An-Najah National University
Faculty of Graduate Studies

Enhanced Fodder Production Using Treated Wastewater from a Pilot Constructed Wetland System

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Dedication

To my father, who told me once "Riyad you should study hard",,,,,

To my mother, who prayed God to show me the right path,,,,,

To Ruba Alshomar, my love who gave me a sound soul and stand always with me to continue my study,,,,,,

To my great son's …

Acknowledgment

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الاقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

نمذجة تعزيز إنتاج الاعلاف باستخدام مياه الصرف الصحي المعالجة بواسطة نظام الأراضي الرطبة

Enhanced Fodder Production Using Treated Wastewater from a Pilot Constructed Wetland System

اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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List of Abbreviations

ARIJ	Applied Research Institute Jerusalem
BOD	Biological Oxygen Demand
BOD5	Biological Oxygen Demand in Wastewater
COD	Chemical Oxygen Demand
CWs	Constructed Wetlands
HFCWs	Horizontal Flow Constructed Wetlands
MACs	Mediterranean-African countries
MCM	Million cubic meters
MENA	the Middle-East and North Africa
MoA	Ministry of Agriculture
NARC	the National Agriculture Research Center
PCBS	Palestinian Center Bureau of Statistics
PMD	Palestinian Metrological Department
PMDP	Palestinian Market Development Program
PSI	the Palestinian Standards Institute
PWA	Palestinian Water Authority
TWW	Treated Wastewater
VFCWs	Vertical Flow Constructed Wetlands
MENA	Middle East and North Africa
WHO	World Health Organization
WUE	Water Use Efficiency

Enhanced Fodder Production Using Treated Wastewater from a Pilot Constructed Wetland System

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Abstract

Worldwide, constructed wetlands (CWs) are treatment units used for the treatment of diverse sources of wastewater. CWs are not widespread in Palestine due to variable topographies and scattered nature of rural communities. Even though it is a potential solution due to the nature of scattered villages and topography of the villages location. A hybrid system of horizontal and vertical surface flow constructed wetland unit is constructed in the National Agriculture Research Center (NARC) in Qabatya – Jenin. During the experiment, the treatment units were planted with reed plants. This experiment aimed to study the impact of reuse of resulted treated effluent on the growth and production of three different forage crops (barley, clover, and common vetch), and in the same time the efficiency of the treatment units planted with reeds.

The results show medium efficiency of the treatment unit in term of nitrogen removal (18%), but good efficiency in BOD and COD removal 77% and 78% consequence. The existing salts reduced by 42% in the treatment unit due to plants.

The irrigated crops showed an enhanced water use efficiency (WUE) compared to the rain fed. However, in the same time the plants irrigation

with treated wastewater show an increase in WUE for the three crops where it increases from 10.2 to 14.25 kg/ m^3 in barley, 9.9 to 22.8 kg/m^3 in vetch, and 31.46 to 49.83 kg/m^3 for clover. A WUE enhancement was not accompanied with a significant increase in the fresh weight biomass production, as reflected in the insignificant differences in the fresh weight bio mass production for the three crops under study. The result show that the crude protein content has decreased in both barley and clover, while it has increased in vetch, but even this reduced protein content is still in the accepted level of protein content

The results obtained on the use of CWs for domestic wastewater treatment could have high application potential in Palestinian rural communities. The widespread of this type could enhance the environmental conditions and an increase in the forage crop production using treated use in irrigation.

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Chapter One

Introduction

Chapter One

Introduction

Water is the base stone of life and the crucial condition of civilization existence. Since all human activities require the presence of water. The old civilizations were born near water bodies as the old Mesopotamia, and Nile rivers.

Now a days the demand on water is growing severely as World population continue to grow exponentially, In the past 20 years it jumped from 6 billion to reach around 7.8 billion in 2020. As a matter of fact, a tremendous increase happened in the last hundred years, where the world population was estimated to be 2 billion in 1930, 3 billion in 1960, 4 billion in 1974, 5 billion in 1987, and as stated earlier 6 billion in 2000 (world meter, 2020).

This huge growth in population is creating a continuous and growing pressure not only on water rather than the other natural resources around the world; The demand is growing continuously on food and energy. while the food production is not growing in the same pattern. This will lead to widening the gap between the demand and production of food.

Currently the agricultural sector is the main water consumer, as it is estimated to consume around 70% in average of the fresh water resources (World Bank, 2020), while it is estimated to be around 65% in USA according to the Center of Disease Control (CDC) (2016).

Palestine as the remaining countries is facing the continuous population growth rate with a relatively high ratio (2.5% as estimated in 2018) (PCBS, 2019a). The Palestinian population is estimated to be around 5.05 million (PCBS, 2020), among them West bank 3.05 million. This population need food supply, clean water. Therefore, the pressure on water resources is increase.

Palestine as one of MENA region which is arid to semi-arid region. This location together with the climatic changes, and the requirements of food supply, and fibers. increase the demand of all sectors on water.

The dilemma of water supply is sharply affected by the complex political status, where the Israeli occupation control more than 85% of the water resources, and the Palestinians have only an access to less than 15% (Salameh, 2020), The Total available water for all purposes is estimated to be (375 MCM) (PCBS, 2019b), or in other words, the percapita is estimated to be 88 L/day.

Another aspect of the problem in Palestine is an environmental aspect resulting from the domestic use of water. The produced wastewater from the different life activities require treatment to prevent pollution.

Currently there is limited functional treatment plants in the cities of Ramallah, Nablus, Jenin, and Jericho in the cities of West Bank, even though there are plans to construct new plants in Hebron, Tubas, Nablus east. But the inhabitants distribution obstruct the implementation of central treatment plants. In Palestine the population are located in 557 inhabitants, among them 524 are located in West Bank as estimated in 2015 (WAFA, 2015).

Therefore, the construction of medium to small treatment plants become more rational rather than the construction of central plants. These plants require energy for operation, which increase the competition on energy. Due to the scattered towns and villages the construction of medium and small efficient treatment plants become more rational for the Palestinian communities. These plants should be low energy consuming also to guarantee the sustainability of operation.

On the other hand of the problem, the Israeli occupation is currently taking fees from the Palestinians on the produced wastewater, and in the same time it is using these water quantities after treatment.

Alhaj Hussein and Nofal (2015) studied the agricultural water efficiency in Palestine, they mentioned in their report that agricultural sector in Palestine since it is the largest water consuming sector (the agricultural share of water is estimated to be 45%), This quantity is not satisfying the estimated required quantities for agriculture. This complicated status is pushing toward investigating the possibility of using new non-conventional water resources in irrigation, in order to save more freshwater for domestic use in hand, and on the other hand reduces the treated wastewater effluent in the wadies for both environmental purposes (reducing pollution) and economical (reducing the paid fees to the occupation).

The use of treated wastewater in irrigation is a worldwide practice, and many studies were published on it. In addition, a Palestinian obligatory technical regulation on the use of treated wastewater in agriculture is issued (TR 34 – 2012). (PSI, 2012)

Among the efficient low energy cost treatment plants is the constructed wetland treatment plants, where in this method the United States Environment Protection Agency (EPA) is defined it as " natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality " (EPA, 2015), This method of treatment is low cost and easy to maintain and operate, therefore it is more sustainable in poor rural communities.

Previous studies treated wastewater in Palestine concentrated on two aspects mainly:

- The technical aspect of wastewater treatment.

- The crop production when irrigated with treated wastewater compared to that irrigated with fresh water. These studies took the different crop production parameters.

The main objectives of this research study are:

- To evaluate the efficiency of CWs for the treatment of domestic wastewater.

- To study the impact of treated water from CWs on fodders production and compare with a reference suing freshwater source.

This study is taking into account the two aspects, where it compares the produced effluent and the level of treatment corresponding to the Palestinian regulations, the production of the crops, in addition to the impact of utilizing the effluent coming from constructed wetlands with that of fresh water on the nutritional value of the crops.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 The Reuse of Treated Wastewater in Irrigation

The reuse of Treated wastewater (TWW) is well known around the world. This is due to the water scarcity and the need to meet the requirements. The conventional water resources are becoming increasingly scarce. Climate change and pollution caused by anthropogenic activities have considerably reduced the available quantity of water (Mahjoub et al, 2016). (Hettiarachchi and Ardakanian, 2016) confirmed the need to shift toward utilization of treated wastewater in agriculture due to the increasing water shortage and other factors like energy and fertilization costs. This is confirmed by (El-Gamal and Housian, 2016) where they see that the reuse of treated wastewater is the solution for the increase of water demand in Egypt to meet the requirements. (Barbagallo et al, 2012) not only confirmed the need to reuse treated wastewater in irrigation, but they insisted on the need to have integrated approach on water management . Similar to this is found in (Dario Frascari et al, 2018) where they analyzed the water status in three Mediterranean countries, they proposed that". The analysis of the current situation of wastewater treatment, irrigation, and water management in Mediterranean-African countries (MACs) and of the research projects targeted to these countries indicates the need for 1) an enhanced capacity to analyze water stress, 2) the development of water management strategies capable of including wastewater reuse, and 3) development of locally adapted water treatment and irrigation technologies". (Aiello et al, 2013) assessed the potential risk of the reuse of treated wastewater in Italy, they found that the restrictive approach which is followed for TWW reuse in agriculture is inhibiting the reuse and has led to create difficulties in promoting this practice.

In their study Castorina et al (2015) assessed the potential environmental impact on using constructed wetlands effluent, they irrigated vegetables crop in their experiment, they found that using this water quality is not risky.; their results on irrigating some vegetables as lettuce, zucchini and eggplants, they found that the resulted crops risk is correspond to WHO (2006) standards. (Ines et al, 2017) stated that the TWW is safe, their results show that the risk parameters are under those recommended by WHO. However, the risk could be reduced by the farm measures and management according to (Mahjoub et al, 2016) they said" Farm-based measures can play an important role in reducing the risks related to wastewater reuse, especially in countries where treatment is rather decentralized or with low efficiency". Moreover, the regulations in Palestine it is prohibited to use treated wastewater in irrigation of vegetables crops.

2.2 Reuse of TWW for forages irrigation

Livestock production is an important constitute of the food security. In Palestine 12.8% of total agricultural holdings are livestock holdings it is estimated that this percentage is equivalent to 14,241 family (MoA, 2016). Globaly over than 33% of crop lands are dedicated for growing fodders, (Waitrose & Partners, 2018), it is estimated that 26% of earth’s ice-free land is dedicated for grazing(Waitrose & Partners, 2018). The green fodder production require large quantities of water, 29% of the water used in agriculture is used in livestock production, the largest share of this quantity goes to animal feed cultivation (Al-Karaki, 2011). For this in arid and semi-arid countries, it is preferred to use non – conventional water resources as treated wastewater. In Jordan the use of TWW was largely limited to irrigation of forages and forestry (Nsheiwat, 2007). (Al-Karaki, 2011) confirmed that the reuse of treated wastewater is required to achieve suitable and good quality green fodders in Jordan and other countries in the region.

In Their study (Lahlou et al, 2021) review the studies published on the reuse of treated wastewater for animal feeding growing crops. They gatherd 73 documents published in the period 1989 up to 2020. The result of these documents analysis is that the most investigated crop is rice followed by maize.

