied wastewater SAR values with the current salinity are acceptable according to (USEPA, 2003; FAO, 1985 & PS-742-2003) guidelines standards. Which the value of SAR should not exceed the permissible level of 10.

- **Chloride (Cl)**

In the Gaza Strip, most of the area suffer from high concentration of chloride which is higher than recommended by international standards which refer to sea water intrusion in the aquifer of the Gaza Strip (Al-Khatib & Al-Najar, 2011). The excepted is the northern area as the chloride concentration is within the acceptable range by different standards for drinking purposes (250 mg/l and 500 mg/l) which meets is the maximum allowable Cl level in all guidelines standards. The mean values of Cl for RWW and BW were 1040 and 660 mg/l respectively. It was clearly noticed that Cl values for applied wastewater meet the maximum allowable value 1050 mg/l according to (USEPA, 2003; FAO, 1992 & PS-742-2003) guidelines standards, but it was exceeded slightly the maximum concentration of Cl assigned by PS guidelines, but Zea mays which was used in this experiment, is salt tolerant plant.

- **Nitrate (NO_3)**

Results indicated that Nitrate NO_3 values was 12.2 mg/l for RWW, while it was 48 mg/l for BW. Nitrate values of RWW and BW were lower than usual limits stated by (USEPA, 2003) and PS guidelines which is reported to be 50 mg/l.

The reason of which nitrate in RWW is within the permissible level and lower than source water because during any biological treatment process, up to 30% of the total nitrogen is converting in cell synthesis by ammonification, in addition to that removed during the sedimentation processes, (Horan, 1997).

- **Total Kjeldahl Nitrogen (TKN) and Ammonium-nitrogen (NH_4-N)**

The average values of Total Kjeldahl Nitrogen (TKN) and ammonium-nitrogen (NH_4-N) were 46 mg/l and 40 mg/l for RWW and 14 mg/l and 9.3 mg/l for BW. These results are within the acceptable range assigned by different reference standards for irrigated water quality which reported to be 40 mg/l as NH_4-N. Therefore, it is classified as a major nutrient.

- **Potassium (K)**

The average values of Potassium (K) were 30 mg/l for RWW and 15 mg/l for BW. These results meet the recommended values of different standards for irrigated water quality, thus fertilizer contains additional K values can be added.

According to (USEPA, 2003 & FAO, 1992), the maximum permissible K level of applied wastewater is 78 mg/l.

- **Phosphate Phosphorus (PO_4-P)**

The average values of Phosphate Phosphorus (PO_4-P) were 6.2 mg/l for RWW and negligible for BW. The major source of phosphorus in wastewater is from human excreta and synthetic detergent. According to (USEPA, 2003 & FAO, 1992), the maximum permissible Phosphorus value is 32 mg/l. Results indicated that P was within guidelines values. The average values of detergent were 1.3 mg/l for RWW and negligible for BW, these values meet the PS guideline.

- **Total Suspended Solid (TSS)**

TSS values for RWW was 7.1 mg/l and 0.7 for BW, which indicated a good sign that TSS value is located within the guidelines and standards for irrigation with RWW, It is worth mentioning, low concentration of TSS in RWW may refer to the sand filter were used before irrigation network, and settling process occurred in the storage bond of RWW at the field which may minimize the value of TSS as mention in the chapter 3 of irrigation water.

- **Bicarbonate (HCO_3)**

The average values of Bicarbonate (HCO_3) were 716 mg/l for RWW and 510 mg/l for BW. The value of RWW is slightly exceed the maximum permissible Bicarbonate value According to (USEPA, 2003 & FAO, 1992), as the maximum permissible Bicarbonate value is 610 mg/l.

- **Sulfate (SO_4)**

The average values of Sulfate (SO_4) were 220 mg/l for RWW and 170 mg/l for BW. The both of RWW and BW meet the maximum permissible Sulfate value according to (USEPA, 2003; FAO, 1992 & PS-742-2003) as the maximum permissible Sulfate value is 1920 for USEPA, FAO guidelines and 500 mg/l for PS guideline.

- **Metals and Heavy Metals (HM)**

The results of heavy metals for the RWW and BW obtained in Table 4.4 comply with the all standards for wastewater reused in agriculture as (EQA, 2003; USEPA, 2004 & FAO, 1992).

Table 4.4: Results of heavy metals for irrigation water

Metals and Heavy metals	Unit	BW	RWW
Ag	µg/l	BDL	0.5
Al	µg/l	< 20	< 20
As	µg/l	< 20	< 20
Cd	µg/l	< 1	< 1
Co	µg/l	< 5	< 5
Cr	µg/l	< 5	< 5
Cu	µg/l	3.63	12.5
Fe	µg/l	17.4	36.7
Mn	µg/l	3.85	120
Ni	µg/l	< 5	5.24
Pb	µg/l	< 20	< 20
Si	µg/l	7920	13300
Sr	µg/l	3180	3820
Zn	µg/l	112	74.7

- **Biochemical and chemical oxygen demands (BOD_5 and COD)**

The BOD_5 values for RWW in the present study was 15 mg/l, while COD values was 170 mg/l. Values of COD was 62 mg/l for BW and BOD_5 Value was below detection method for BW. In this study RWW values of COD, and the values of BOD_5 were within the allowable value 200 mg/l for COD and 60 mg/l for BOD_5 which was recommended by Palestinian standards for irrigated water quality.

4.3.3 Biological Quality

- **Fecal & total coliform (FC, TC)**

Fecal & total coliform (FC, TC) were investigated as indicator parameters for biological characteristics of wastewater. Results indicated that average values of FC and TC in applied wastewater in GWWTP meet (USEPA, 2003; FAO, 2003 & PS-742-2003) guidelines standards (1000 CFU/100 ml).

4.4 Evaluation of the soil used in the experiment

In order to evaluate the soil which was used in the experiment, Samples were taken from agricultural area that has not been irrigated with wastewater before. Parameters such as pH, EC, soil texture, TKN, NH_4-N, (Na, Ca, K, and Mg) as cations exchangeable and available. Also PO_4-P, $CaCO_3$, NO_3-N and organic matter. In the other hand metals and heavy metals were evaluated, table 4.5 summarizes the parameters were measured according to Methods of soil Analysis (Miller And Keeney, 1982).

Table 4.5: Characteristics of soil used in the experiment

Parameter		Soil
pH		7.269
EC	µS/ cm	295
Soil Texture		
Gravel	%	0.3
Sand	%	87
Silt	%	2.1
Clay	%	10.6
CEC	meq/100ml	2.65
TKN	mg/kg	66
NH_4-N	mg/kg	5.3
NO_3-N	mg/kg	9
Na(Available)	mg/kg	295
Na(soluble)	mg/kg	45
Ca(Available)	mg/kg	285
K(Available)	mg/kg	77.5
Mg(Available)	mg/kg	159
PO_4-P(Available)	mg/kg	10

Parameter		Soil
$CaCO_3$	%	3.3
O.M	%	Nil
H.M		
Ag	mg/kg	0.1
Al	mg/kg	4725
As	mg/kg	<0.02
Ba	mg/kg	27.65
Cd	mg/kg	<0.005
Co	mg/kg	4
Cr	mg/kg	13
Cu	mg/kg	5
Fe	mg/kg	5945
Li	mg/kg	2
Mn	mg/kg	149
Ni	mg/kg	6
Pb	mg/kg	3
Sr	mg/kg	49
Zn	mg/kg	18

Note: the results based on dry weight

Results obtained in table 4.5 showed that pH of soil samples was slightly basic, and it was in the accepted range to be reused in agricultural according to EQA standards (EQA, 2005).

Soil pH is important, since it influences how easily plants can take up nutrients from the soil. Nutrients are more available at the soil pH range of 6.5–7. It is important to note that maintaining soil pH above 6.5 reduces the availability of heavy metals to plants.

Soil Salinity is used to indicate soluble salt concentration in soil, as crops only remove small amounts of salt, (Heidarpour *et al*., 2007). Saline soils exert severe stress on plants, Salt-affected soils are more common in arid and semi-arid regions than in humid areas. Salt-affected soil is adversely changed by the presence of soluble salts. Saline soils contain enough soluble salt to limit plant growth while sodic soils contain excessive exchangeable sodium that destroys soil structure. Saline-sodic soil is excessive in both soluble salts and exchangeable sodium and thereby interferes with normal crop growth.

Salinity value of the soil samples was 295 µS/cm, and soluble sodium was 45 mg/kg as shown in Table 4.5.

The soil texture for the soil was used in this experiment was classified as loamy Sand according to the United States Department of Agriculture (USDA) soil texture classification. The clayey fraction was 10.6%; the silt fraction was 2.1%; and the sand fractions was 87%.

Nitrogen (N) is considered a major or macronutrient element and ranks fourth in importance among essential elements with carbon. The nitrogen concentration of most crop plants averages (2-4%). The form used by plants depends in part on rainfall, soil pH, and the age of the plant. High amounts of nitrogen stimulate shoot growth more than root growth probably because N is needed to make chlorophyll besides the genetic proteins and cell walls needed by all cells. However, an adequate supply of N promotes deep and numerous roots due to the greater leaf area providing energy for growth (Ward, n.d).
The average TKN concentration was 66 mg/kg and NH_4-N was 5.3 mg/kg and NO_3-N was 9.2 mg/kg. It seems that soil have a low content of nitrogen, so nitrogen fertilization is advised.

Cation-exchange capacity "CEC" is one of the most important chemical properties of soils. Term used to measure the fertility and nutrient retention capacity of soils, and it is the degree to which a soil can adsorb and exchange cations (Miller and Keeney, 1982), calcium and magnesium and potassium are considered the most cations influence CEC value. It was indicated as 2.65 meq/100 ml.

Potassium is another essential nutrient for plants, which is required in large quantities for the proper growth and production. The Results showed that the average available K was 77.5 mg/kg so potassium fertilization is advised.

Calcium is one of the necessary plant nutrients, Calcium is an integral part of the plant cell walls, and Calcium is important to proper plant cell organization. Calcium is essential for cell division and elongation as it is a critical factor in regulating cell membrane permeability. Meristematic or shoot tip growth also needs Ca. It is also needed to convert the amino acid tryptophan to a plant growth hormone, indole acetic acid (IAA), commonly called auxin. Auxin controls leaf and fruit drop, and initiates plant growth response to a light source. IAA also increases respiration and potassium uptake as IAA binds to cell membranes. The deficiency of Ca causes loss in production (Ward, n.d).

Most soils contain high levels of magnesium, Magnesium is also necessary for plant growth and development, Mg is part of the chlorophyll molecule. Magnesium deficiency, like any deficiency, leads to reduction in yield, and it also leads to higher susceptibility of cultivated plants to diseases (Ward, n.d).

Results obtained in table 4.5 showed that the average available Ca was 285 mg/kg and the average available Mg was 159 mg/l. it is appear that Mg concentration is high as mentioned in table 4.6.

Table 4.6: The interpretation of Mg soil test levels follows

Mg Soil test (mg/kg)	Ratinng	Comments
0-25	Low	Magnesium deficiency symptoms may be general in most field crops, vegetables and fruits. Magnesium fertilization is advised.
26-50	Medium	Magnesium deficiencies are expected in sugar beets. Potatoes and fruit crops. Magnesium fertilization is advised for these crops especially General crops would not be expected to respond consistently
51-100	High	Magnesium deficiency is not expected in Field or vegetable crops. Magnesium fertilization is suggested for fruit crops.
+101	Very high	No magnesium deficiencies are expected.

Source: (Ward, n.d)

Phosphorus is absorbed by plants roots in the orthophosphate form, generally as $H_2PO_4^-$ or HPO_4^{-2}. The amounts of these ions in the soil solution are determined by soil pH as shown in Figure 4.1. At pH 7.2, there are approximately equal amounts of these two forms in solution. Maximum solubility of calcium phosphate minerals occurs at about the same pH, therefore maximum plant available P occurs at approximately pH (7.0). It is mobile in the plant and redistributes from older to younger plant parts as demand changes. As pH changes in either direction, P availability is decreased (Tisdale et.al, 1993).

The result obtained showed that the average PO_4-P concentration was 10 mg/kg. It a low concentration for plant so phosphorus fertilization is advised.

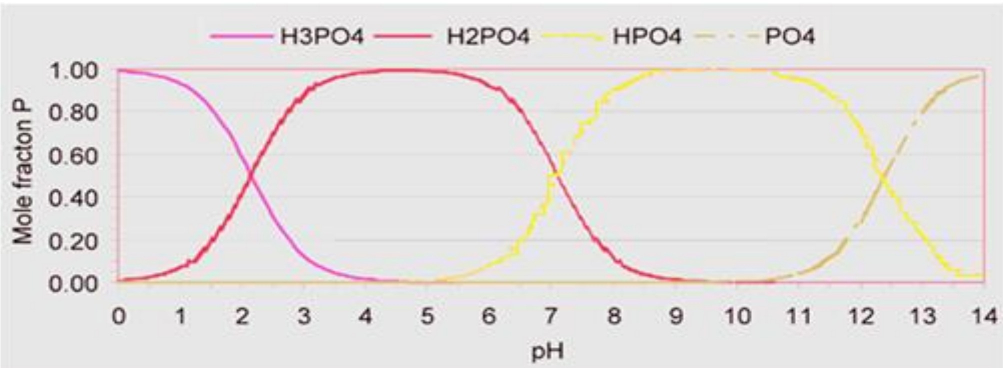

Figure 4.1: Influence of pH on the distribution of orthophosphate

Organic matter (O.M) influences physical and chemical properties of soils. In some soils O.M may be responsible for nearly half of the cation exchange capacity (CEC). It is also important in maintaining the stability of soil aggregates. According to (Donald, 1995), CEC less than 3 meq/100ml in sandy soils corresponds with low organic matter, while CEC of the sandy soil higher than 25 meq/100ml corresponds to high organic matter. Further, soil organic matter will develop greater CEC at near neutral pH than under acidic conditions.