(Ines et al, 2017) stated that the TWW can be used for irrigation of fodder and it is a valid alternative of fresh water for irrigation of fodder species. (Al-Rifaee, 2014) presented that in Jordan the strategy is to conduct research's on the production of fodders irrigated with non – traditional water resources as treated wastewater. In his review of the Jordanian experience, he confirmed that TWW could supply high percentage of the required macro nutrient (Al-Rifaee, 2014). (Lahlou et al, 2021) see that treated wastewater is an opportunity to reduce the stress on fresh water in addition to its high content of nutrients that can be a substitute to the mineral fertilizers. (Lahlou et al, 2020) reported that diluted wastewater, or treated wastewater has a higher nutrient concentration than conventional water resources.

The reuse of treated wastewater participate not only on reducing the stress on fresh water, but in addition, it contribute to increase the forages production (Alkhamisi, 2014), he reported that yield of sorghum and maize was increased by 30%, barely increase was 43% to the production under fresh water (Alkhamisi, 2014).

2.3 Reuse of treated wastewater in Palestine

Palestine as one of the MENA countries is facing severe and continuous water scarcity (Arafat, 2015; Salameh, 2020). Treated wastewater is considered an invaluable additional source of water for agricultural and landscape irrigation. The reuse of treated wastewater reduces the amount of freshwater used for irrigation and the amount of wastewater discharged in the environment, creating a significant potential for health, environment and economic benefits, especially in the Middle-East and North Africa (MENA) region (Nassar et al., 2015; Shomar and Dare, 2015), Therefore, treated wastewater reuse can significantly alleviate the water scarcity in Palestine and fit to the complexity of the geopolitical context (Al-Khatib et al, 2017).

According to Yaqob et al (2015) the reuse of TWW have high potential due to different prospective, among these is the absence of other alternatives, and the fact that raw wastewater is an environment problem, (World Bank, 2018) estimated that 25 MCM of wastewater flow to the environment each year, 85 percent of this quantity is discharged beyond the green line(1948 border), and that Israel has charged the Palestinian 31 Million US Dollars as a charge for the necessary treatment (World Bank, 2018). (Mizyed, 2012) mentioned that reuse of treated wastewater is scattered and still in pilots.

The estimated volume of generated wastewater is around 15 MCM per year in the West Bank, in which around 10.3 MCM/year is totally or partially treated through six centralized wastewater treatment plants in addition to 16 collective wastewater treatment plants (ARIJ, 2015; PWA, 2012). As a matter of fact, the results which are achieved is limited when compared to the investments in the field of reuse of treated wastewater (Abu Madi et al, 2009) (ARIJ, 2015) reported that the volume of reuse in Palestine is close to zero, and most of the effluent is discharged into valleys.

MoA implemented the first large scale project in 2015 in Jenin Governorate (ANERA project) to reuse the effluent coming from the aerated lagoons in the primary treatment plant in Jenin city to irrigate more than 400 dunums. and currently there is another project in the study phase (Nablus west project). The remaining are scattered in villages were treatment plants is implemented such as Beit Dagan, Anza, Misilya, Attil, villages.

Palestinian Guidlines for treated waste water reuse in Agriculture

In 2003 the Palestinian Standards Institute (PSI) issued the first standards regarding the reuse of treated wastewater in agriculture named The Safe Use of the Treated Wastewater in Agriculture and coded as, PSI 742 – 2003 (PSI, 2003), in order to regulate the use of treated wastewater in safe way for human and environment. In which it determined the specifications of treated wastewater accepted to be reused in irrigation and the number of barriers for each crop. Where it classified treated wastewater into excellent, very good, good, poor qualities.

These specifications prohibited the reuse of treated wastewater in irrigating vegetables crops. However, these standards are guidance and doesn't have legal enforcement. In order to overcome this issue, an obligatory regulations have been issued by the Cabinet in 2012 named Obligatory Technical Specifications for Treated Wastewater Reuse in Agriculture (PSI, 2012) (Annex 1, table 2.1) coded as PSI TR 34 – 2012. This document of the technical regulations also classified the water following the quality into four groups as following:

- Grade A High quality BOD5 20 mg/l at most, TSS 30 mg/l, NO3-N 20 mg/l, at most and Feacal coliforms at most 200 per 100 ml.
- Grade B Good quality BOD_5 20 mg/l at most, TSS 30 mg/l, NO3-N 20 mg/l, at most and Feacal coliforms at most 1000 per 100 ml.

- Grade C Average quality BOD_5 40 mg/l at most, TSS 50 mg/l, NO3-N 30 mg/l, at most and Feacal coliforms at most 1000 per 100 ml.

- Grade D Low quality BOD5 60 mg/l at most, TSS 90 mg/l, NO3-N 40 mg/l, at most and Feacal coliforms at most 1000 per 100 ml.

Table (2.1): The main quality parameters in TR 34 – 2012

	Parameter (mg/L unless otherwise stated)							
Grade Quality	pH	BOD_5	COD	TSS	TDS	Total-N	NO3-N	F-Coliforms cfu/100m
High quality A	9-6	20	50	30	1200	30	20	200
Good quality B	9-6	20	50	30	1500	30	20	1000
Medium quality C	9-6	40	100	50	1500	45	30	1000
Low quality D	9-6	60	150	90	1500	60	40	1000

It determined the kind and number of barriers required for each crop groups. But The most important is that it mentioned that the reuse should follow the Palestinian standards, and in the same time it asked to update any regulations to agree with these standards.

According to the obligatory technical regulations it is prohibited to use treated wastewater in the following case:

- The reuse for animal drinking.

- Irrigation of vegetables despite the kind of vegetables.

- The direct injection to the groundwater.

- The use for aquaculture.

For that, the process of updating PSI 742 – 2003 started by the participation of public and private sector. Annex 1 show the specifications according to the final draft of the new standards, which agree with TR 34 – 2012. This draft was issued in 2016 and not officially approved yet.

According to TR 34 – 2012 and the proposed standards the barriers it is not required for high, good, and medium quality effluent, while it is prohibited to use low quality treated wastewater in irrigation in case of green fodders. For the dry fodders the obligatory regulation allows the use of low quality treated wastewater in irrigation.

Table (2.1) presents the required barriers for different crops according to the obligatory technical regulations.

Table (2.2): The required barriers for different crops according to the obligatory technical regulations TR 34 – 2012

Crop/ use	**High quality A**	**Good quality B**	**Medium Quality C**	**Low quality D**
Gardens, Sports fields, parks	0	Not allowed	Not allowed	Not allowed
Ground water recharge by infiltration Discharge into seas at least 500 m in sea, green fodders	0	0	0	Not allowed
Crops for seed s, dry fodders, forests not used as parks, industrial crops and grains	0	0	0	0
Corn	0	2	2	4
Citrus	0	3	3	4
Citrus irrigated with drip, nuts (almond, walnuts, pistachio, pine nuts), stone fruits (peaches, cherries, apricots), apple, tropical fruits (mangos, coco), grapes, cactus, palms, olives	0	2	2	3
Vegetables	**Not allowed**	**Not allowed**	**Not allowed**	**Not allowed**

In the Palestinian regulations, the level of heavy metals in forages or fodders is not existing, however, the Permissible limits of heavy metals in soil and plants as recommended by WHO (1996) are presented in table (2.3).

Table (2.3): The Permissible limits of heavy metals in soil and plants

Elements	*Target value of soil (mg/kg)	***Permissible value of plant (mg/kg)
Cd	0.8	0.02
Zn	50	0.6
Cu	36	10
Cr	100	1.3
Pb	85	2
Ni	35	10

The regulations proposed potential crops to be irrigated with TWW are mainly:

- Fodder crops.
- Tropical fruits.
- Stone fruit.
- Grapes and nuts.

2.4 Constructed Wetlands

Constructed Wetlands (CWs) as a treatment process is well known and practiced around the world. (Konnerup et al, 2009) recommended to use constructed wetlands (CWs) in the developing countries especially in the countries of warm climates, they consider CWs a good solution in these countries for treating wastewaters.

Kaur, (2016) found that constructed wetlands are more saving energy by half, his results show that the system is consist of 54.24% of renewable energy resources, while the remaining (non renewable) is for construction, maintenance, and electricity.

Constructed wetlands for water treatment are complex, integrated systems of water, plants, animals, microorganisms, and the environment (Siegrist, 2017), it is an artificial system with engineering designed in order to treat wastewater. (Zamora et al, 2019) define CWs as "Constructed wetlands (CWs) are engineered systems that have been designed and constructed to enhance the natural processes for wastewater treatment", which mean that the same processes in natural wet land is occurred in more controlled system .This kind of systems had started in Germany in 1950s according to (Jan Vymazal, 2010). The constructed wetlands have evolved with the evolution of technology, to be of various types of wastewater. For this kind of treatment techniques, there are many calcifications; the life form of macrophyte, systems with free-floating, floating leaved, the level of root merging, the wetland hydrology (free or sub surface) (Jan Vymazal, 2010), CWs could be classified according to the flow direction (horizontal and vertical). (Asghar et al, 2013) these two common systems are the most spread, but vertical flow (VF CWs) systems are getting more popular at present (Asghar et al, 2013).

Due to the low requirements of maintenance and operating costs, and high efficiency CWs systems has been gaining interest in rural and urban areas.

by physical, chemical, and biological processes that natural wetlands have, which are also called planet kidneys (Mitsch, and Gosselink, 2015). In the same time CWs have high environmental impact, where when compared to the conventional treatment plants the potential environmental impact of CWs is between 2 and 5 times higher (Garfí et al,2017).

CWs have number of advantages among them is water purification, water storage, carbon and macro micro nutrient recycling (Abou-Elela, 2017). Moreover different types of CWs could be attached to increase the efficiency of treatment especially for nitrogen (Jan Vymazal,2010). Hybrid systems comprise most frequently vertical (VF) and horizontal (HF) systems arranged in a staged manner.

Dong et al (2015) found that enhancing the ventilation by using air blowing fan enhanced the purification significantly, they confirmed that TN treatment efficiency increased rapidly by 16.6% in units use the air blower , with an average removal efficiencies of BOD, SS, TN, and TP in the effluent were 98.8, 97.4, 58.0, and 48.3% in the CW using an electric fan air blower. Therefore, to increase the removal of nutrients in CWs, an improved ventilation system, providing ventilation via an electric fan air blower with the renewable energy, is recommended.

Calheiros et al (2007) studied the most common kinds of plants used in CWs in Europe, they stated that most used plants in wetlands are Phragmites australis. However, other species such as Typha spp., Scirpus spp., and Phalaris arundinacea are also used in wetlands. (Ashgar et al , 2013) assessed the impact of Cyperus alternifolius on the CWs efficiency, they found that the treatment efficiency enhanced.

Constructed wetlands with free water surface (FWS CWs) are not used as much as the HF or VF systems despite being one of the oldest designs in Europe".

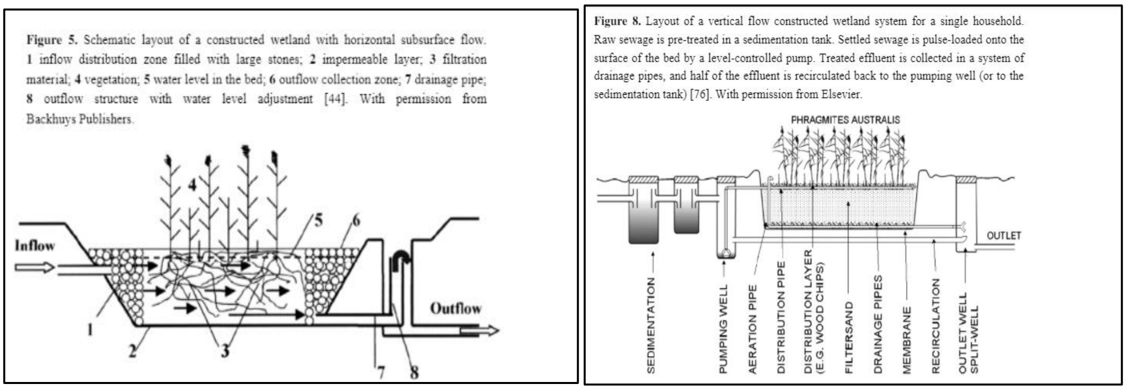


Figure (1): CW with its main component in HF and VF (Jan Vymazal, 2010).

2.5 Constructed wetlands in Palestine

In Palestine the constructed wetland technology is considered new technology and yet it is not spreaded on wide scale ecenthough it has started in 2003 – 2004, and is used successfully in few small villages (Majd Masoud, 2011). However, there are some problems which are mainly operational ones. These systems were done as experiments in three villages to show if the system is applicable. These villages are Bidya, Kharas and Bani Zaid. All of these systems were implemented in the period between (2000-2004) (Majd Masoud, 2011). (Al-Sa`ed, 2018) summarized the existing CWs in Palestine with the establishment year:

Table (2.4): The existing constructed wetlands units in Palestine

Location	Year of establishment
Nuba in Hebron	2002
Kharras in Hebron	2003
Bani Zaid/Deir Ghassane	2004
Hajja, Sarrah & Biddya villages	2004
Misilya town	2017
Pilot systems Several pilot scale Greywater treatment	ARIJ 2010

In addition to those implemented in Birzeit University and in NARC. (Raed Alary, 2019) assessed the performance of four CWs units implemented in Sarra, Misillya, Hajjah, and Beit Hasan. (Majd Masoud, 2011), (Abed, 2012), (Mahran, 2015), (Raed Alary, 2019), Analyzed the performance of different direction flow constructed wetlands in Palestine. In their study they concentrated on the performance aspects as Nitrogen removal, BOD, TSS,… etc. All of them recommended CWs as a potential non expensive treatment method, however, non of these studies has analyzed the impact of effluent on soil nor on plants. The studies were focusing on the performance of the treatment units itself.

2.6 Forages and fodders in Palestine

Livestock sector is one of the main pillars of the Palestinian sgricture, as stated earlier 12.8% of total agricultural holdings are livestock holdings (MoA, 2016). In the same time, it is estimated that around 70% of the costs in the livestock production is for animal feeding as estimated by the Palestinian Market Development Program (PMDP) (2015). The Palestinian Ministry of Agriculture gives more detailed figures, where we find that 75-85% of total milk production costs, and 55-65% of the total costs are for feeding (MoA, 2016). Most of the animal feed in Palestine is imported mainly from Israel since More than 95% of wheat feed and 85% of protein feed is imported from Israel to feed sheep and goats. Furthermore, most of feed and coarse fodder (high-cellulose feed, such as hay, straw and grass) to feed dairy cattle is imported from Israel (MoA, 2016). The planted area of field crops in Palestine forms 26.5% of the agricultural area (241 935 dunums) among them (223905 dunums) in West Bank (PCBS, 2011).

The planted forages are presented in (table 2.5). These crops only form 9.4% of the total field crops planted in Palestine. All of these crops are rainfed crops and not irrigated. An exception is found in Jenin area where, around 400 dunums are planted with alfalfa irrigated with treated wastewater through a project for reuse of treated wastewater implemented by ANERA and MoA in 2015

Table (2.5): Area of forage crops planted in Palestine as in the agricultural census

Crop	Area in dunum
Wheat	13783
Sorghum	126
Barley	5069
vetch and Sern	2569
clover	1267

Source: collective results from (PCBS, 2011).

Recently there are an attempts to introduce new forage crops as panicum (genus Panicum) through research projects that is still ongoing with cooperation between NARC and AN – Najah University.

2.7 Clover

Picture (2.1): Clover.

Source: https://www.gurneys.com.

Clovers (Trifolium spp.) are well known to the animal raising farmers, it is an important component for improving the nutritive value of forages. Trifolium is one of the two most important legume genera for forage–livestock systems because of the diversity of available species, wide adaptation to different soils and climates, and general ability to reseed (Van Keuren and Hoveland, 1985). (Evers, 2011) reported that annual, cool-season clover species are used more readily than perennials because of their persistence and ability to complement warm-season perennial grass pastures. In addition to its value, clovers biologically fix atmospheric N, have an inherently greater nutritive value than warm-season grasses, and help the sward outcompete undesirable winter weed species (Hoveland and Evers, 1995).

Research indicates that cool-season legumes have an optimum germination temperature below 20°C approximately (Butler et al, 2014), while (Baxter et al, 2019) reported that". The germination at approximately 1.0°C increments and tested cultivars maintained 80% + germination from 4.9 to 28.2°C, on average".

Darweesh (2018) reported that "Egyptian clover can produce high forage under irrigation. It’s a heavy Nitrogen (N) producer and the least winter hardy of all true annual clovers. This makes it an ideal winter cover before all summer crops nitrogen-demanding crops. Berseem clover draws down soil N early in its cycle". "A Berseem hay crop can have high yield and quality potential. Berseem is a high water use forage crop because it generates a substantial amount of above ground biomass, and has a longer growing season comparing with other irrigated crops". Therefore clover have relatively high eater use efficiency (WUE). (Din et al, 2014) found that the seed yield for Egyptian clover was severely reduced about 47% when the irrigation was decreased from ten to four watering events.

Leghari et al. (2018) studied the irrigation interval impact, they have different treatments;12 irrigations with 15 days interval, 8 irrigations with 18 days interval and 4 irrigations with 21 days interval and found that they reported that 12 irrigations with 15 days interval produced significant green fodder and seed yield.

Kassab et al. (2012) found that average production ranges between 7.8 ton/dunum and 8.2 ton/ dunum for dry, semi-dry and the common cultivation, with WUE ranging between 15.52, and 20.06kg/ m^3.

Clover is a Legume forage crop of high nutritional value (Feedipedia,2013a), the nutritional value of clover is presented in table (2.6).

Table (2.6): The nutritional content of clover (Trifolium alexandrinum L)

Parameter	Unit	Avg
Dry matter	% as fed	12.5
Crude protein	% DM	19.9
Crude fibre	% DM	22.3
NDF	% DM	44.8
ADF	% DM	27.6
Lignin	% DM	5.1
Ether extract	% DM	3.2
Ash	% DM	15.4
Water-soluble carbohydrates	% DM	5.1
Gross energy	MJ/kg DM	17.4

2.8 Vetch

Picture (2.2): Vetch.

Source https://www.bestforage.com/product/hairy-vetch/.

Vetch (Vicia sativa) is a well-known legume fodder crop. Hairy vetch fixes large amounts of nitrogen (N) that help meet N needs of the following crop, protects soil from erosion, helps improve soil tilth, and provides weed control during its vigorous growth in the spring and when left as a dead mulch at the soil surface (Duiker, 2010).

Grains Research and Development Corporation (GRDC) (2017) reported that "Vetch High-protein forage or grain legume for livestock suits: Mediterranean or cool temperate environments; Moderate to high-fertility soils with good drainage and low frost potential at flowering. Vetech require around 250 mm / season of water according to (GRDC, 2017).

Ashton (2013) mentioned that: "Dairy farmers report vetch hay or silage can increase milk production per cow by more than 12% compared with grass or cereal hay". (GRDC, 2017) confirmed that vetch increased the soil nitrogen content they puplished th "Results from the Australian National Vetch Breeding Program (ANVBP) across five sites over three years have shown increases in soil nitrogen after vetch was grown for grain (56 kg/ha), hay (94 kg/ha) and green manure (154 kg/ha)".

Vetch is a Legume forage crop of high nutritional value (Feedipedia,2013b), the nutritional value of this crop is presented in table (2.7).

Table (2.7): The nutritional value of vetch

	Unit	**Avg**
Dry matter	% as fed	19.3
Crude protein	% DM	23
Crude fibre	% DM	25.4
NDF	% DM	36.7
ADF	% DM	28.5
Lignin	% DM	6.1
Ether extract	% DM	2.5
Ash	% DM	9.8
Gross energy	MJ/kg DM	18.6

In Palestine both crops (clover and vetch) are rainfed planted and rarely to be planted under irrigation. As the agriculture statistics show, where the area planted with vetch is estimated to be around 1656 dunums and clover is 1267 dunums. according to the agricultural census 2009/2010. (PCBS, 2011).

2.9 Barley

Barley (Hordeum vulgare L.) is a cearial crop and considered among the most important grains in the world. The global production is estimated to be 140 million tonnes while the estimated area is about 550 million dunums (Meixue Zhou, 2010). While (Ulziijargal et al, 2019) estimated the global production of 145.96 million metric tons in the 2016 to 2017.

Barley is a very old crop, it was planted in Nile area 17,000 years ago (Patricia et al, 2019), it contain a huge diversity and a large number of varieties , it is fast growing, cool season and annual crop. It is used for human consumption and also known as animal feeding crop, as a forage or can be used as a cover crop to improve soil quality. (Waly et al, 2015).

The protein content, is strongly affected by environmental conditions and changes from 10 % to 15%.(Akar et al, 2004).

Meng et al. (2015) indicated that barley is rich in minerals such as Zn, Fe and Ca. (Anderson, 1985) estiated dry matter production of grazed barley at tillering stage to be 20 – 100 kg/ dunum, as a result of seeding rate and N fertilization.

Barley as a silage OECD (2004) published that the whole plant silage is rich in fiber and low in protein content, and could be used in extensive cattle production. As a forage barley is either to be sown as the sole crop or sown in mixture with a legumes such as vetch, pea, berseem or Persian clover (Eskandari et al, 2009) who mentioned thar intercropping with leguemes enhance the protein content copared to cerial alone. Acording to (McLellan, 2011) the dry matter production may reach 3 to 8 t DM/ha and the crop should be cut 30 – 40 cm hight and after each cut fertilizer should be applied. By this it sould be cut 2 – 3 times. (Akar et al, 2004) puplished that dry matter is around 12% of humidity.

Table (2.8): The nutritional value of barley as a green forgae (Feedipedia, 2013c)

Main analysis	Unit	Avg
Dry matter	% as fed	25
Crude protein	% DM	11
Crude fibre	% DM	28.1
NDF	% DM	57.6
ADF	% DM	32.7
Lignin	% DM	2.4
Ether extract	% DM	3.8
Ash	% DM	11.5
Starch (enzymatic)	% DM	8
Water-soluble carbohydrates	% DM	7.8

In Palestine barley crop is planted mainly for grain and the straw is consumed as dry hay.