Microbes in the soil also utilize O.M as a food source. Also microbiological activity improved after application of sewage sludge (Vieira, 2001).
Three general reactions occur in soil upon addition of organic tissues:

1. Enzymatic oxidation increases.
2. N, P, and S are mineralized and/or immobilized.
3. Compounds resistant to degradation are formed either from compounds present in the original plant tissues or by microbial synthesis.

Organic matter is one soil constituent that helps maintain aggregate stability. The resins and scums present in organic matter help bind particles together to form aggregates. Organic matter (OM) influences physical and chemical properties of soils.

The results obtained for CEC and O.M was agreement with (Donald, 1995).

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).

The Results obtained in table 4.6 indicated that all values of metals and heavy metals meet the recommended limits as internationally as USEPA and Locally as Egyptian and Jordanian Standards for Agricultural Use.

4.5 Evaluation of the sludge from GWWTP

In order to evaluate the sludge of GWWTP, Samples were taken from the accumulated bonds at the GWWTP. Parameters such as pH, EC, TKN, (Na, Ca, K, and Mg) as cations exchangeable. Also PO_4-P, $CaCO_3$, NO_3 and organic matter. In the other hand metals and heavy metals were evaluated, Table 4.7 summarizes the parameters were measured according to Methods of soil Analysis (Miller and Keeney, 1982).

Table 4.7: Characteristics of sludge from GWWTP

Parameter		Sludge
pH		6.552
EC	µS/ cm	7160
CEC	meq/100ml	22.7
TKN	mg/kg	5440
NH_4-N	mg/kg	3594
Na(Exchangeable)	mg/kg	1000
Ca(Exchangeable)	mg/kg	1569
K(Exchangeable)	mg/kg	525
Mg(Exchangeable)	mg/kg	1623
PO_4-P	mg/kg	213
$CaCO_3$	%	4
NO_3-N	mg/kg	125
C/N		44/1
O.M	%	50
H.M (Total)		
Ag	mg/kg	11
Al	mg/kg	8215
As	mg/kg	8
Ba	mg/kg	233
Cd	mg/kg	2
Co	mg/kg	3
Cr	mg/kg	119
Cu	mg/kg	245
Fe	mg/kg	9755
Li	mg/kg	4
Mn	mg/kg	132
Ni	mg/kg	24
Pb	mg/kg	92
Sr	mg/kg	369
Zn	mg/kg	1660

Note: the results based on dry weight

It was found that the pH of sludge samples taken from GWWTP was slightly acidic, and it was in the accepted range to be reused in agricultural according to EQA standards (EQA, 2005).

The importance of pH value of sludge is the solubility of heavy metals in sludge samples and pH-dependent. Accordingly, acidic media may enhance the solubility of heavy metals in sludge samples and make them dynamically toxic. Thus, high risk may be associated with acidic pH range and the opposite is true for alkaline pH.

Salinity value of the sludge samples was 7160 µS/cm, and sodium was 1000 mg/kg as shown in Table 4.7. This may be due to the accumulation of high soluble salts in the sludge samples due to the nature of sludge which was kept for six month at least which led to evaporate water and concentrate the salinity, Also results indicated that the sludge cannot be applied in all agricultural crops due to this high salinity. But in this experiment, different ratios were use and the Zea mays was use is tolerant for high content of salinity.

The results obtained showed that the average TKN concentration was 5440 mg/kg and NH_4-N was 3594 mg/kg and NO_3-N was 125 mg/kg, It is a high content of nitrogen, but it is an essential nutrients as the Allowed range (dry solids) of nitrogen concentration of Fertilizer Value of Sludge for Agricultural Use 2-3% (EQA, 2003)

C/N ratio is one of the most important chemical properties of soils and composts , For microorganisms, carbon is the basic building block of life and is a source of energy, but nitrogen is also necessary for such things as proteins, genetic material, and cell structure.

Results obtained in table 4.7 showed that the C/N was 44:1. The result slightly exceed the Allowed range (dry solids) of C/N of Fertilizer Value of Sludge for Agricultural Use <35:1 (EQA, 2003).

Potassium is another essential nutrient for plants, which is required in large quantities for the proper growth and production. Results obtained in table 4.7 showed that the average available K was 118 mg/kg. The result meet the Allowed range (dry solids) of Potassium of Fertilizer Value of Sludge for Agricultural Use 0.5 – 2% (EQA, 2003).

Phosphorus is another one of the three most essential nutrients for plant, the average PO_4-P concentration was 213 mg/l. The result meet the Allowed range (dry solids) of Potassium of Fertilizer Value of Sludge for Agricultural Use 1.5 – 2% (EQA, 2003).

Metals and Heavy metals of sludge used in this work was analyzed by preparing appropriate sample and analyzed at Heidelberg laboratory in Germany by Agilent Technologies 700 series (ICP/OES).

Heavy metals contamination from industrial wastewater is not probable since the limited number of factories presented in the Palestinian territories.

Results indicated that (Cr, Cd, Ni, Cu, Pb, Zn) meet the maximum permissible heavy metals value According to (EQA, 2003), and meet also regional standards as Egypt and Jordan, and international standards as USEPA. This show a good agreement with the results obtained by (Shomer, 2004) as the sludge in general is clean of heavy metals.

Results indicated that as exceed the Palestinian standard but meet regional and international standards as Egypt and Jordan, and USEPA.

Some of heavy metals are not illustrated in Palestinian standard but illustrated in Jordan standard like Co and meet this standard. Some of heavy metals are not illustrated in all standards like (Ag, Al, Ba, Fe, Li, Mn, Sr).

4.6 Plant Morphology

Plant morphology examines the pattern of development, the process by which structures originate and mature as a plant grows (Lambers, 2008). The morphology parameters were examined (plant height, number of leaves, number of fruits and fruit dry weight, plant thickness, crop yield) the next sections summarizes the findings.

4.6.1 Plant height

Plant height is associated with growth, it was measured manually by meter every two weeks. Results obtained in figure 4.2 showed plant height every two weeks for all ratios were used in this experiment. Results indicated that the treatment 20% and 30% had the highest value and there was no significant difference according of type of irrigation.

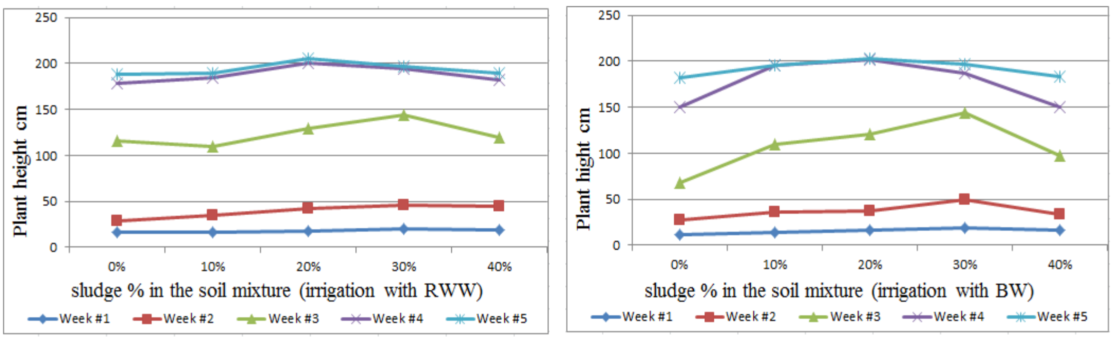

Figure 4.2: Plant height level every two weeks

4.6.2 Plant thickness

Plant thickness was measured manually by caliber every two weeks, Results obtained in figure 4.3 showed plant thickness every two weeks for all ratios were used in this experiment. Results indicated that the treatment 30% had the highest value of plant thickness and there was no significant difference according of type of irrigation.

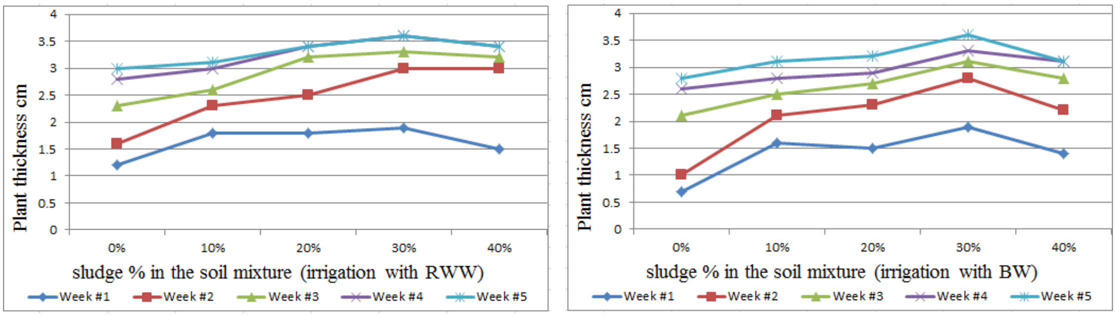

Figure 4.3: Plant thickness level every two weeks

4.6.3 Number of leaves per plant

Number of leaves was measured manually every two weeks, Results obtained in figure 4.4 showed number of leaves per plant for all ratios were used in this experiment. The results does not have a good indicator as leaves can be removed by air.

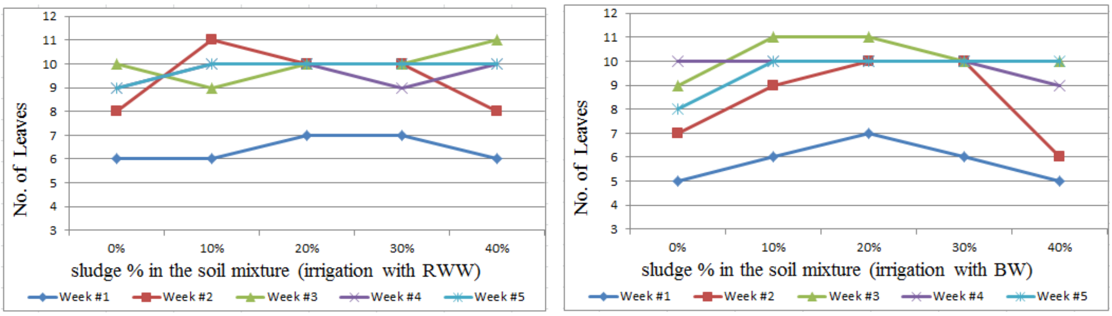

Figure 4.4: Number of leaves per plant

4.6.4 Fruit weight

The size of the fruit and thus the yield is the most important criteria to assess for studies related to the possibility of using sludge combining with RWW. Results obtained in figure 4.5 showed plant fruit weight at the end of cultivation for all ratios were used in this experiment. Results indicated that the treatment 30% had the highest value ,also there was no significant difference in the weight of corn plants irrigated with RWW, combined with (30%) sludge, or which irrigated with BW.

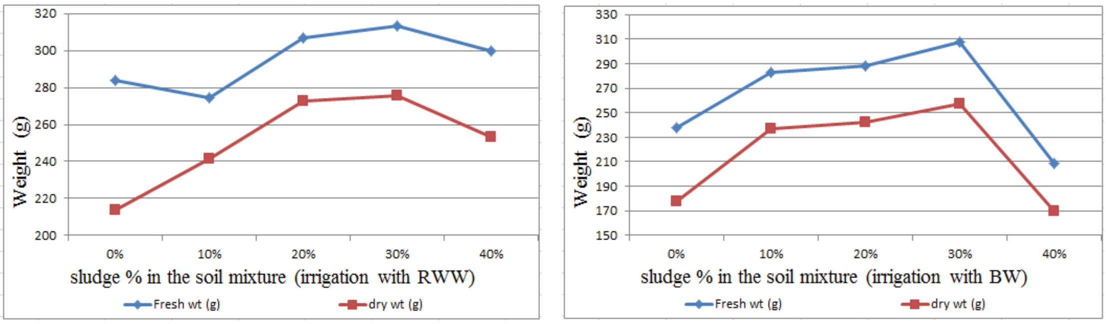

Figure 4.5: Plant weight at the end of cultivation

4.6.5 Crop Yield

Results obtained in table 4.8 showed that corn plants irrigated with RWW, combined with (30%) sludge, were significantly have the highest yield .There was no significant difference in weight of corn plants irrigated with RWW, combined with (30%) sludge, and which irrigated with BW. Figure 4.6 showed Mean of Grain yield at the end of cultivation.