2.10 Water Use Efficiency

Water is considered the major input of crop production. (Geerts and Raes ,2009) studied and investigated the concept of water productivity, and the effect on production and water consumption. They connected the increase in demand on water to the food production, which is related to the increase of ET. This make the accurate calculation of ET a crucial factor governing the water management (Tyagi et al, 2000).

The water use efficiency is a term connecting the production of crop to the water consumption (Barbour et al, 1995; Tonmukayakul, 2009; Darweesh, 2018). (Lazaridou and Koutroubas, 2004) studied the effect of drought on clover production, where they found that the production was reduced by 67% (two third) in clover. (Tonmukayakul, 2009) estimated different cultivar of clover to have WUE of around 21 kg/m^3. While studies on vitch water use efficiency is not available, but it worth to consider that vitch is a ligueme crop, therefore, it could have close WUE to clover. (Morell et al, 2011) estimated to have a WUE of 11 – 23 kg/m^3 in barley.

Chapter Three

Material and Methods

Chapter Three

Material and Methods

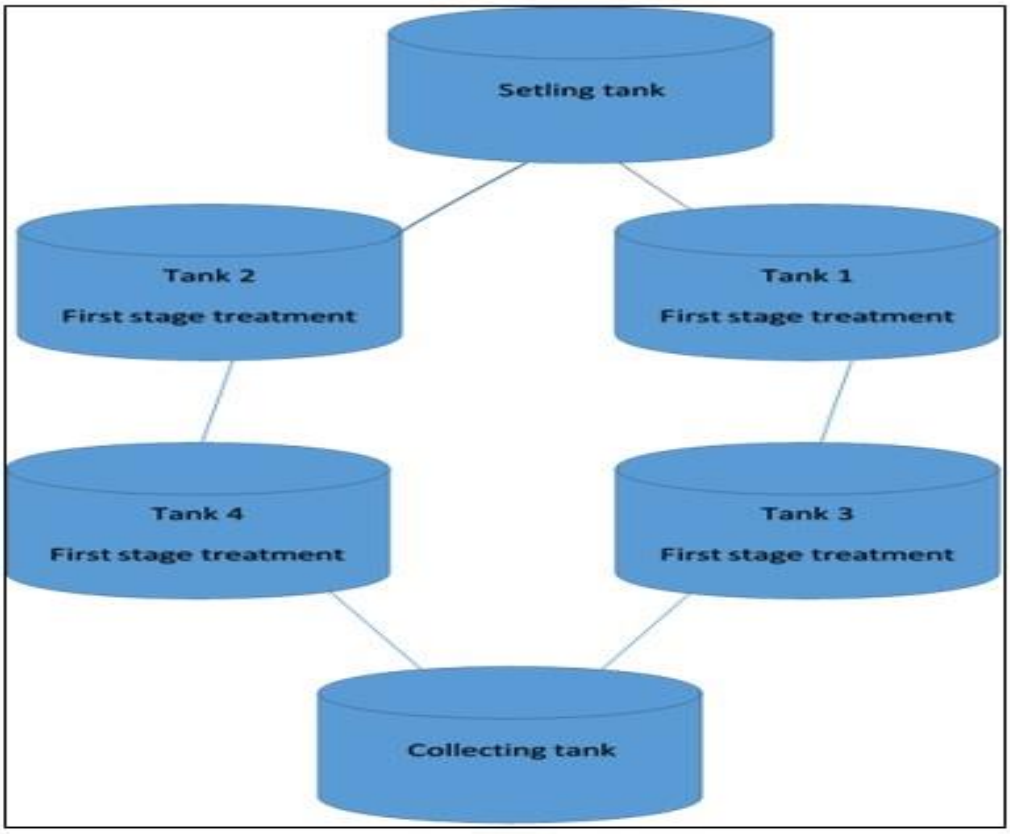
3.1 Introduction

This experiment was carried out inside the research station in the National Agriculture Research Center (NARC) site, which is located in Qabatya – Jenin, in the north of West Bank, with an average rainfall of 566 mm/year and temperature ranging from– 11/18 C^o as minimum/maximum in January to reach – 25/35 C^o as minimum/ maximum in August.

Inside the station a small constructed wet land was conducted. This treatment unit is originally designed to have sub –surface horizontal flow, where it is consisted of 500 L settling tank for the solid sedimentation followed by the two lines composed of two treatment units, each is 1 m^3 plastic tank filled with volcanic tuff, and planted with common reed plants (Phragmites australis; Picture 3.1).

Picture (3.1): The wet land treatment unit in NARC.

The diagram of the treatment unit is shown in picture 3.2.



Picture (3.2): The treatment unit diagram.

In this scheme the water samples were taking as following:

- S 1 from tank 1.
- S2 from tank 2.
- S3 from tank 3.
- S4 from tank 4.
- S5 from collecting tank.

3.2 Design of a HFCW

According to vyzamal (2005) HFCWs consists of the following parts.

Surface area:

Jan Vymazal (2005) proposed the following equation, for determination of horizontal subsurface flow systems for domestic sewage treatment:

$$Ah = Qd(\ln Cin - \ln Cout)/KBOD$$

Where:

Ah is the surface area of the wetland (m2),

Qd the average flow (m3/day),

Cin the influent BOD5 (mg/l),

Cout the effluent BOD5 (mg/l) and

KBOD is the rate constant (m/day). (0.4 m/day)

In order to identify the unit capacity

Darcy's law was used to determine the capacity of the wetland

to conduct the flow through it.

$$\mathbf{Q = K_s * A_s}$$

Where:

Q = flow capable of being passed through the SSCW, m3/s

K_s = Hydraulic conductivity of a unit area of the wetland media (259 $m^3/d/m^2$)

S = Hydraulic gradient of the water surface in the system, m/m (1-2%)

A = Surface area of HSSFCW (m2) **(1*0.6 m = 0.6 m^2)**

Q = 259 * 0.6 = 155.4 m^3/ day

Depth and Bottom slope:

The (0.6-0.8) m depth of bed was derived from the maximum depth of the Macropites root of the frequently used common reed. When coarse filtration materials are used, the wetlands beds have a slope of less than 1%.

For this the treatment tank has the following dimensions:

slope =1%, Length= 1 m, width= 0.6m, deep = 0.8 m and porous media depth = 0 .5 m and the sample perforated PVC pipe and with 0.2m from each side.

Hydraulic design parameters

Hydraulic retention time (HRT) is the average residence time of the water in the wetland. The HRT can be defined by the following equation.

HRT=nV/Q

HRT = (d)

V = capillary capacity of the wetland (equal to water volume of the bed) m^3

Q = flow rate (m3/d)

n=porosity (usually =0.4)

In the design process the estimated flow rate is 80 l/day.

HRT = 0.4 *0.3/0.08 = 1.5 day.

Considering the income BOD = 300mg/l and the out BOD = 10 mg/l

$$Ah = Qd(ln\,Cin - ln\,Cout)/KBOD$$

The actual efficiency of the unit is 0.6 = Q (ln 300 – ln C)/0.4

Ln C = 0.4*0.6/(0.08* ln 300)= 0.53, this result that out BOD = 1.7

And the treatment unit should have an efficiency higher than 99%

Granular medium

Two layers from the bottom to top include 10cm of sand and 40 cm of volcanic tuf equivalent to the normal gravel size.

3.3 Plant

The most frequently used plant in horizontal flow subsurface flow around the world is Phragmites australis (common reed). The plant density was 100 plants/m^2.

The seeds of local varieties for the three crops were obtained from NARC. The local varieties were chosen to have similarity with the farmers practices in local community, and the weight of 1000 seeds was measured for the three crops by weighing 100 seeds for three samples and taking the average of this weight for each crop; this weight was:

- (50 g/ 1000 seeds) for barley.
- (2 g/ 1000 seeds) for clover.
- (15 g/ 1000 seeds) for vetch.

The seeds were planted inside 8 liters' plastic plots, with (0.09m^2) surface area, filled with a mixture of 1:1 v/v peat moss to silty clay soil (Terra Rossa) which is heavy rich soil, neutral pH, with ECe 0.8 dS/m.

The soil is coming from the field and soil sampled to analyze the soil before planting where the pH = 7.09, EC = 0.78 dS/m. The planting density inside the plots is calculated on the bases of field plant density according to the farmers practices as following:

- The clover 4 g/m^2 (0.36 g/plot). The seeds amount is mixed with fine sand to guarantee good distribution of seeds in the pots.

- Barley 13 g/m^2 (1.17 g/plot).

- Vetch 15 g/ m^2 (1.35 g/plot).

The experimental design is completely randomized plot designed with two treatments for each crop replicated 9 times as shown in picture 3.3, and placed inside the protected green house, each replicate is composed of three plots for each:

- T1: treated wastewater coming from the treatment unit.

- T2: fresh water.

Picture (3.3): The design of the plots inside the green house.

For each crop 18 plots are planted 9 for each treatment.

The plots are irrigated with fresh water for the period from the planting until the germination of 90% of the seeds, then the drip irrigation system for each treatment is placed and the irrigation is started for each treatment.

Five water samples were collected within two months before the experiment to monitor the sewage quality arriving to the treatment unit. 5 other samples are collected during the experiment, the average of these samples is considered in the evaluation.

The irrigation requirements during the experiment is calculated according to FAO modified Penman – Montieth formula. To eliminate any effect for factors affecting growth, there is no fertilizers added and no pesticides.

During the experiment treated wastewater is monitored and analyzed frequently for BOD, COD, and fecal coliform. The Plant growth was monitored during the growing period and samples of the following plant parameters is collected;

1. Plant growth rate (plant height) (weekly).
2. Fresh weight at cutting date.
3. Dry weight at cutting date.
4. Leaves number/plant.
5. Protein content (Total protein).
6. Fiber content.

The Analysis method:

The analysis method for different parameters were following (ICARDA, 2013) procedure:

- BOD is measured following the BOD5 method, measures the consumed oxygen after sample is incubated in the lab for 5 days at 20 C^o and then tested for the amount of dissolved oxygen remaining (final).

- COD is measured using a strong oxidant (potassium dichromate) under acidic conditions. A known excess amount of the oxidant is added to the sample. Once oxidation is complete, the excess amount of oxidant remaining is measured by titration, and the oxidized organics is calculated by knowing the amount of oxidant consumed.

- Crude protein is measured by measuring nitrogen using Kjeldahl method.

- Potassium is measured following ICARDA procedure using flame photometer.

- Phosphorus is measured following spectrophotometer.

- Water requirements is calculated based on the modified FAO – Penman Montieth formula, as the data on climatic parameters is collected then using CROPWAT 8 software ET_o is calculated and the crop water requirements is identified.

- The Water Use Efficiency is calculated taking the results of dry weight Biomass and the crop water consumption results by the formula

WUE = Dry weight of Biomass (kg)/ Water consumption (m^3).

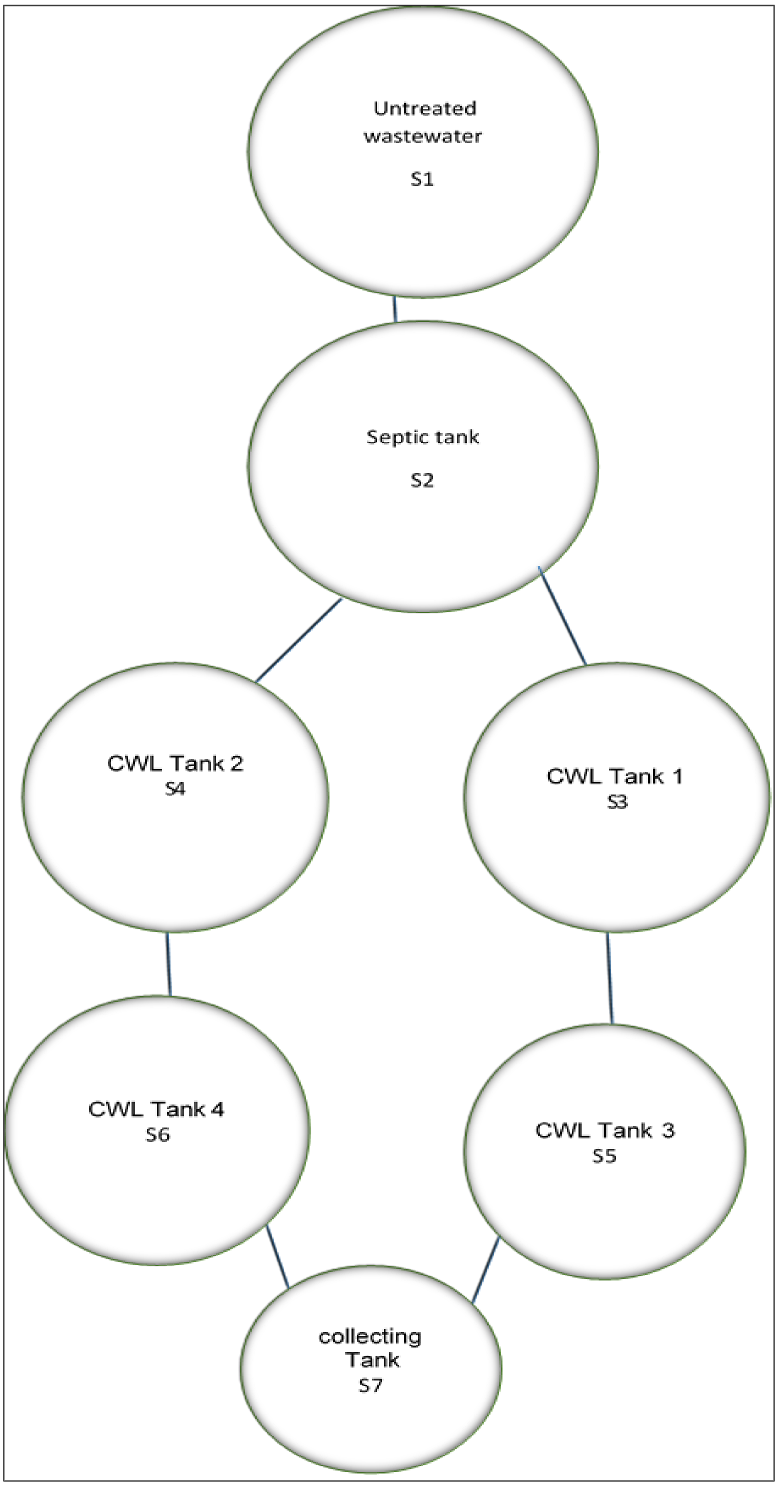


Figure (3.1): The water sampling scheme.

Chapter Four

Results and Discussion

Chapter Four

Results and Discussion

4.1 Climatic data and Irrigation

In order to identify the water requirements of the three crops, ET_o is needed to calculate the crop water requirements. The long-term averages of the climatic parameters were collected for Jenin District from the Ministry of agriculture, this average covers the last 25 years. Table 4.1 shows the different climatic data. From these data the reference evapotranspiration was computed using the FAO procedure) by CROPWATT software (modified Penman – Montieth formula). The resulted ET_o is shown in picture 4.1 in addition to the table.

Table (4.1): The long – term average climatic parameters of Jenin

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.1	17.5	72	104	5.6	10.5	1.55
February	10	18	74	118	5.3	12.1	1.87
March	12.2	21.9	67	112	7.5	17.4	2.91
April	15.1	26.3	62	119	8.5	21.2	4.08
May	18.6	28.9	60	131	9.7	24.2	5.05
June	22.7	31.7	62	136	11.6	27.3	5.98
July	25.4	33.4	64	139	11.5	26.9	6.21
August	26.5	33.8	66	135	10.8	24.8	5.85
September	24.7	32.4	65	107	9.4	20.7	4.71
October	21.2	30.1	62	86	8	16	3.44
November	14.8	24.1	66	82	6.7	12	2.19
December	11.2	19.2	70	90	5.7	9.9	1.56
Average	17.6	26.4	66	113	8.4	18.6	3.78

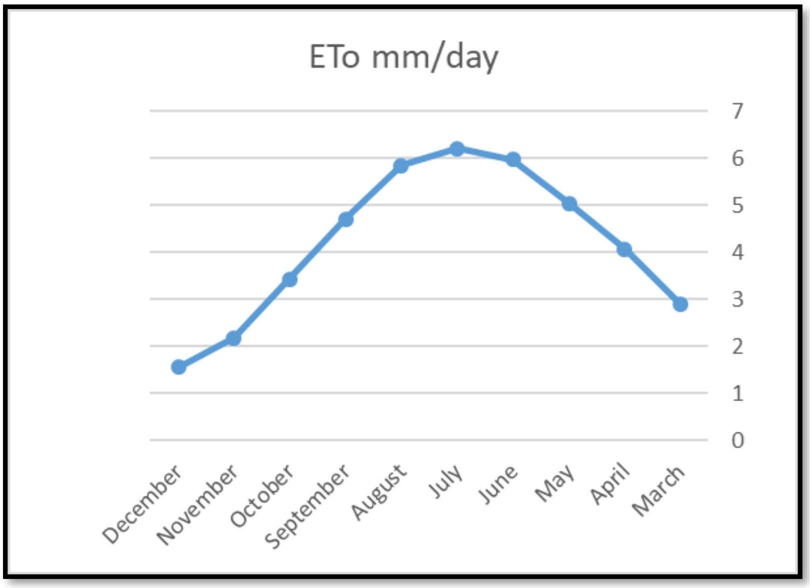
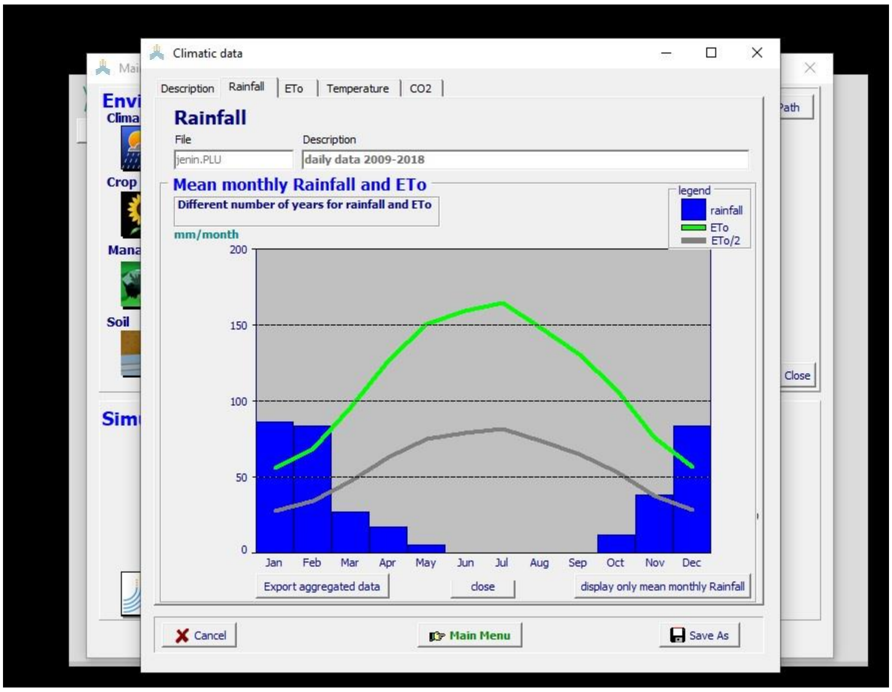


Figure (4.1): The daily reference evapotranspiration in Jenin.

As the results show the reference evapotranspiration ranged from 1.55 mm/day in January to reach a maximum 6.21 mm/day in July. With annual average of 3.78 mm/day.

The daily data of the climatic parameters were processed using FAO AquaCrop software, the results of the processed data is shown in picture 4.2



Picture (4.2): The processed daily climatic parameters for the period 2009–2018.

The results show that the normal rainfall is distributed within the months of October – May, which is the growth period for the examined crops, in addition the results show that within the rain period the average rainfall is higher than ($ET_o/2$) (the grey line) which means that the area is capable for the rain – fed plantation in general.

From table (4.1), the crop water requirements are calculated as mentioned and table (4.2 (a, b and c)) show the plant water requirements during this period as a result of introducing the crop factor during different growth stages for clover and vetch. It is noticed that both crops have similar growth stages and crop coefficients, therefore the irrigation requirements were very close.

During the experiment period the higher irrigation requirements of the vetch were considered and used to avoid any water stress coming from irrigation shortage and to limit the effect by the water quality not the quantity.

Table (4.2 a): The plant water requirements for clover

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Irr. Req.**
				mm/day	mm/dec	mm/dec
Dec	3	Init	0.4	0.62	5.6	5.6
Jan	1	Init	0.4	0.62	6.2	6.2
Jan	2	Deve	0.46	0.72	7.2	7.2
Jan	3	Deve	0.58	0.96	10.6	10.6
Feb	1	Deve	0.7	1.23	12.3	12.3
Feb	2	Deve	0.81	1.52	15.2	15.2
Feb	3	Mid	0.9	2	16	16
Mar	1	Mid	0.91	2.33	23.3	23.3
Mar	2	Mid	0.91	2.65	26.5	26.5
Mar	3	Mid	0.91	3	33	33
Apr	1	Mid	0.91	3.36	33.6	33.6
Apr	2	Late	0.89	3.61	18.1	18.1
					207.5	207.5

Table (4.2 b): The plant water requirements for vetch

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req.**
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	3	Init	0.85	1.32	11.9	0	11.9
Jan	1	Init	0.85	1.32	13.2	0	13.2
Jan	2	Deve	0.85	1.32	13.2	0	13.2
Jan	3	Deve	0.87	1.44	15.8	0	15.8
Feb	1	Deve	0.89	1.56	15.6	0	15.6
Feb	2	Deve	0.91	1.69	16.9	0	16.9
Feb	3	Mid	0.92	2.04	16.3	0	16.3
Mar	1	Mid	0.92	2.36	23.6	0	23.6
Mar	2	Mid	0.92	2.68	26.8	0	26.8
Mar	3	Mid	0.92	3.04	33.5	0	33.5
Apr	1	Mid	0.92	3.4	34	0	34
Apr	2	Late	0.88	3.57	21.4	0	21.4
					242.5	0	242.5

Table (4.2 c): The plant water requirements for barley

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req.**
			coeff	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Dec	2	Init	0.3	0.47	1.9	0	1.9
Dec	3	Init	0.3	0.47	5.1	0	5.1
Jan	1	Deve	0.47	0.74	7.4	0	7.4
Jan	2	Deve	0.79	1.23	12.3	0	12.3
Jan	3	Mid	1.07	1.76	19.4	0	19.4
Feb	1	Mid	1.09	1.93	19.3	0	19.3
Feb	2	Mid	1.09	2.05	20.5	0	20.5
Feb	3	Mid	1.09	2.43	19.4	0	19.4
Mar	1	Mid	1.09	2.8	28	0	28
Mar	2	Late	1.07	3.1	31	0	31
Mar	3	Late	0.81	2.68	29.5	0	29.5
Apr	1	Late	0.52	1.91	19.1	0	19.1
Apr	2	Late	0.31	1.25	6.2	0	6.2
					219.1	0	219.1

The irrigation was stopped before the second decay of April, for the irrigation quantities were reduced by 18.1 mm for both crops.