Table 4.8: The Yield of plants at the end of cultivation for all treatments

Treatment / Yield (kg/ha)	0	10	20	30	40
Irrigated with BW	21867	29755	29733	31656	24700
Irrigated with RWW	26757	30422	31422	32744	31755

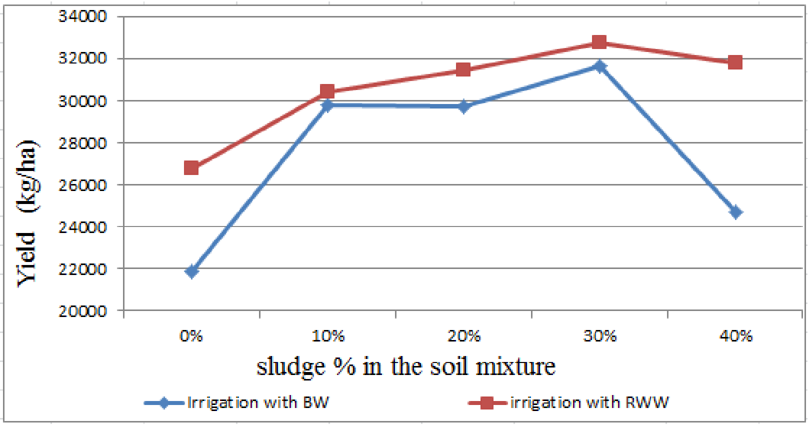

Figure 4.6: Mean of Grain yield at the end of cultivation

4.6.6 The optimum sludge/soil mixture

The optimum percentage of sludge/soil mixture was 30% according to the findings of plant morphology, which gave the highest tall, the highest thickness, the highest weight and highest yield of product,. So this study focused at this ratio to assess the effect of irrigation and using of sludge on the physical and chemical properties of soil, in parallel the soil with 0% ratio was studied as control samples.

The increase in weight was observed directly proportional to 30% sludge/soil mixture , this could be due to the nutrients contained in the sludge,(Bozkurt, 2003) , then decrease in weight was observed , this could be due to the high salinity contained in the sludge.

4.7 Physico-chemical properties for sludge/soil (30% ratio)

The majority results soil and sludge were presented in Table 4.9. The suitability of the optimum mixture was evaluated according to the guidelines and standards of local, regional and international references.

The values were evaluated from the tow different sampling periods, (at the start of project, and at the end of the project) as shown in Table 4.9.

Table 4.9: The results of physico-chemical properties for treatments of the experiment

Parameter		S1	S2	S3	S4	S5	S6
pH		7.269	7.507	7.536	6.799	7.037	7.017
EC	µS/ cm	295	730	883	4200	4220	4350
CEC	meq/100ml	2.65	2.82	2.89	8.00	8.55	8.79
TKN	mg/kg	66	69	71	1478	583	798
NH_4-N	mg/kg	5.3	52	60	803	531	656
NO_3-N	mg/kg	9.3	18	19	52	119	122
Na (Exchangeable)	mg/kg	250	400	450	750	500	525
Ca (Exchangeable)	mg/kg	245	260	265	680	778	796
K (Exchangeable)	mg/kg	70	90	90	200	150	163
Mg (Exchangeable)	mg/kg	150	155	160	491	514	528
PO_4-P	mg/kg	10	Nil	Nil	85	43	45
$CaCO_3$	mg/kg	3.3	3.3	3.3	5	5	5
O.M	%	Nil	Nil	Nil	12	11.7	11.9

Note : the results based on dry weight
S1 soil before planting (control), S2 soil after planting irrigated with BW, S3 soil after planting irrigated with RWW, S4 Sludge :soil (30%) before planting, S5 Sludge :soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

4.7.1 Physical Properties

- **Hydrogen Ion Activity (pH)**

Results showed that pH values for soil was 7.269 and 6.799 for Sludge/soil mixture (30%) before cultivation, which is the most desired range in agricultural soils.

This result is due to the fact that sludge samples contain large fraction of total Kjeldahl Nitrogen, NH_4 nitrification process in the soil may release protons which contribute to the pH lowering (Bolan *et al.,* 1991). However, this value of pH indicated that the sludge/soil mixture acidity is not so severe and it is in the acceptable range in term of agricultural use (Sial *et al*., 2006). The result show agreement with (Mazen *et* *al*., 2010) . Also results indicated that there were no significant effects ($p<0.05$) on soil pH due to reclaimed wastewater or brackish water application in the treatment mixed with sludge or not as shown in Figure 4.7, in the treatment mixed with sludge, results indicated that soil has slightly acidic value for soil before cultivation and it reached to the neutral point after cultivation, this increase is due to the chemistry and high content of basic cations such as Na, Ca and Mg in the applied water and high content of the same cations in sludge.

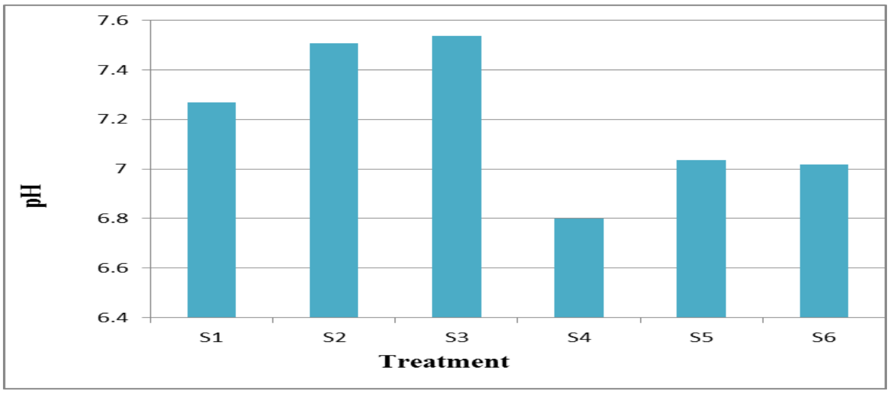

Figure 4.7: Influence of sludge treatments on pH level of the soil planted with Corn
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Soil Salinity**

The electrical conductivity of the sludge before starting the experiment and after the mixing with the soil was too high , and there was real significant differences between the soil (control) and between soils that was mixed at (30%) ratios before cultivation. However, there were no significant differences ($p<0.05$) according to type of water irrigated for treatment mixed with sludge or not mixed as shown in figure 4.8.

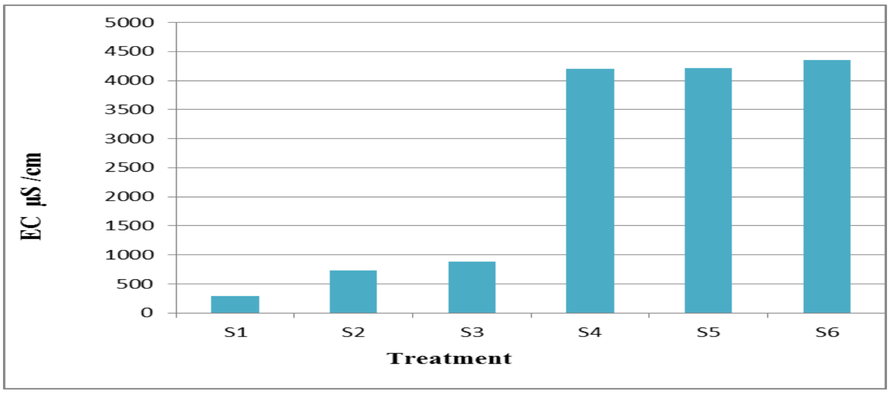

Figure 4.8: Influence of sludge treatments on EC level of the soil planted with Corn
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

In general, soil salinity increased by irrigation with RWW (Al-Shdiefat *et al.*, 2009). In this study there was no significant difference ($p<0.05$) of soil salinity according type of irrigation for both treatment (mixed with sludge or not).

The salinity was for Sludge/soil (30%) before cultivation which was 4200 µS/cm, and this result is suitable for Zea mays where the tolerant salinity is 6000 µS/cm as shown in table 4.10.

Table 4.10: Relative salt-tolerance limits of crops

Crop	EC(µS/cm)
Maize (Zea mays)	6000

Source: (Ayers & Westcot, 1985)

4.7.2 Chemical Properties

- **Exchangeable Calcium & Magnesium (Ca+Mg)**

In this study, results revealed that Ca^{+2} and Mg^{+2} levels were increased in the treatment amended with sludge (before cultivation), as shown in Figure 4.9 & Figure 4.10.

Results indicated that there was no significant difference ($p<0.05$) between treatment irrigated with BW and treatment irrigated with RWW for values of Ca^{+2} for treatment not amended with sludge and there was no significant difference ($p<0.05$) between treatment irrigated with BW and treatment irrigated with RWW for values of Ca^{+2} for treatment amended with sludge.

Also it is indicated that there was significant difference ($p<0.05$) between treatment amended with sludge or not for Mg^{+2} concentration before cultivation. also there was no significant difference ($p<0.01$) between treatment before or after cultivation which irrigated with BW or RWW for values of Mg^{+2} for treatment amended with sludge.

This explained as the total soil magnesium is found in non-exchangeable form. Therefore, the exchangeable magnesium level changes slowly with time because of the equilibrium with non-exchangeable forms. Also this variations of the exchangeable cations are explained by the combined effects of supply from irrigation, and root uptake (Tarchouna *et al.*, 2010).

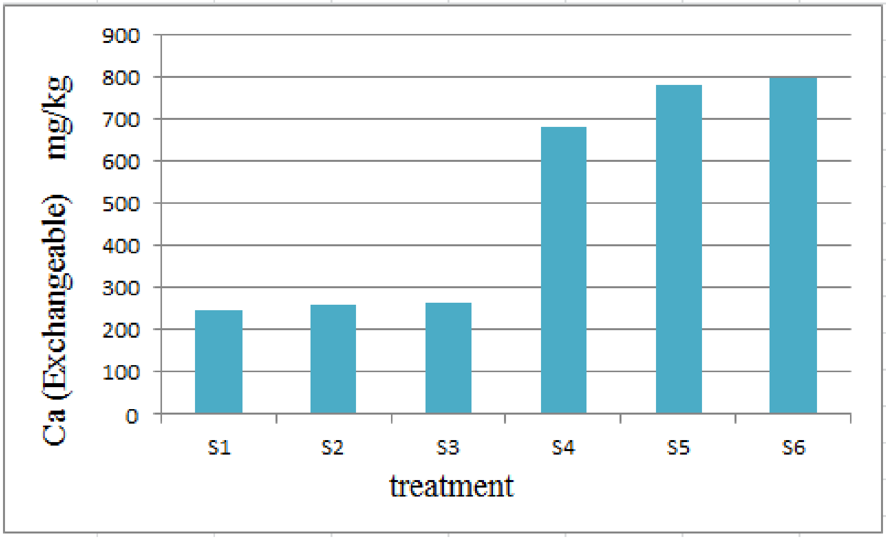

Figure 4.9: Influence of sludge treatments on Ca (Exchangeable) level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

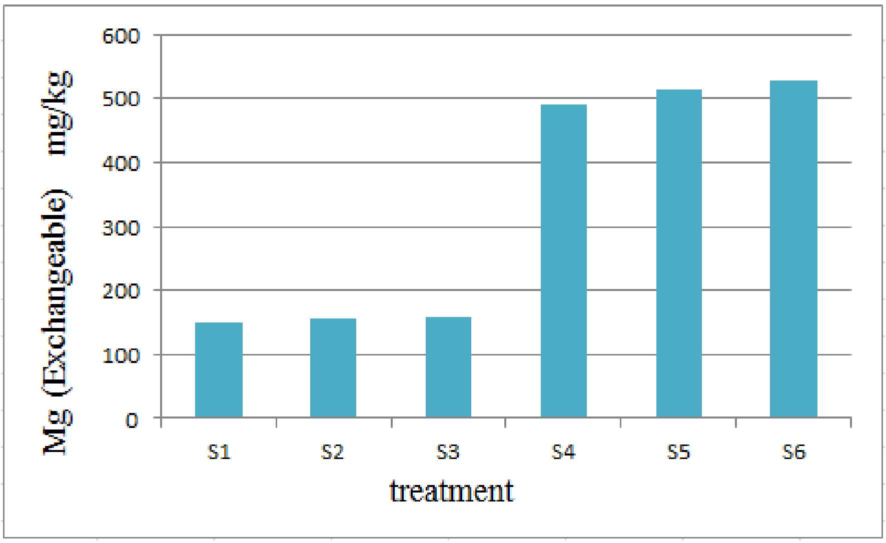

Figure 4.10: Influence of sludge treatments on Mg (Exchangeable) level of the soil planted with Corn
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Exchangeable Potassium (K)**

As mention before potassium is an essential for plant in large quantities. Results obtained in figure 4.11 showed that there was high significant difference in the value of potassium before and after amended of sludge before cultivation, and there was no significant differences in the value of potassium ($p<0.05$) in the treatment not amended with sludge for both type of irrigation, but in the treatment mixed with sludge there was significant decrease of K^+ value concentration. As discussed before CEC is a term used to measure the fertility and nutrient retention capacity of soils, and it is the degree to which a soil can adsorb and exchange cations. The reduction in K^+ concentration may be due to plant uptake (Heidarpour *et al*., 2007).

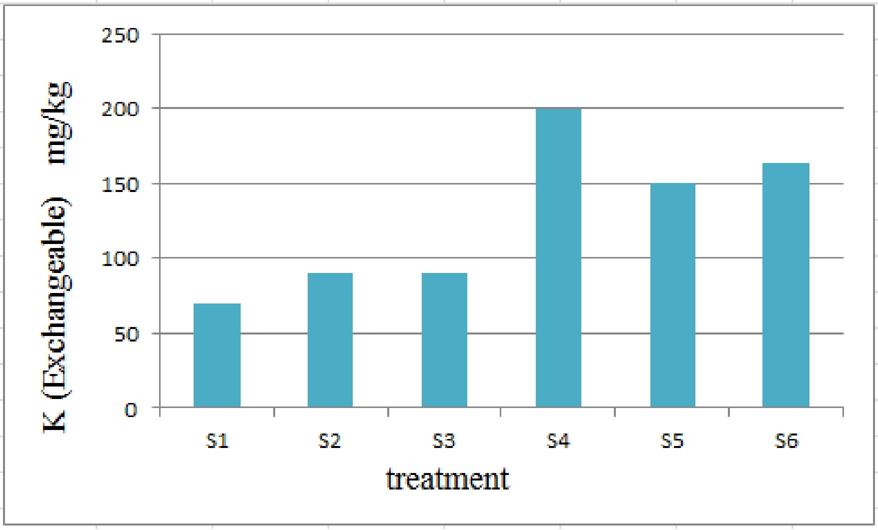

Figure 4.11: Influence of sludge treatments on K (Exchangeable) level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Organic Matter (O.M)**

As discussed before O.M influence the physical and the chemical properties of soil. The results obtained in figure 4.12 showed that there was significant improvement after amended of sludge before cultivation

From the results obtained for organic matter content, it is noticed that no significant changes occurred ($p<0.05$) before and after irrigation of the soil mixture in both types of water used. It is normal and consistent with literature since the balance of O.M of the sewage sludge application promoted a fast mineralization of the organic matter, transforming it into stable composts in the soil maintaining itself for many years (Sanches, 1981).

These results have high relevance because the organic matter is one of the most important soil quality indicator (Doran *et al*., 1996), and one of the main indicators of the degraded soils mitigation.

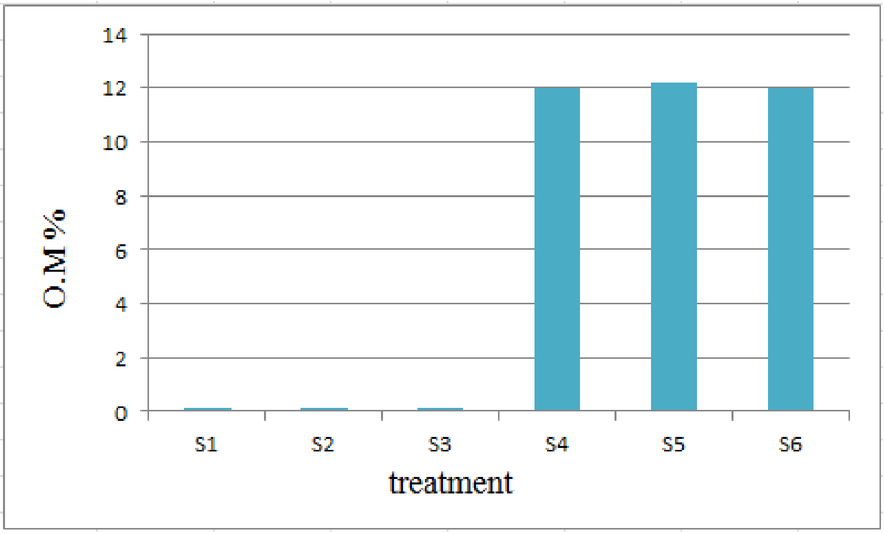

Figure 4.12: Influence of sludge treatments on O.M level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Cation- Exchange capacity (CEC)**

CEC is one of the most important chemical properties of soil, Calcium, Magnesium and Potassium are considered the most cations influence CEC value.

Results obtained showed that there were high significant differences in the value of soil CEC in the soil mixed with sludge compared with soil before cultivation, the main reason behind the high level of the soil CEC after amended with sludge was the increase of organic matter from sludge. Since it is common that organic matter enhance the properties of metal exchange with soil.

Also results obtained showed that there were no significant differences ($p<0.05$) in the value of soil CEC in both types of irrigation in the treatment mixed with sludge or not as shown in Figure 4.13. The results show a very good agreement with (Donald, 1995).

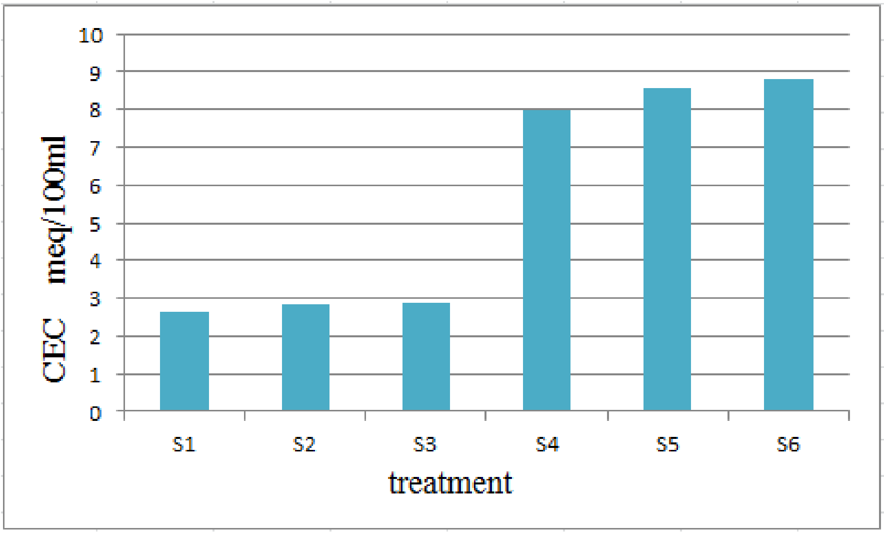

Figure 4.13: Influence of sludge treatments on CEC level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Sodium hazard (Na)**

It is known that high concentrations of sodium reduces the uptake of important mineral nutrients, K^{+} and Ca^{+2}. Irrigation with RWW often leads to high salts and Na concentrations in the soil (Pescod, 1992).

In this study there was high significant difference in the value of Na for treatment mixed with sludge or not mixed before cultivation.

Results shown in figure 4.14 showed that there were high significant differences in the concentration of Na in the treatment mixed with sludge compared before and after cultivation (Sodium was highly decreased). There was significant difference ($p<0.05$) in the concentration of soil Na in both types of irrigation in the treatment mixed with sludge or not mixed with sludge.

The reason beyond this is that, Calcium exchanges with sodium, which reduces sodic properties. This show a very good agreement with our results as high content of Calcium from sludge (Tejada *et al.* 2006) reported steady decline in the sodium content, which was accompanied by a marked increase in plant cover and soil porosity, upon the addition of compost and poultry manure to saline-sodic soil.

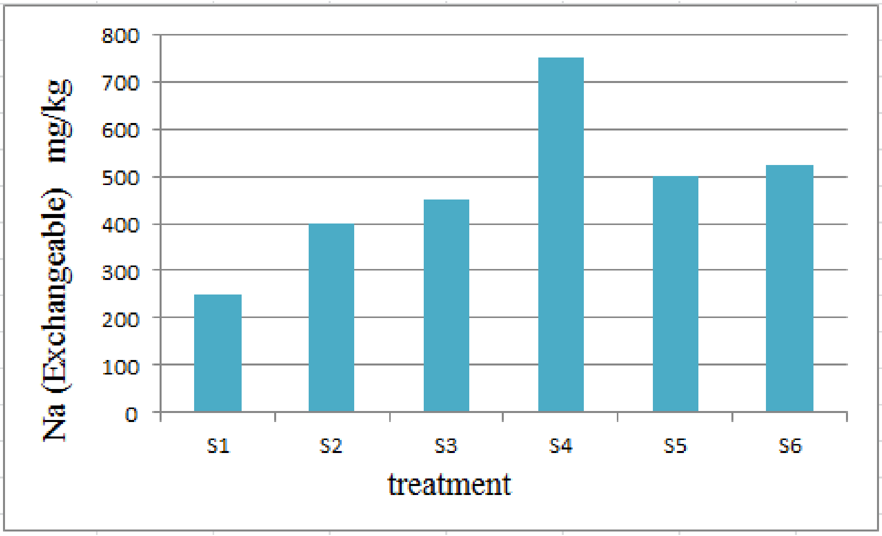

Figure 4.14: Influence of sludge treatments on Na level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Nitrogen Fractions**

(Total Kjeldahl Nitrogen (TKN), Ammonium- Nitrogen (NH_4-N) and Nitrate - Nitrogen (NO_3-N).

The nitrogen is considered as a major or a macronutrient element for pants, results obtained showed that there were high significant differences in the value of TKN and NH_4-N in the treatment mixed with sludge or not mixed before cultivation. Also results indicated that TKN and NH_4-N were highly decreased after cultivation. and there were significant differences ($p<0.05$) in the amount of soil TKN and NH_4-N according type of irrigation for the treatment mixed with sludge or not mixed with sludge as shown in figure 4.15.

Results obtained in figure 4.16 showed that there were high significant differences in the value of NO_3-N in the treatment mixed with sludge or not mixed before and after cultivation. There was no significant differences ($p<0.05$) in the amount of soil NO_3-N according type of irrigation for the treatment mixed with sludge or not mixed with sludge as shown in figure 4.16.

A reduction in ammonium and increase in nitrate nitrogen concentration is related to the soil mineral and chemical characteristics, (Tamanini *et al.*, 2008), or due to biological nitrification de-nitrification process as a high biological activity, (Almeida,

2014) who observed a high improvement in the biological activity sewage sludge application.

Equation 1 & 2 describe biological nitrification process in the presence of organic matters and micro-organisms.

$$NH_4\text{-}N + 1.5\,O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + 2\,H^+ + H_2O + \text{Energy} \qquad \text{(Equation 1)}$$

$$NO_2^- + 0.5\,O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- + \text{Energy} \qquad \text{(Equation 2)}$$

Application of sludge increases the concentration of nitrate due to possible degradation of organic nitrogen. The results showed high organic nitrogen content in sludge. This organic nitrogen compound may be degraded in soil to nitrate due to the high fraction of organic carbon and high oxygen content which enhance the oxidation of ammonium compounds to corresponding nitrate.

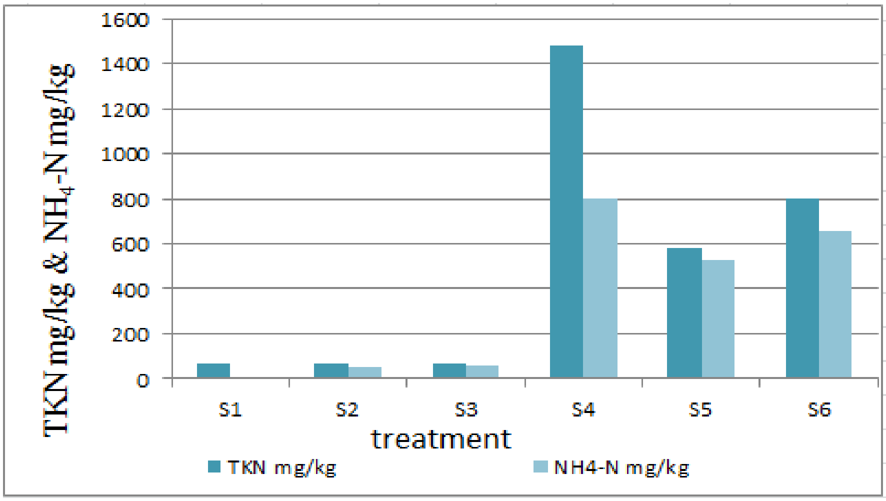

Figure 4.15: Influence of sludge treatments on TKN & NH_4-N level of the soil plantedwith Corn.

S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

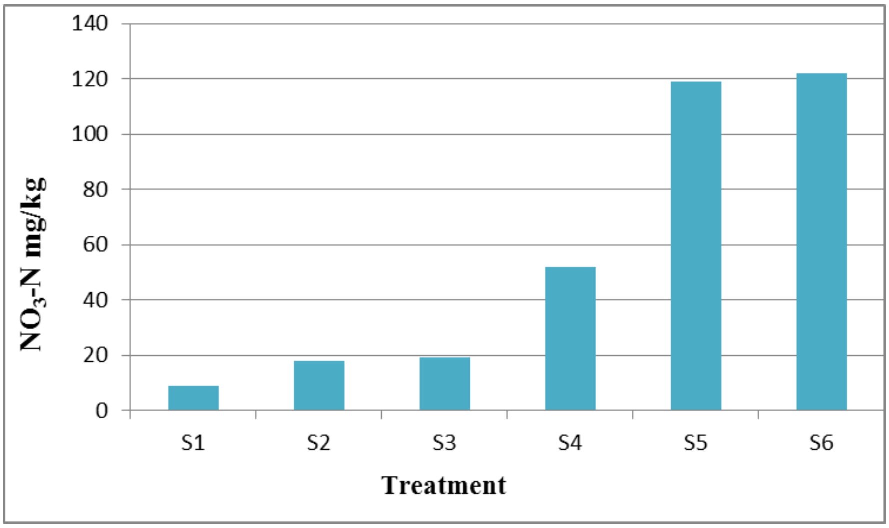

Figure 4.16: Influence of sludge treatments on NO_3-N level of the soil planted with Corn.