4.2 The treatment unit

4.2.1 Water

As the crop water requirements are identified, the quality of irrigation water should be considered, therefore, results on CWL treatment unit is processed. The results of water sampling in the different stages of the constructed wetland treatment unit is shown in table 4.3. The samples were collected from the two parallel treatment lines, tank 1 and 3 is for the first treatment line, while tank 2 and 4 are the second treatment lines as explained in chapter (3).

Table (4.3): The results of average of water samples of the treatment unit

Average results of the 5 samples			
Tank	BOD	COD	Total Nitrogen
Untreated wastewater	230	520	40
Septic Tank	91	375	40
CWL Tank 1	35	160	30
CWL Tank 2	23	119	32
Treated Water Tank	20	81	25
Fresh water	5	60	18

The results show that the resulted water quality from the unit is over the upper limit of high and good quality water according to the Palestinian regulations since the BOD_5 is 20, 23 for tank 3 and 4 on consequence (the average in the collecting tank is 21.5) and in the same time the COD is higher than 50. This could be explained by considering the temperature in that period, the average temperature is 13.3 in January and February, which reduces the bacterial activity. As indicated by (Kapur et al, 2004). However, the total nitrogen is within the high quality limits.

The nitrogen removal in the constructed wetland was 18.6% which is low compared to the data published by (Dong et al, 2015) (58%). This reduction is supporting the explanation that the treatment unit efficiency is reduced due to the low temperature in winter as a result of low microorganisms' activity.

Fresh water analysis indicated a high content of total nitrogen (18 ppm) were the maximum accepted limit of nitrate is 10 ppm (equivalent to 50 ppm total nitrogen) for nitrate in drinking according to United State department of health (2016).

The results of water pH and salinity content is shown in able 4.4, where the results show that salinity content is low in general and decreased with the treatment.

Table (4.4): Water pH and salinity content

Samples	pH	Ec	tank
Before treatment	7.07	767	
S1	7.07	480	1
S2	7.34	441	2
S3	7.26	422	3
S4	7.77	465	4
S5	7.51	4511	Collecting tank
	7.37	583	fresh

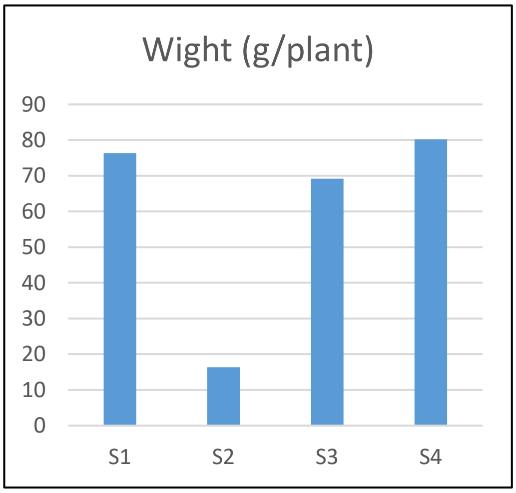
The results show that salinity content of treated water is lower than the fresh water. This is due to the treated water source which is coming from the washing sinks in the training center, therefore it is expected to have low salinity content.

4.2.2 Reeds

The results of the plant analysis for the reeds growing in the treatment tanks are shown in table 4.5 and graph:

Table (4.5): The results of the reed growing in the treatment tanks

	Reed	
Sampels	**Wight (g/plant)**	**length (cm)**
S1	76.323	93
S2	16.346	106
S3	69.196	166
S4	80.197	142
Sig. (2-tailed)	0.285383048	0.104165



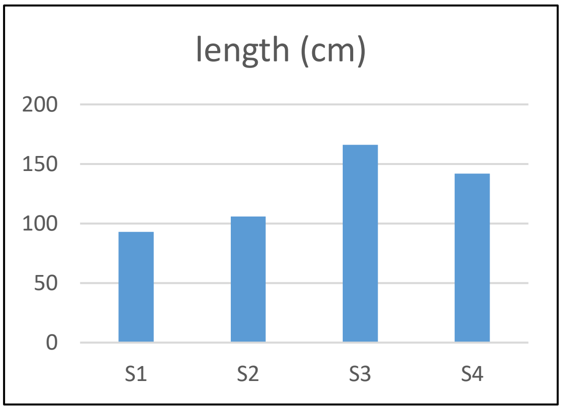


Figure (4.2): The weight and length of reeds.

As the results show, there is significant differences between the plants growing in the first treating unit and those of the second treating tanks in the first treating tanks the average weight was 46.3 g/plant compared to 74.7 g/plant for plants growing in the second tank. The same is correct for plant length, where the plant length is higher for plants in the second tank. These differences is resulting from both the reduction of salts and chemical content and salts in the second tank (table 4.2 and 4.3), in general the pattern of enhancing the growth agree with (Abou-Elela, 2017).

The results of water quantities and quality are utilized to schedule the irrigation on the base of three days irrigation interval. The results of different plant parameters are statistically processed to understand the difference in production due to the treatment (water quality effect on plants). In the following, crops results are presented as separate results discussing the effect of the treatment on each crop.

4.3 Barley

The results of the statistical analysis for barley is shown in table 4.6(a, b) for the different plant parameters for both fresh water and treated water irrigated barley.

Table (4.6a): The results of barley

Group Statistics					
	exp	N	Mean	Std. Deviation	Std. Error Mean
Number of spikes	fresh	9	2.222	1.0929	0.3643
	treated	9	6.000	1.2247	0.4082
Tillers	fresh	9	3.444	0.8819	0.2940
	treated	9	4.667	0.8660	0.2887
Fresh weight (g)	fresh	9	85.92111	11.553838	3.851279
	treated	9	122.311	26.474571	8.824857
Plant length	fresh	9	52.2000	2.97405	0.99135
	treated	9	67.3967	10.17966	3.39322
Root length	fresh	9	9.5667	2.37645	0.79215
	treated	9	9.5711	2.37349	0.79116

Table (4.6b): The statistical analysis of Barley

Independent Samples Test			
	T	df	Sig. (2-tailed)
Number of spikes	-6.904	16	0.000*
Tillers	-2.966	16	0.009*
Fresh weight (g)	-3.779	16	0.002*
Plant length	-4.299	16	0.001*
Root length	-.004	16	0.997

The results indicated that there are no significant differences between plants irrigated with treated water and fresh water at confidence level of 95% ($\alpha = 0.05$).

In graph 4.2 the fresh weight is shown, where we see that the plants irrigated with treated water still have higher fresh weight

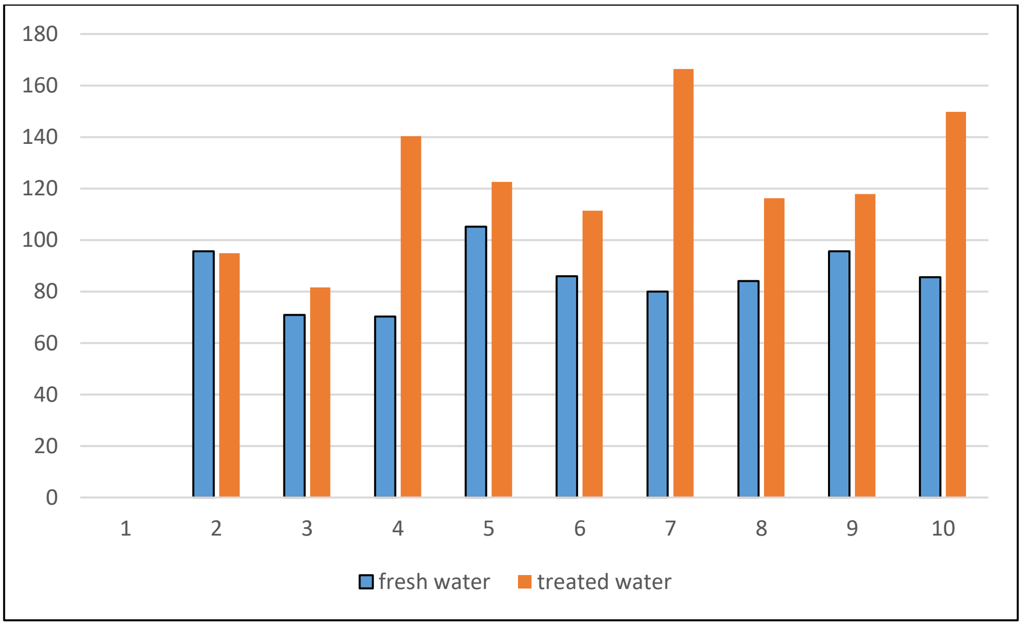


Figure (4.3): Barley plants fresh weight according to the type of irrigation.

The average fresh weight for plants irrigated with treated water was 85.9 g/ plant. When this weight is converted to equivalent area it would be 13kg/ dunums * 1000 seeds/ 50 g = 260,000 seeds (assume 90% germination) it becomes 234,000 plants.

85.9 g/plant * 234,000 = 20,100 kg/dunum of fresh weight. Considering the dry weight (12% humidity) the production is equivalent to 2412 kg/ dunums.

This production is 3 times higher than estimated by (Akar et al, 2004). This result is mainly coming due to the irrigation. This production of hay is very high compaired to the farmer production under rain – fed agriculture, where the farmers production is estimated to be 250 kg/ dunum of hay and 200 kg/ dunum of grains. Therefore, barley planting as a forage, could be economically feasible under irrigation.