S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Phosphate Phosphorus (PO_4-P)**

As mentioned before Phosphorus is an essential nutrient for plants. Results obtained showed that there was significant differences ($p<0.05$) in the value of PO_4-P in the treatment mixed with sludge or not mixed before cultivation as shown in figure 4.17. Also, plants absorb P mainly as $H_2PO_4^-$ or HPO_4^{--}, the concentrations are related to soil pH levels. The $H_2PO_4^-$ ion predominates in acid environments, as at the treatment mixed with sludge before cultivation, while HPO_4^{--} occurs above pH 7.0 as at the treatment mixed with sludge after cultivation.

This shows a very good agreement with this results as pH change before and after cultivation from acidic to neutral point, this is due to sludge amended which enhance plant uptake which improve plant growth.

In the treatment not mixed with sludge, the concentration decrease after cultivation as plant uptake.

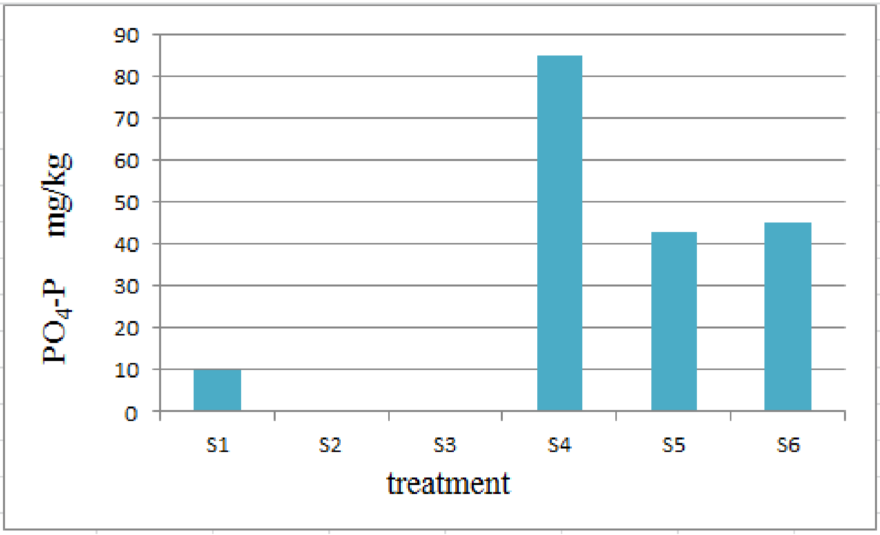

Figure 4.17: Influence of sludge treatments on PO4-P level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Calcium Carbonate ($CaCO_3$)**

In this study there was significant difference in the value of $CaCO_3$ for treatment mixed with sludge or not mixed before cultivation.

Also results indicated that there was no significant differences ($p<0.05$) in the amount of soil $CaCO_3$ in the treatment mixed with sludge or not for both type of irrigation as shown in figure 4.18. The presence of calcium as lime ($CaCO_3$) affected on soil pH, which improve plant growth. Almost $CaCO_3$ is added to the soil to re-mended by adjust pH value.

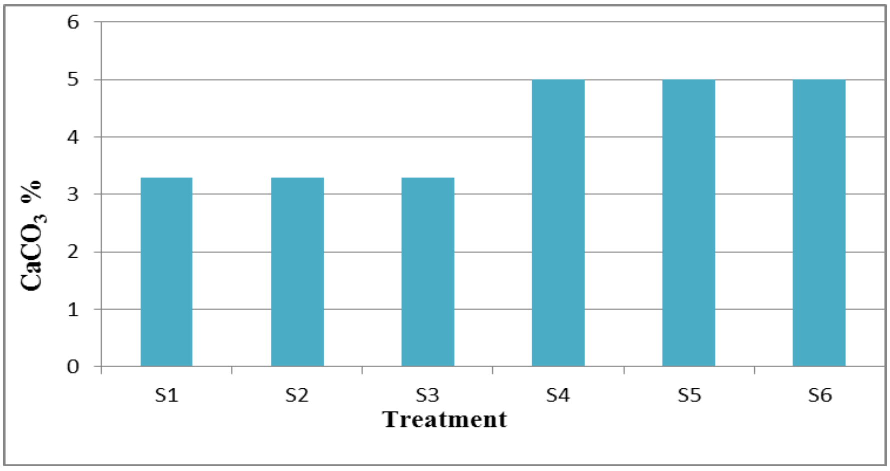

Figure 4.18: Influence of sludge treatments on $CaCO_3$ level of the soil planted with Corn.
S1 soil before planting (control), S2 soil after planting irrigated with BW
S3 soil after planting irrigated with RWW, S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

- **Metals and Heavy Metals (H.M)**

The total metals and Heavy metals content of the sludge used in this work was analyzed by preparing appropriate samples and analyzed at Heidelberg laboratory in Germany by Agilent Technologies 700 series (ICP/OES).

As mention before heavy metals contamination from industrial wastewater is not probable since the limited number of factories presented in the Palestinian territories. Some heavy metals in sewage sludge are micro-nutrient that are essential for plant growth (e.g. copper, and zinc) and they are beneficial to crops. However, like most elements, the excess amounts of these elements may present problems for plant growth. The heavy metals that are essential for plant or animal nutrition have a very limited availability range, and become toxic to plants, animals and humans at define concentrations. In this respect, (Smith, 1992) noticed that sewage sludge, which contains high levels of toxic metals, may limit their application to soils due to food chain contamination.

Results obtained in Table 4.11 showed that there were significant differences in the concentrations of heavy metals in soil before and after mixing of sludge, before mixing it have lower value according to Ag, Al, As, Ba, Cd, Cr, Cu, Li, Ni, Pb, Sr, and Zn, but it have higher value according to Co, Mn. And there were no significant difference according to Fe.

Results showed that there were no significant differences ($p<0.05$) in the concentrations of heavy metals according to the type of irrigated water for the treatment mixed with sludge for Ag, Al, As, Li, Co, Mn, Ni, Pb, Sr, and Zn, also results showed that there was slightly significant difference ($p<0.05$) in the concentration of heavy metals according to the type of irrigated water for Ba, Cu, Fe, and Cr as shown in figure 4.19-4.31.

Results indicated that all values of heavy metals in the treatment amended with sludge and soil before cultivation meet the recommended limits as internationally as USEPA and Locally as Egyptian and Jordanian Standards for Sludge use in agriculture. Also results of heavy metals meet the Palestinian standard for the Maximum Concentrations of Heavy Metals in Sludge for Agricultural Use as shown in figure 4.19-4.31.

Table 4.11 : The results of metals and heavy metals for treatments of the experiment

Metals and H.M		S1	S4	S5	S6
Ag	mg/kg	0.1	1.8	1.6	1.8
Al	mg/kg	4725	5510	5550	5595
As	mg/kg	<0.02	<0.02	<0.02	<0.02
Ba	mg/kg	27.65	86	81	101
Cd	mg/kg	<0.005	<0.005	<0.005	<0.005
Co	mg/kg	4	3	3	3
Cr	mg/kg	13	31	33	23
Cu	mg/kg	5	43	39	44
Fe	mg/kg	5945	6325	6700	5185
Li	mg/kg	2	3	2	3
Mn	mg/kg	149	127	124	126
Ni	mg/kg	6	9	9	9
Pb	mg/kg	3	20	21	24
Sr	mg/kg	49	106	107	106
Zn	mg/kg	18	312	323	331

S1 soil before planting (control),
S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW,
S6 Sludge: soil (30%) after planting irrigated with RWW

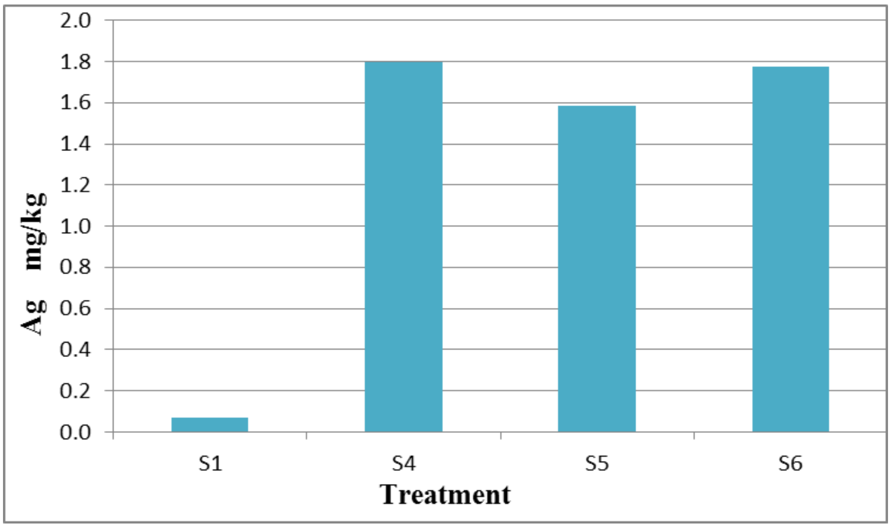

Figure 4.19: Influence of sludge treatments on Ag level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

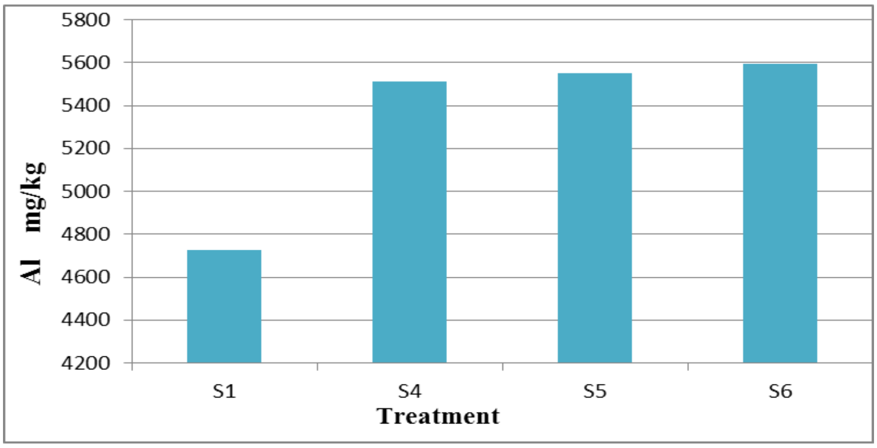

Figure 4.20: Influence of sludge treatments on Al level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%)
after planting irrigated with RWW

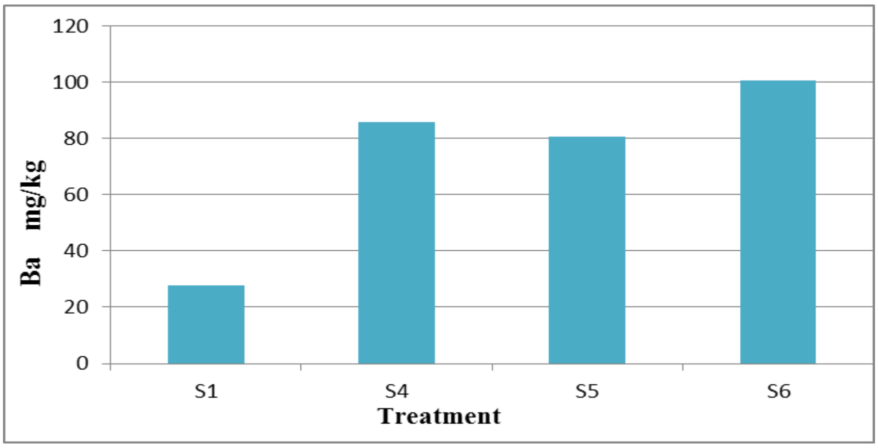

Figure 4.21: Influence of sludge treatments on Ba level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%)
after planting irrigated with RWW

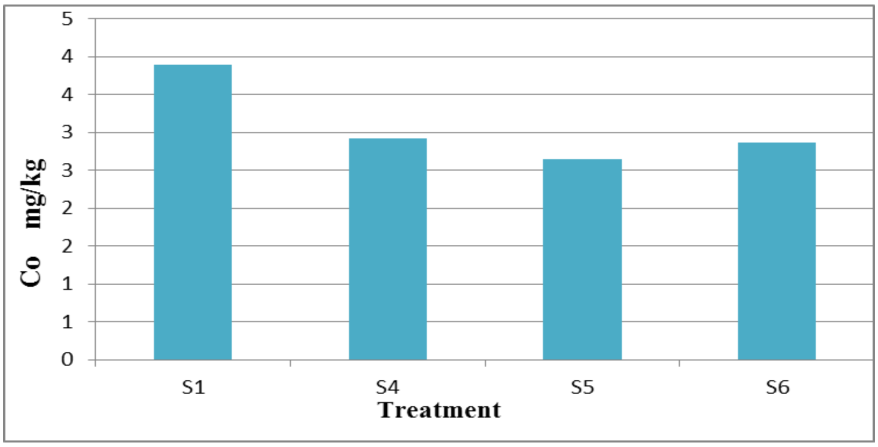

Figure 4.22: Influence of sludge treatments on Co level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%)
after planting irrigated with RWW