4.4 Clover

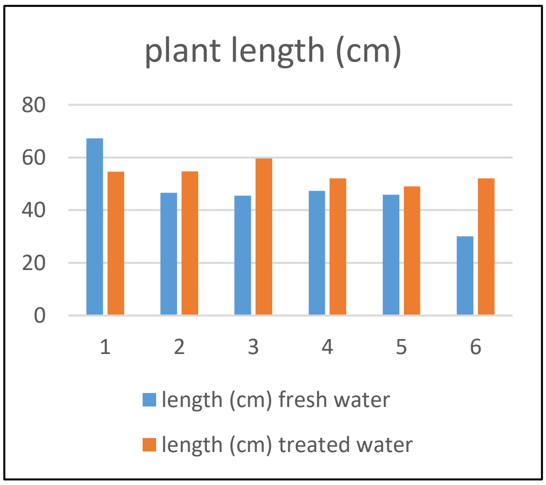
The results of clover plants irrigated with treated and fresh water is shown in table 4.7 (a &b). The results show that The fresh weight in plants irrigated with treated wastewater coming from the CWL unit is higher than plants irrigated with fresh water with a significant difference under confidence level of 95%. The average weight is ranging from 20.01 g/plant – 65.91 g/ plant with an average of 51.76 g/plant in the plants irrigated with treated water compared to 15.71 – 55.16 g/plant with an verage of 32.64 g/plant for those irrigated with fresh water.

Table (4.7a): The results of clover plants irrigated with fresh and treated water

	exp	N	Mean	Std. Deviation	Std. Error Mean
Number of leaves	Fresh	6	3.500	1.0488	0.4282
	Treated	6	4.667	0.5164	0.2108
Length (cm)	Fresh	6	47.1167	11.84338	4.83504
	Treated	6	53.6583	3.58620	1.46406
Number of flowers per plant	Fresh	6	2.000	0.6325	0.2582
	Treated	6	2.833	0.7528	0.3073
Fresh weight (g)	Fresh	6	32.64133	14.808942	6.045725
	Treated	6	51.76550	17.867237	7.294269
Root length (cm)	Fresh	6	12.300	3.6721	1.4991
	Treated	6	9.150	1.4419	0.5886

Table (4.7b): The statistical analysis of clover irrigated with fresh and treated water

	t-test for Equality of Means		
	t	df	Sig. (2-tailed)
Pot number	0.838	10	0.422
Number of leaves	-2.445	10	0.035*
Length (cm)	-1.295	10	0.224
Number of flowers per plant	-2.076	10	.05*
Fresh weight (g)	-2.019	10	0.049*
Root length (cm)	1.956	10	0.079



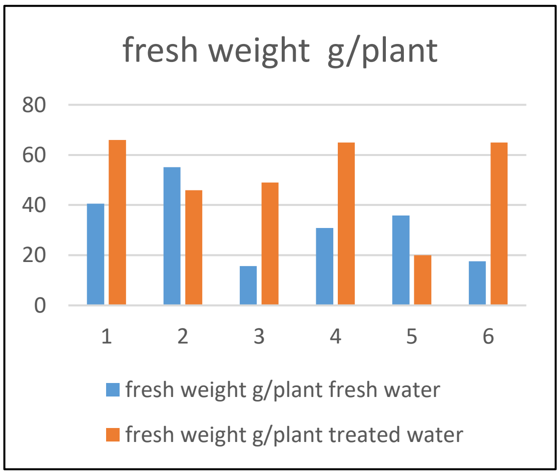


Figure (4.4): The plant fresh weight and length for clover.

As shown in figure (4.4) the length and fresh weight in plants irrigated with treated water is higher, this is due to the nutrients existing in the treated water as stated by (Lahlou et al, 2020; and Alkhamisi, 2014).

When the number of plants in fields (the farmers sowing rate is 7 kg/ dunum, compared to 4kg/dunum as recommended):

4000 g/dunum * 1000 seeds/ 2 g = 2,000,000 plants. Taking germination of 90%

The plants density is 1,800,000 plants/ dunum The fresh weight production is equivalent to (65.91 g/ plant * 1,800,000 plants/ dunum = 118,638 ton/ dunum.) Converting this to the dry matter would give 11.86 ton/dunum.

The fresh weight production is 82.09 Ton/ dunum of green hay and, 8.21 Ton of dry hay. These results agree with (Kassab et al., 2012) found that average production ranges between 7.8 ton/dunum and 8.2 ton/ dunum for dry, semi-dry and the common cultivation, This indicates that the farmers could increase their production by 43% when irrigating with treated wastewater or 14 times of what the farer gains under rain – fed (800 kg/ dunum) . The economical value of clover becomes ore clear when considering that the average price is 350 $ / Ton in the local market. The irrigation will increase the income from 280$ in rain fed to be 4,130% with irrigation.

4.5 Vetch

The results of vetch plants irrigated with treated and fresh water is shown in table (4.8 a and b).

Table (4.8 a): The average results for vetch plants irrigated with treated water compared to fresh water

	exp	N	Mean	Std. Deviation	Std. Error Mean
Leaves length	Fresh	9	13.0189	3.52570	1.17523
	Treated	9	15.5344	3.26243	1.08748
Plant length	Fresh	9	46.3044	4.61005	1.53668
	Treated	9	57.3333	13.36955	4.45652
Number of flowers	Fresh	7	2.857	1.5736	0.5948
	Treated	9	3.556	1.9437	0.6479
Fresh weight per plant	Fresh	9	24.09100	12.254723	4.084908
	Treated	9	55.24144	22.522305	7.507435
Root length	Fresh	9	8.522	1.5336	.5112
	Treated	9	6.411	1.3224	.4408

Table (4.8b): Statistical analysis of the vetch plant results

	t	df	Sig. (2-tailed)
Leaves length	-1.571	16	0.136
Plant length	-2.340	16	0.033*
Number of flowers	-.772	14	0.453
Fresh weight per plant	-3.645	16	0.002*
Root length	3.128	16	0.006*

The results show that plants irrigated with treated water have higher results than those irrigated with fresh water (graph 4.5a and 4.5b), however this difference is not significant except for leaves length and the number of flowers per plant. where the difference is significant at confidence level of 95%.

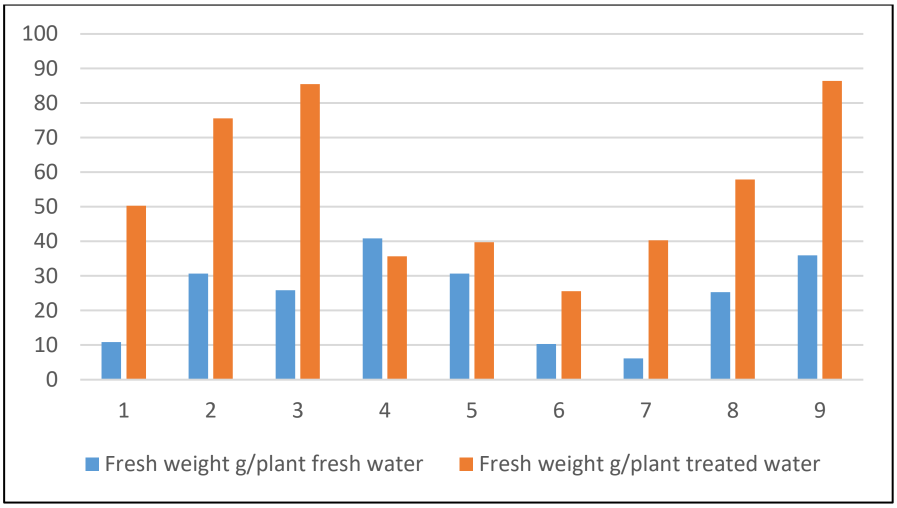


Figure (4.5a): The fresh weight of vetch plants irrigated with fresh and treated water.

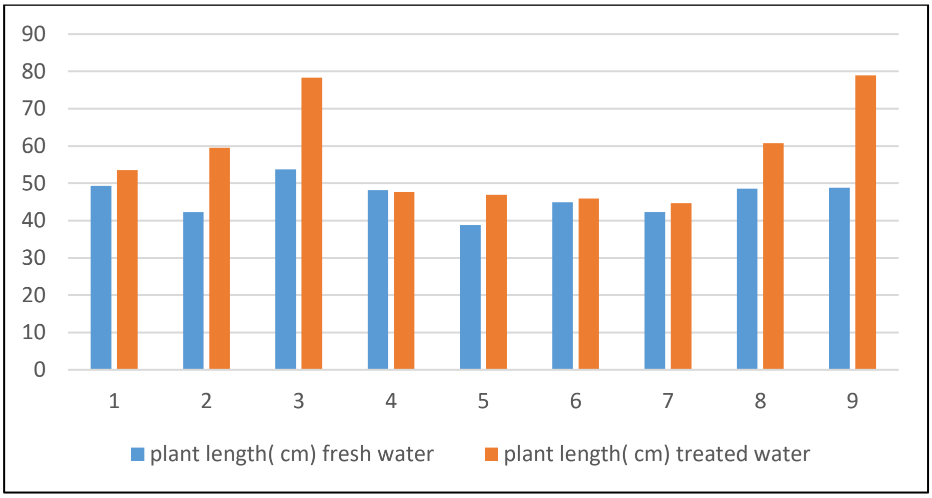


Figure (4.5b): The plant length of vetch plants irrigated with fresh and treated water.

The results indicate that the plants would have higher fresh weight and plant length when irrigated with treated wastewater but without any statistical significant even though the averages difference is high where the is an average plant fresh weight of 24.09 g/plant and 55.24 g/plant for fresh water and treated water consequence, but in the same time the deviation from the average is high in the treated water irrigated plants, therefore the difference is not significant on the large scale (field bases). This is correct except for leaves length and number of flowers.

4.6 Crude Protein

The results of crude protein analysis for the three crops is the indicator on the effect of the role of changing the water quality (i.e. the irrigation with treated wastewater) on the nutritional value of the forage crops. These results are showing different pattern, where the crude protein content of plants irrigated with treated wastewater was less than plants irrigated with fresh water (table 4.9). For vetch the protein content was higher in the plants irrigated with treated wastewater.

Table (4.9): The crude protein content for the different crops

Crop	Crude protein (%)
Fresh barley	15.91
Treated barley	9.21
Fresh clover	16.73
Treated clover	12.62
Fresh vetch	8.21
Treated vetch	14.12

The results of clover in general agree with the published data, where the clover content is 15 – 25% (Feedipedia, 2013a), however the results in the experiment are lower for clover. It could be justified that the high increase in fresh weight reduced the protein in the plant tissues, This is supported by the results of vetch where the protein content in plants irrigated with treated wastewater is higher than those irrigated with fresh water, while the fresh weight was lower as shown in table (4.8). Moreover, the protein content in barley was higher than the content published by (feedipedia, 2013c), where the protein content is 9.21% in the results compared to 3.8% for barley straw. The suggested content is for straw separately, while the content for grain is

11%. The method of sampling affects the protein content; in the experiment the samples are composite samples of the whole plant parts. For this, the protein content is lower in the results and higher than the straw alone. This justification agrees with the published data of (feedipedia, 2013b) where the protein content of vetch plants is 23%, while (Tisserand and Alibes, 1989) presented a value exceed 6%.

4.7 Water Use efficiency

As it is defined the water use efficiency (WUE) is the ratio of the produced biomass to the water consumed. The effect of water quality would be better understood when comparing the water use efficiency for the crops, in other words the connection of crop utilization of water.