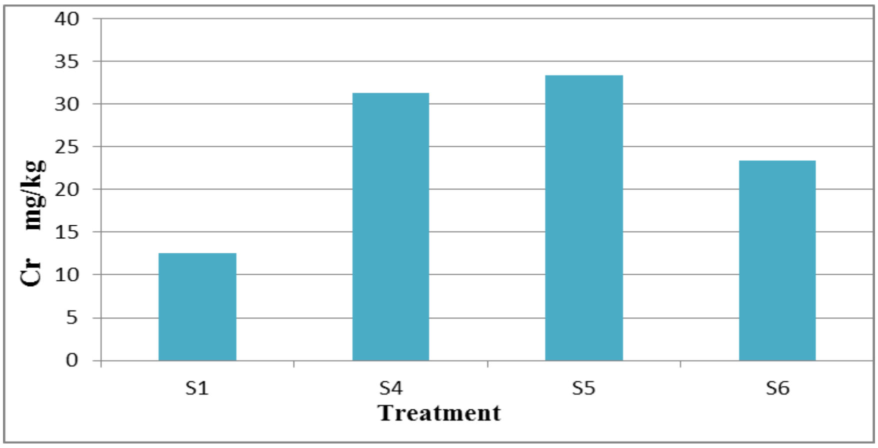

Figure 4.23: Influence of sludge treatments on Cr level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

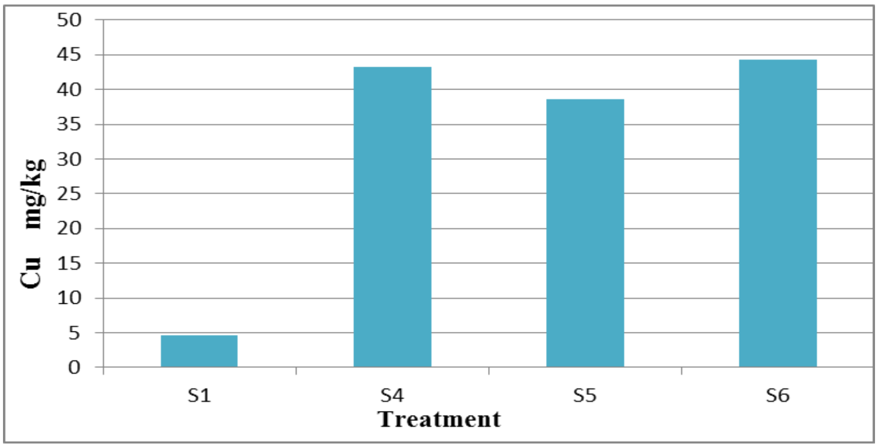

Figure 4.24: Influence of sludge treatments on Cu level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

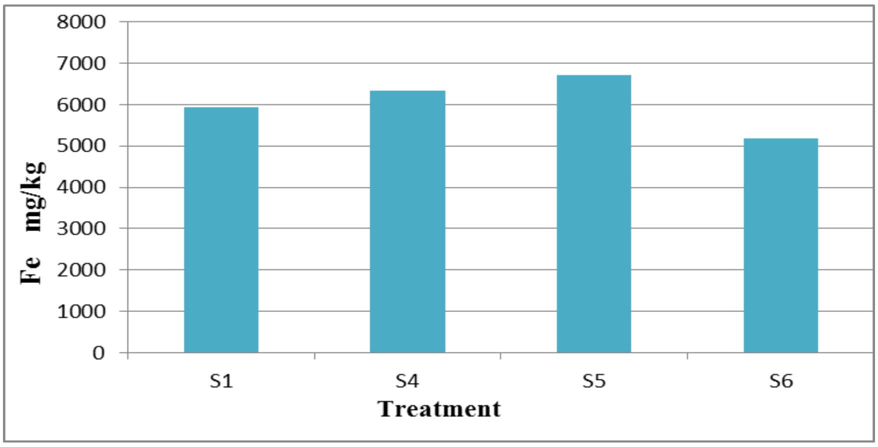

Figure 4.25: Influence of sludge treatments on Fe level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

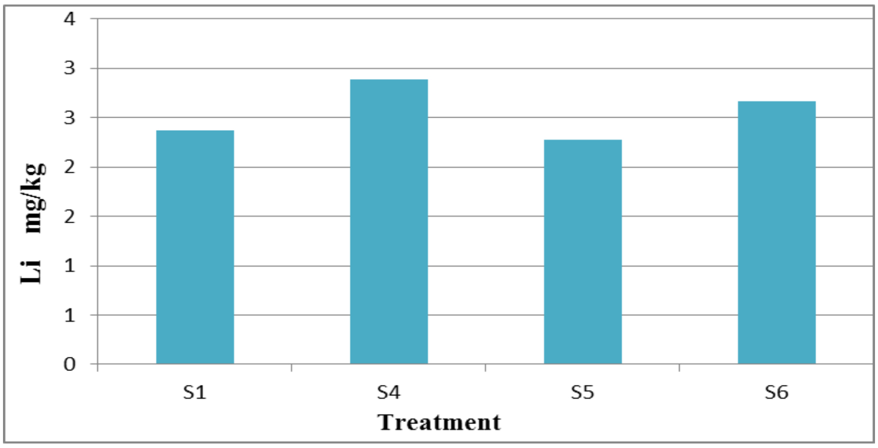

Figure 4.26: Influence of sludge treatments on Li level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

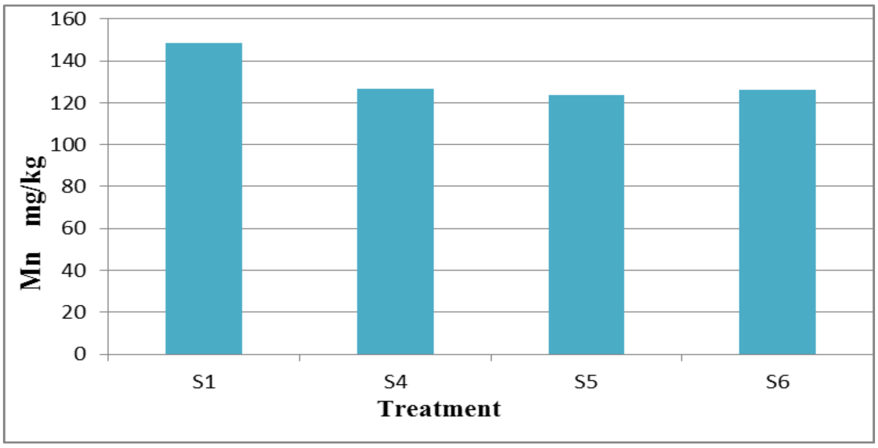

Figure 4.27: Influence of sludge treatments on Mn level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

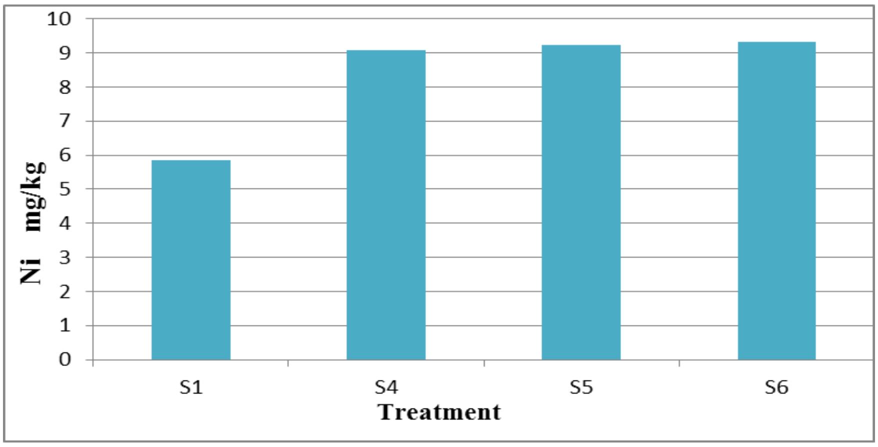

Figure 4.28: Influence of sludge treatments on Ni level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

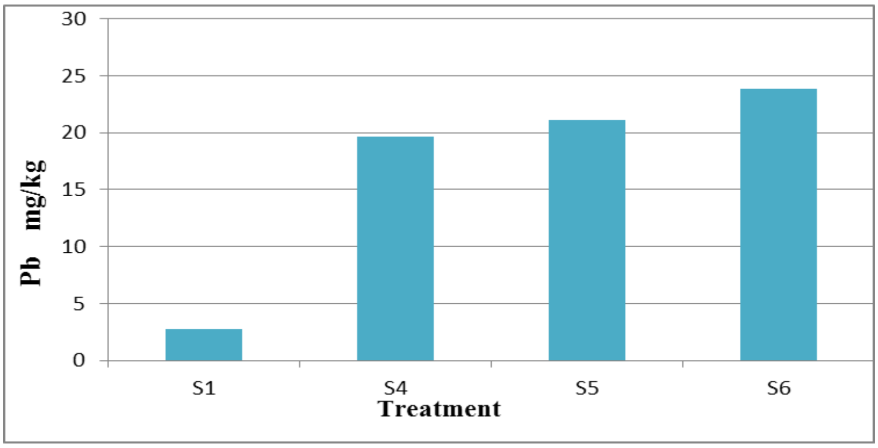

Figure 4.29: Influence of sludge treatments on Pb level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

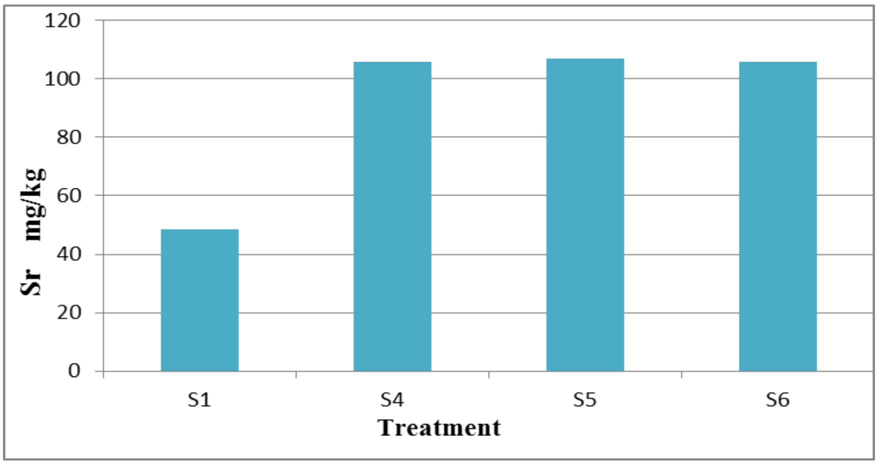

Figure 4.30: Influence of sludge treatments on Sr level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

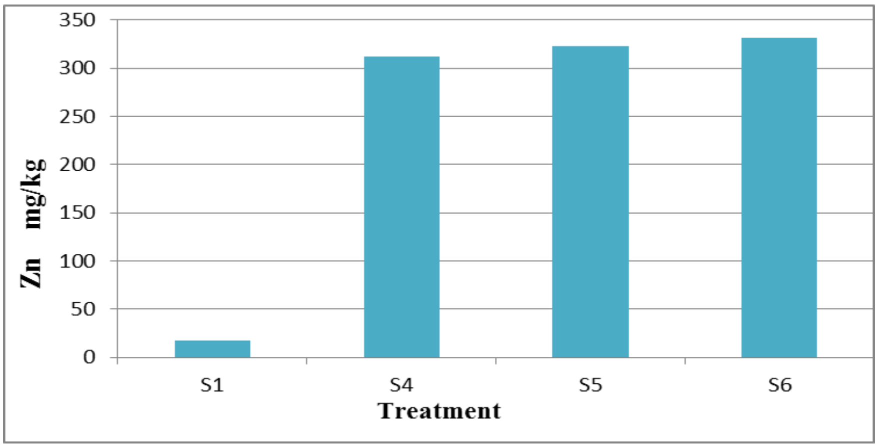

Figure 4.31: Influence of sludge treatments on Zn level of the soil planted with Corn.
S1 soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW, S6 Sludge: soil (30%) after planting irrigated with RWW

4.8 Plant analysis

4.8.1 Grains pathogenic E.coli

The contamination of fruits with *E.coli* bacteria was investigated, the purpose of this test was to evaluate the effect of sludge combine with RWW on the incidence of *E.coli* in corn that intended for use, as disease transmission may occur through direct physical contact of farmers with wastewater or through consumption of products irrigated with wastewater (FAO, 2003). The WHO standards for Faecal coliform in irrigation water are less than 1000 CFU/100 ml. Pathogens can accumulate in the soil and enter the food chain due to irrigation with sewage effluent. In our study, it was found that *E.coli* was absent in all of the treatments units, it is due to using dry sludge. Also this is due to the exposure of sludge to solar drying before usage, and the adoption of cultivation in pots; both are assumed to eliminate pathogens in the amended sludge. Similar results obtained with (Ogleni and Ozdemir, 2010).

4.8.2 Mineral content of major feed grains

Results obtained in Table 4.12 indicated that there were significance differences for treatment amended with sludge or not amended for P, K, and Na concentration. The concentrations of K and Na were lower for corn at the treatment not amended with sludge compared with the treatment amended with sludge, and the concentration of P was higher for corn at the treatment not amended with sludge compared with the treatment amended with sludge. Figures 4.32- 4.34 showed P, K and Na content in corn plant respectively.

Table 4.12 : Mineral content of major feed grains at the end of cultivation

		C1	C2	C3	C4
K	mg/kg	26000	26000	40000	40000
P	mg/kg	157	180	82	100
Na	mg/kg	32000	40000	48000	64000

C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

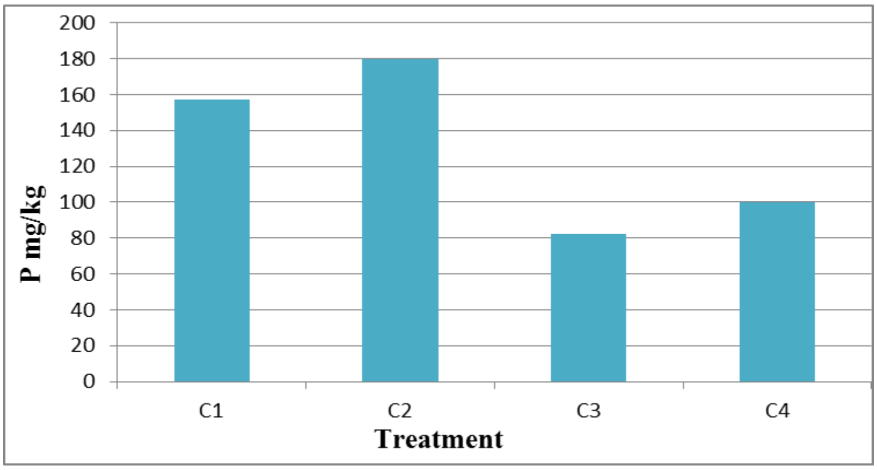

Figure 4.32: PO_4-P content in corn plant
C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

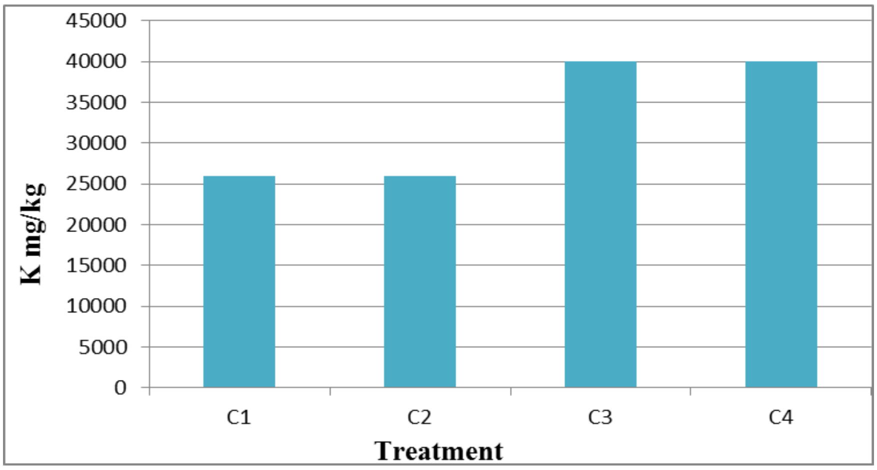

Figure 4.33: K content in corn plant
C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

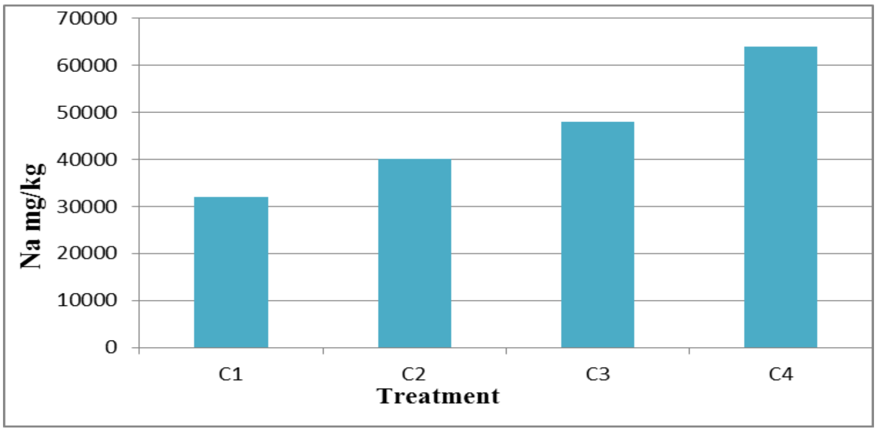

Figure 4.34: Na content in corn plant
C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

4.8.3 Leaves analysis

- **Chlorophyll content**

Chlorophylls are the most important pigments in plants due to their role in photosynthesis, and its deficiency leads to the yellowing of leaves, and this leads to reduction in the growth and plant yield (Khayatnezhad *et al*., 2012). 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). Chlorophyll content can also be used as an indicator to the nutritional status of some nutrients (Janali *et al*., 2008). Deficiency in Mg, Fe, and other nutrients such as Ca, Mn and Zn can reduce chlorophyll formation and results in leaf chlorosis (Shaahan *et al*. 1999).

Results obtained in Table 4.13 showed that treatments irrigated with RWW combined with sludge led significantly to higher chlorophyll content compared to non-combined with sludge treatments. Figure 4.35 showed Influence of sludge treatments on the chlorophyll level of corn plants.

Table 4.13: Mean of chlorophyll content

	C1	C2	C3	C4
chlorophyll content (mg/kg)	107	110	180	220

C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

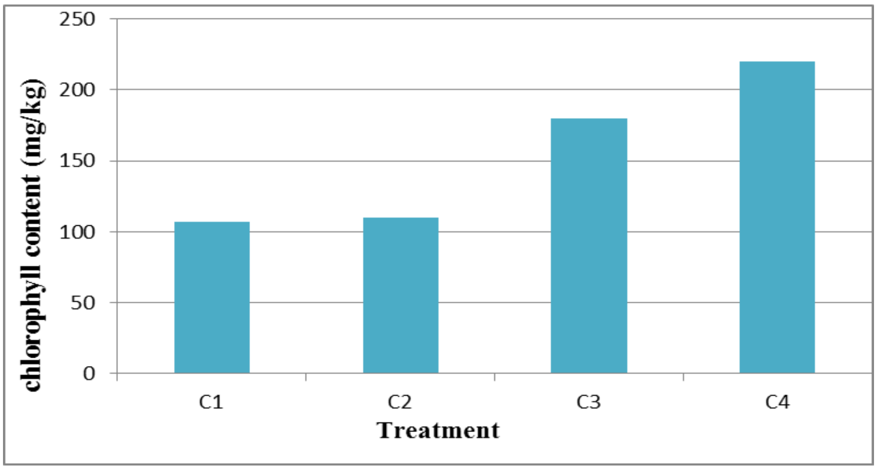

Figure 4.35: Influence of sludge treatments on the chlorophyll level of corn plants
C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

4.8.4 Crude protein in Grains

Fruit crude protein were measured at the end of cultivation, Results obtained in Table 4.14 showed that corn plants irrigated with RWW, combined with (30%) sludge, were significantly had the most crude protein compared to plants irrigated with brackish water without any addition of sludge or combined with sludge. There was significant difference ($p<0.05$) in crude protein content of corn plants irrigated with RWW compared with corn plants irrigated with BW. Figure 4.36 showed Mean of plants crude protein

Table 4.14: Mean of plants crude protein

	C1	C2	C3	C4
crude protein %	0.22	1.24	3.7	5.4

C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

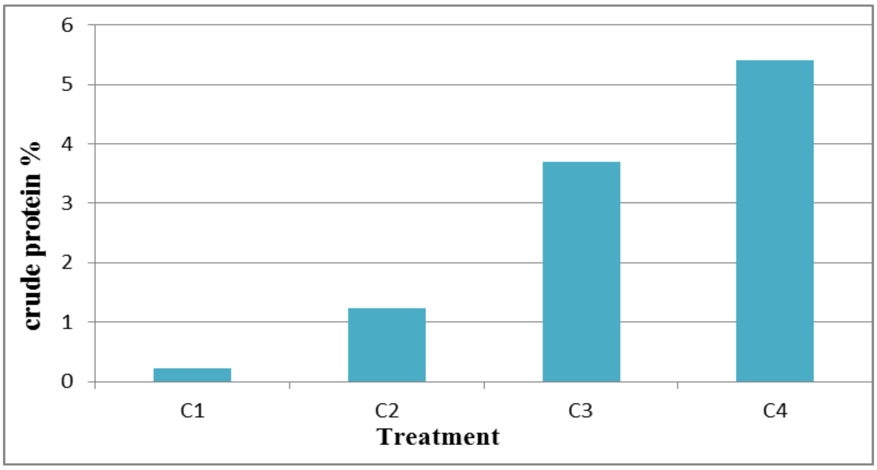

Figure 4.36: Crude protein content in grain corn
C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

4.8.5 Grains metals and heavy metals

The major obstacle of using sludge as fertilizer is the concern about heavy metals contamination which can move to plants and accumulate in the fruits (Amin and Sherif, 2001), so it is important to run this test, the following metals were tested: Silver, Aluminum, Arsenic, Barium, Cadmium, Cobalt, Chromium, Copper, Iron, Lithium, Manganese, Nickel, Lead, Strontium, Zinc.

Palestinian standard does not specify the concentrations of heavy metals in the corn used as human food or animal feed stuff, while the concentrations of heavy metals in treated wastewater used in agriculture have been identified. Also heavy metals in soil or sludge used in agriculture have been identified.

Results obtained in table 4.15 showed that fruits from soils mixed sludge are not contaminated with heavy metals. These results may allow for future use in agriculture. Results obtained in table 4.15 indicated that values of heavy metals such as (As, Ba, Cd, Cr, Co, Cu, Pb, Ni, Zn) in the treatment mixed with sludge or not, meet the recommended limits as total threshold limit concentration for hazardous toxic waste as illustrated by California Department of toxic Substance Control. The others of H.M were not illustrated in this reference guideline.

Sewage sludge may contain some potential hazardous compounds and elements (e.g. heavy metals). In this respect, (Li *et al*., 2005) reported that the concentrations of Cd and Zn increased in alfalfa upon the addition of sludge. Furthermore, (McBride, 2003) showed that adding sludge to soil increased Cd, Ni, Cu and Zn concentrations significantly in the edible portions of cultivated crops.

Table 4.15: The results of the metals and heavy metals for grains at the end of cultivation

Metals &H.M	Unit	C1	C2	C3	C4
Ag	mg/kg	0.03	0.02	0.82	0.38
Al	mg/kg	24	21	6	23
As	mg/kg	<0.02	<0.02	<0.02	<0.02
Ba	mg/kg	2.5	1.3	1.6	2.2
Cd	mg/kg	0.01	0.01	0.01	0.03
Co	mg/kg	0.02	0.02	0.01	0.01
Cr	mg/kg	0.5	0.3	0.4	0.2
Cu	mg/kg	2.9	2.0	0.8	0.7
Fe	mg/kg	14.6	11.5	9.8	10.3
Li	mg/kg	2.5	3.5	2.6	2.8
Mn	mg/kg	4.9	5.1	2.5	1.8
Ni	mg/kg	0.4	0.4	2.6	0.2
Pb	mg/kg	1.7	1.3	2.6	5.1
Sr	mg/kg	5.4	2.3	2.3	8.7
Zn	mg/kg	22	15	15	15

C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

- **Conclusion**
- **Recommendations**

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following conclusions can be drawn from this experiment:

1. RWW has major benefits since it can be an alternative irrigation source to brackish water resources.

2. RWW could be suitable for corn irrigation which moderate salt tolerant without causing significant health effect.

3. RWW effluent is suitable to use for corn irrigation without causing significant heavy metals pollution to soil and fruits.

4. The vegetative growth and yield of corn are enhanced by the application of treated wastewater combined with sludge.

5. According to the findings of this study, sludge might be considered as a suitable source of fertilizer, since it improves soil properties, thereby a lower cost is expected due to less fertilizer use.

6. Moreover, amending sludge in soil is considered as a valuable environment-friendly disposal technique.

7. In this experiment, the optimum sludge/soil mixture was 30% sludge amending with optimum results.

5.2 Recommendations

1. Sludge and RWW need quality monitoring to ensure safe effect on public and animal health.

2. It is recommended for using RWW outlet from GWWTP-Sheikh Ejleen in agricultural water demand in order to minimize the water problems specially for the crop production.

3. It is recommended for using the sludge from GWWTP as fertilizer for the planting of corn for different purposes.

4. It is recommended for corn crop production to use 30% sludge/soil mixture in order to have the maximum yield.

5. Research should be done on from similar projects on a larger scale and for a long period of time.

6. Further research studies are needed to explain sludge effect from agriculture ministry and health ministry for more public health.

7. Further research studies are needed to apply the sludge reuse on other crops

8. Workshops and presentations should be held to the public about the benefits and economic value of using treated wastewater for irrigation and sludge instead of fertilizers.

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ANNEXES

- **Study Data**
- **Tables of Results**
- **Documentation by Photos throughout the experimental process**

ANNEXES

A. Study Data

A.1) Plant height every two weeks

RWW	After 5 W	After 7W	After 9 W	After 11 W	After 13 W	BW	After 5 W	After 7W	After 9 W	After 11 W	After 13 W
0%	16	29	116	178	188	0%	11	28	68	150	182
10%	17	35	110	185	190	10%	14	36	110	190	195
20%	18	42	129	200	205	20%	17	37	121	200	203
30%	20	46	144	194	197	30%	19	49	144	187	197
40%	19	45	119	182	189	40%	16	34	98	150	183

A.2) Plant thickness every two weeks

RWW	After 5 W	After 7 W	After 9 W	After 11 W	After 13 W	BW	After 5 W	After 7 W	After 9 W	After 11 W	After 13 W
0%	1.2	1.6	2.3	2.8	3	0%	0.7	1	2.1	2.6	2.8
10%	1.8	2.3	2.6	3	3.1	10%	1.6	2.1	2.5	2.8	3.1
20%	1.8	2.5	3.2	3.4	3.4	20%	1.5	2.3	2.7	2.9	3.2
30%	1.9	3	3.3	3.6	3.6	30%	1.9	2.8	3.1	3.3	3.6
40%	1.5	3	3.2	3.4	3.4	40%	1.4	2.2	2.8	3.1	3.1

A.3) No. of Leaves every two weeks

RWW	After 5 W	After 7 W	After 9 W	After 11 W	After 13 W	BW	After 5 W	After 7 W	After 9 W	After 11 W	After 13 W
0%	6	8	10	9	9	0%	5	7	9	10	8
10%	6	11	9	10	10	10%	6	9	11	10	10
20%	7	10	10	10	10	20%	7	10	11	10	10
30%	7	10	10	9	10	30%	6	10	10	10	10
40%	6	8	11	10	10	40%	5	6	10	9	10

A.4) Weight of corn at the end of cultivation

RWW	Fresh wt (g)	Dry wt (g)	BW	Fresh wt (g)	Dry wt (g)
0%	283.6667	213.6667	0%	237.8333	177.6667
10%	274.5	241.5	10%	283.1667	237
20%	306.8333	272.6667	20%	288.1667	242.6667
30%	313.1667	275.5	30%	307.5	257.5
40%	300	253	40%	208.75	169.5

A.5) Yield of corn at the end of cultivation

yield (kg/ha)	BW	RWW
0%	21876	30422
10%	29755	31422
20%	29733	32744
30%	31656	31755
40%	24700	31755

B. Tables of results

B.1): The efficiency of GWWTP

Parameter	Inlet from GWWTP	Outlet from GWWTP	Removal %
pH	7.881±0.09	7.664±0.37	-
EC µS/cm	4860±45.8	4360±7.25	10.3
TDS mg/l	3020±15.3	2700±13.5	10.5
TSS mg/l	568±8.0	84±1.9	85.2
COD mg/l	945±10.3	225±5	76.2
BOD mg/l	444±4.26	85±1.7	81
TKN mg/l	78±5.4	66±3.9	15.4
FC (CFU/100ml)	$25*10^6$	$24*10^4$	99
TC (CFU/100ml)	$26*10^7$	$25*10^5$	99

B.2): Characteristics of irrigation water

Parameters	Unit	RWW Average	BW Average
Turbidity	NTU	0.45±0.3	0±0.0
Ph	-	7.622±0.13	6.841±0.08
Conductivity (EC)	µS/cm	4580±50.1	2900±5.4
TDS	mg/l	2840±25.2	1740±14.1
TSS	mg/l	7.1±2	0.7±0.01
HCO_3	mg/l	716±2.59	510±2.86
SO_4	mg/l	280±6.5	170±0.0
NO_3	mg/l	12.2±1.85	48±0.25
Cl	mg/l	1040±8.3	660±6.13
PO_4-P	mg/l	6.2±0.4	0±0.0
K^+	mg/l	30±0.3	15±0.11
Na^+	mg/l	520±3.5	320±2.5
Mg^{+2}	mg/l	114±1.7	84±1.0
Ca^{+2}	mg/l	136±2.2	107±1.5
SAR	meq/100ml	7.92±0.14	5.62±0.03
TKN	mg/l	46±0.45	14±0.0
NH_4-N	mg/l	40±0.7	9.3±0.7
COD	mg/l	170±5.2	62±1.63
BOD_5	mg/l	15±1.8	BDL
Surfactants	mg/l	1.3±0.8	BDL
TC	CFU/100ml	400±2.9	8±1.25
FC	CFU/100ml	120±1.85	0±0.47

BDL: below detection limit

B.3): Results of metals &heavy metals for irrigation water

Metals & Heavy metals	Unit	BW	RWW
Ag	µg/l	BDL	0.5
Al	µg/l	< 20	< 20
As	µg/l	< 20	< 20
Cd	µg/l	< 1	< 1
Co	µg/l	< 5	< 5
Cr	µg/l	< 5	< 5
Cu	µg/l	3.63±0.001	12.5±0.001
Fe	µg/l	17.4±	36.7±
Mn	µg/l	3.85±1.09	120±2.51
Ni	µg/l	< 5	5.24±0.002
Pb	µg/l	< 20	< 20
Si	µg/l	7920±1.5	13300±1.9
Sr	µg/l	3180±7.1	3820±7.9
Zn	µg/l	112±8.5	74.7±8.2

B.4): Characteristics of soil used in the experiment

Parameter		Soil
pH		7.269±0.80
EC	µS/ cm	295±70.3
Soil Texture		
Gravel	%	0.3±0.002
Sand	%	87±0.001
Silt	%	2.1±0.001
Clay	%	10.6±0.2
CEC	meq/100ml	2.65±0.5
TKN	mg/kg	66±0.005
NH_4-N	mg/kg	5.3±0.002
NO_3-N	mg/kg	9±1.53
Na(Available)	mg/kg	295±3.0
Na(soluble)	mg/kg	45±2.58
Ca(Available)	mg/kg	285±3.94
K(Available)	mg/kg	77.5±3.7
Mg(Available)	mg/kg	159±3.65
PO_4-P(Available)	mg/kg	10±1.85
$CaCO_3$	%	3.3±2.0
O.M	%	Nil
H.M		
Ag	mg/kg	0.1±5.5
Al	mg/kg	4725±1.6
As	mg/kg	<0.02
Ba	mg/kg	27.65±1.6
Cd	mg/kg	<0.005
Co	mg/kg	4±0.002
Cr	mg/kg	13±0.001
Cu	mg/kg	5±3.85

Parameter		Soil
Fe	mg/kg	5945±1.2
Li	mg/kg	2±0.5
Mn	mg/kg	149±1.65
Ni	mg/kg	6±0.003
Pb	mg/kg	3±3.62
Sr	mg/kg	49±0.002
Zn	mg/kg	18±0.4

B.5): Characteristics of sludge from GWWTP

Parameter		Sludge
pH		6.552±0.12
EC	µS/ cm	7160±70.8
CEC	meq/100ml	22.7±0.8
TKN	mg/kg	5440±0.04
NH_4-N	mg/kg	3594±0.40
Na(Exchangeable)	mg/kg	1000±1.53
Ca(Exchangeable)	mg/kg	1569±0.65
K(Exchangeable)	mg/kg	525±2.64
Mg(Exchangeable)	mg/kg	1623±3.4
PO_4-P	mg/kg	213±0.59
$CaCO_3$	%	4±8.4
NO_3-N	mg/kg	125±7.5
C/N		44/1±0.001
O.M	%	50±0.5
H.M		
Ag	mg/kg	11±0.4
Al	mg/kg	8215±95.9
As	mg/kg	8±0.15
Ba	mg/kg	233±1.9
Cd	mg/kg	2±0.01
Co	mg/kg	3±0.4
Cr	mg/kg	119±1.3
Cu	mg/kg	245±0.31
Fe	mg/kg	9755±77.2
Li	mg/kg	4±0.002
Mn	mg/kg	132±1.7
Ni	mg/kg	24±.71
Pb	mg/kg	92±0.1
Sr	mg/kg	369±0.74
Zn	mg/kg	1660±1.0

B.6): The results of physico-chemical properties for treatments of the experiment

Parameter		S1	S2	S3	S4	S5	S6
pH		7.269±0.80	7.507±0.7	7.536±0.5	6.799±0.40	7.037±0.54	7.017±0.41
EC	µS/ cm	295±70.3	730±87.2	883±70.5	4200±65.2	4220±70.2	4350±65.0
CEC	meq/100ml	2.65±0.5	2.82±0.4	2.89±0.5	8.00±0.35	8.55±0.5	8.79±1.2
TKN	mg/kg	66±0.005	69±0.006	71±0.2	1478±0.2	583±0.4	798±0.05
NH_4-N	mg/kg	5.3±0.002	52±0.1	60±0.3	803±0.5	531±0.002	656±0.004
NO_3-N	mg/kg	9±1.53	18±1.3	19±1.2	52±1.5	119±1.3	122±1.1
Na (Exchangeable)	mg/kg	250±0.05	400±0.06	450±0.05	750±0.3	500±0.3	525±0.05
Ca (Exchangeable)	mg/kg	245±7.4	260±8.0	265±6.5	680±5.0	778±5.5	796±8.1
K (Exchangeable)	mg/kg	70±0.5	90±0.6	90±0.35	200±0.4	150±0.32	163±0.5
Mg (Exchangeable)	mg/kg	150±0.36	155±0.5	160±0.9	491±1.2	514±1.1	528±0.85
PO_4-P	mg/kg	10±1.85	Nil	Nil	85±2.0	43±0.06	45±0.5
$CaCO_3$	mg/kg	3.3±2.0	3.3±1.89	3.3±1.6	5±2.1	5±2.0	5±1.9
O.M	%	Nil	Nil	Nil	12±0.0	11.7±0.0	11.9±0.0

S1 soil before planting (control), S2 soil after planting irrigated with BW, S3 soil after planting irrigated with RWW, S4 Sludge :soil (30%) before planting, S5 Sludge :soil (30%) after planting irrigated with BW, S6 Sludge :soil (30%) after planting irrigated with RWW

B.7): The results of metals and heavy metals for treatments of the experiment

Metals and H.M		S1	S4	S5	S6
Ag	mg/kg	0.1±5.5	1.8±6.0	1.6±0.4	1.8±1.2
Al	mg/kg	4725±1.6	5510±2.0	5550±2.2	5595±1.9
As	mg/kg	<0.02	<0.02	<0.02	<0.02
Ba	mg/kg	27.65±1.6	86±2.4	81±1.0	101±0.9
Cd	mg/kg	<0.005	<0.005	<0.005	<0.005
Co	mg/kg	4±0.002	3±0.4	3±0.4	3±0.3
Cr	mg/kg	13±0.001	31±1.2	33±1.4	23±0.9
Cu	mg/kg	5±3.85	43±0.3	39±0.163	44±0.20
Fe	mg/kg	5945±1.2	6325±77.2	6700±24.3	5185±36.7
Li	mg/kg	2±0.5	3±0.4	2±0.5	3±0.5
Mn	mg/kg	149±1.65	127±17.9	124±29.8	126±8.2
Ni	mg/kg	6±0.003	9±0.71	9±0.30	9±0.46
Pb	mg/kg	3±3.62	20±2.2	21±1.2	24±2.2
Sr	mg/kg	49±0.002	106±0.74	107±1.0	106±0.85
Zn	mg/kg	18±0.4	312±1.00	323±1.39	331±0.94

S1 Soil before planting (control), S4 Sludge: soil (30%) before planting
S5 Sludge: soil (30%) after planting irrigated with BW,
S6 Sludge: soil (30%) after planting irrigated with RWW

B.8): The results of the metals and heavy metals for grains at the end of cultivation

Metals and H.M	Unit	C1	C2	C3	C4
Ag	mg/kg	0.03±0.0	0.02±0.0	0.82±0.01	0.38±0.0
Al	mg/kg	24±6.5	21±5.1	6±2.1	23±1.8
As	mg/kg	<0.02	<0.02	<0.02	<0.02
Ba	mg/kg	2.5±0.0	1.3±0.0	1.6±0.0	2.2±0.002
Cd	mg/kg	0.01±0.0	0.01±0.0	0.01±0.01	0.03±0.0
Co	mg/kg	0.02±0.01	0.02±0.002	0.01±0.001	0.01±0.0
Cr	mg/kg	0.5±0.6	0.3±0.2	0.4±0.2	0.2±0.6
Cu	mg/kg	2.9±0.4	2.0±0.4	0.8±0.2	0.7±0.2
Fe	mg/kg	14.6±8.3	11.5±2.9	9.8±2.1	10.3±1.8
Li	mg/kg	2.5±0.5	3.5±0.4	2.6±0.3	2.8±0.25
Mn	mg/kg	4.9±1.8	5.1±0.7	2.5±0.7	1.8±1.5
Ni	mg/kg	0.4±0.75	0.4±0.12	2.6±0.10	0.2±0.12
Pb	mg/kg	1.7±0.0	1.3±0.0	2.6±0.0	5.1±0.0
Sr	mg/kg	5.4±0.07	2.3±0.2	2.3±0.14	8.7±0.16
Zn	mg/kg	22±4.9	15±3.9	15±3.9	15±3.9

C1 Corn sample from soil irrigated with BW,
C2 Corn sample from soil irrigated with RWW,
C3 Corn sample from Sludge: soil (30%) irrigated with BW,
C4 Corn sample from Sludge: soil (30%) irrigated with RWW

C. Documentation by Photos throughout the experimental process