The Water use efficiency for the three crops under the different water qualities were calculated based on the water consumption (tables 4.2) and the fresh and dry weight measurements for the different crops. The results of water use efficiency for the three crops planted in the experiment is shown in table (4.10). The results were ranging from 9.9 kg/ m^3 for vetch – 31 kg/ m^3 for clover in the fresh water irrigation.

Table (4.10): The WUE for the barley, vetch, and clover

	fresh water irrigation			**Treated water irrigation**		
	Barley	**vetch**	**clover**	**barley**	**vetch**	**clover**
Water consumption (mm)	219.1	242.5	207.5	219.1	242.5	207.5
WATER volume (L)	19.719	21.825	18.675	19.719	21.8	18.675
Fresh weight (g/plant)	85.92	24.09	32.64	122.2	55.24	51.7
Number of plants	23	90	180	23	90	180
Weight	2010.52	2168.1	5875.2	2810.6	4971.6	9306
Dry weight	201.052	216.81	587.52	281.06	497.16	930.6
WUE (kg/m^3)	10.20	9.93	31.46	14.25	22.81	49.83

The results of WUE for biomass in barley is lower than the published data of (Morell et al, 2011), who published a WUE of 11.3 – 22.3 kg/mm, but for the plants irrigated with treated effluent the results agree with the published values. While for clover the resulted WUE is higher than (Kassab et al., 2012) who published a WUE 15–20 kg/ m^3 but it agrees with (Tonmukayakul, 2009), and even it increased when irrigating with treated wastewater. The increase is caused by the enhanced conditions of availability of nutrients in the treated water quality as explained by (Darweesh, 2018), therefore the production was higher as shown in the fresh weight results (section 4.4).

Chapter Five

Conclusions and Recommendations

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5.1 Conclusions

In Palestine the adaptation of the constructed wetland treatment units in the small areas is a sustainable alternative, due to the low requirements for operation and maintenance of these units. The results show good efficiency of the treatment unit, and the effluent after treatment was of good quality according to the regulations.

The reuse of the treated wastewater for irrigation of winter season forage crops is a solution of economic feasibility for the resulted TWW in winter, especially in the season of low use for other potential crops. The production variables of these irrigated crops were soundly higher than those rain fed planted. In the same time, it is water saving for the local community in term of fresh water saving.

The use of reed plants produced a medium efficiency of CWLs, the nitrogen removal was 18%, while the BOD was 77%. For this an additional plants which enhance nitrogen removal may be used to enhance nitrogen removal, the use of mechanize as post treatment require more energy consumption compared to the plants.

The effluent has low salinity content(EC) and pH is close to 7, this indicates a high salts removal by the reeds, and that the effluent has good impact considering the salinity effect.

The nutrient content of treated wastewater enhanced the production of barley and clover, while it didn't affect the production of vetch, therefore, it is more suitable to plant clover or barley under irrigation in the winter season when treated wastewater is available mainly in the area of low rainfall. The excess content of nutrients may affect the growth of some plants (as excess nitrogen affect grapes).

Irrigation of barley especially in areas of low rainfall increase the production, moreover, the Irrigation with treated wastewater increased the production and enhanced the WUE of barley, in the same time the protein content in the straw was higher than the expected (published average values). Therefore, produced barley under these conditions have higher nutritional value if the whole above ground parts is used for animal feeding.

The production of clover plants was higher than vetch plants with a higher protein content, in the same time the irrigation requirements of vetch is higher and the WUE for clover is higher. This is due to the differences in physiological characteristics of plant (growth stages, formation of seeds, etc....), for that the planting of clover under irrigation with treated wastewater is more economic for the farmers.

5.2 Recommendations

- ❖ The reed shows good salts removal, but yet it is required to have deep studies on the salt removal and nitrogen removal under different thermal conditions.

- ❖ The experiment was conducted under protected conditions in the green house, therefore, it is recommended to continue researches under the open field conditions.

- ❖ It is recommended to continue studies on the nutritional impact of feeding animals with crops irrigated with treated wastewater in the Palestinian conditions.

- ❖ It is required to continue studies on the impact of reuse of treated effluent resulting from the constructed wetlands on large scale.

- ❖ Investigations on the impact of reuse of treated effluent on different forage crops is required, and scaling up of the experiment is crucial for validating the results.

- ❖ The planting of clover under irrigation of treated wastewater is economic feasible according to the result, for that it is highly recommended to plant clover under similar conditions.

- ❖ In area of low rainfall, such as in south Palestine, the impact of irrigation in general is high, and the impact of reuse of treated effluent is clear, therefore, it is highly recommended to spread the constructed wetland technology and scale up the irrigation of resulted effluent in these areas.

- Studies on the impact of irrigation of effluent on trees is required in the Palestinian conditions.

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Annexes

Annex (1)

TWW specifications according to TR 34–2003 and PSI draft for TWW reuse

	TWW Quality			
Maximum limits of chemical, and biological characteristics in mg/liter unless other concentration is mentioned	High Quality	Good Quality	Medium Quality	Low Quality
	(A)	(B)	(C)	(D)
BOD_5	20	20	40	60
TSS	30	30	50	90
FC colony/ 100 ml	200	1000	1000	1000
COD	50	50	100	150
DO	1 <	1<	1<	1<
TDS	1200	1500	1500	1500
pH	6 – 9	6 – 9	6 – 9	6 – 9
fat,oil,grease	5	5	5	5
phenol	0.002	0.002	0.002	0.002
MBAS	15	15	15	25
$NO-_3N$	20	20	30	40
$NH-_4N$	5	5	10	15
Total-N	30	30	45	60
Cl	400	400	400	400
SO_4	300	300	300	300
Na	200	200	200	200
Mg	60	60	60	60
Ca	300	300	300	300
SAR	5.83	5.83	5.83	5.83
$PO-_4P$	15 - 20	15 - 20	15 - 20	15 - 20
AI	5	5	5	5
As	0.1	0.1	0.1	0.1
Cu	0.2	0.2	0.2	0.2
Fe	5	5	5	5
Mn	0.2	0.2	0.2	0.2
Ni	0.2	0.2	0.2	0.2
pb	0.2	0.2	0.2	0.2
Se	0.02	0.02	0.02	0.02
Cd	0.01	0.01	0.01	0.01
Zn	2	2	2	2
CN	0.05	0.05	0.05	0.05

Cr	0.1	0.1	0.1	0.1
Hg	0.001	0.001	0.001	0.001
Co	0.05	0.05	0.05	0.05
B	0.7	0.7	0.7	0.7
E.coli colony/100 ml	100	1000	1000	1000
(Eggs/L) Nematodes	1≤	1≤	1≤	1≤

Annex (2)

The complete plant results

Rainfall

Year	Rain
2009	460.5
2010	256.5
2011	368.0
2012	428.0
2013	417.0
2014	235.5
2015	362.0
2016	406.5
2017	166.0
2018	552.0

Fresh Barley

pot number	number of spikes	tillers	fresh weight (g)	plant length	root length
				cm	
9	3	4	95.67	52.2	13
8	2	3	70.92	52.1	12.6
6	1	3	70.3	46.6	10
5	3	5	105.2	55.8	7.3
4	1	3	85.9	56.2	7.6
3	2	3	80	51.9	9.8
2	4	2	84.1	49.9	11.2
1	3	4	95.6	51	8.3
7	1	4	85.6	54.1	6.3

Treated Barley

pot number	number of spikes	tillers	fresh weight (g)	plant length	root length
				cm	
1	6	5	94.913	57.21	13
6	5	4	81.532	67.6	12.6
5	7	5	140.31	77.31	10
2	6	4	122.53	61.52	7.3
7	4	5	111.351	58.32	7.63
3	7	6	166.376	70.68	9.81
8	8	5	116.177	55.02	11.2
4	6	3	117.9	74.2	8.3
7	5	5	149.71	84.71	6.3

Fresh Vetch

pot number	leaves length	plant length	number of flowers	fresh weight per plant	root length
	cm			g	
4	14.6	49.3	3	10.91	10.5
2	12.5	42.21	2	30.71	8.9
3	15.9	53.72	6	25.91	10.8
8	18.3	48.1	3	40.91	8.2
6	8.16	38.79	Non	30.71	6.2
7	16.2	44.9	1	10.3	7.1
1	8.3	42.3	Non	6.139	8.8
5	11.11	48.61	2	25.31	7.2
9	12.1	48.81	3	35.92	9

Treated vetch

pot number	leaves length	plant length	number of flowers	fresh weight per plant	root length
	cm			g	
7	17.6	53.5	3	50.319	4.8
6	18.4	59.5	4	75.6	8.9
1	18.6	78.3	3	85.5	5.7
8	11.91	47.7	2	35.719	8.1
9	10.8	46.9	1	39.795	5.5
5	14.5	45.9	2	25.6	5.7
3	12	44.6	4	40.281	6
2	17	60.7	7	57.9	6.9
4	19	78.9	6	86.459	6.1

Fresh clover

pot number	number of leaves	length (cm)	fresh weight (g)	number of flowers per plant	root length (cm)
4	3	67.3	40.591	2	15.7
5	4	46.6	55.16	3	16.1
2	4	45.5	15.716	2	12
6	5	47.3	30.9	1	8.3
7	2	45.9	35.881	2	7.6
8	3	30.1	17.6	2	14.1

Treated clover

pot number	number of leaves	length (cm)	fresh weight (g)	number of flowers per plant	root length (cm)
1	4	54.6	65.912	3	9.7
6	5	54.71	45.89	3	7.9
3	5	59.6	48.97	2	7.1
2	4	52.01	64.901	3	11
5	5	49.01	20.01	2	9.1
8	5	52.02	64.91	4	10.1

N, P, K content in plant tissues

	N (mlg\l)	P (mlg\l)	K (mlg\l)
fresh barley	2.541	2.1359	789
treated barley	1.472	0.1807	845
fresh clover	2.672	1.2178	886
treated clover	2.016	0.04381	943
fresh vetch	1.312	0.1058	734
treated vetch	2.256	0.5083	700.2

Crude Protein (%)

fresh barley	15.90666
treated barley	9.21472
fresh clover	16.72672
treated clover	12.62016
fresh vetch	8.21312
treated vetch	14.12256

Water samples

untreated wastewater	
BOD	COD
250	613
218	516
254	508
198	443

Septic Tank	
BOD	COD
103	323
81	481
82	413
93	352
96	305

Tank 1+2	
BOD	COD
26	172
33	138
38	144
37	167
42	178

Tank 3+4	
BOD	COD
21	119
18	102
33	129
24	129
18	117

Treated Water Tank	
BOD	COD
20	83
17	76
24	81
22	89
18	78

جامعة النجاح الوطنية
كلية الدراسات العليا

نمذجة تعزيز إنتاج الاعلاف باستخدام مياه الصرف الصحي المعالجة بواسطة نظام الأراضي الرطبة

إعداد
رياض راغب عامر أبو سمرة

إشراف
د. عبد الفتاح حسن

قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في العلوم البيئية بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2021

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إشراف

د. عبد الفتاح حسن

الملخص

تعتبر تقنية المعالجة بالأراضي الرطبة من التقنيات المنتشرة في العالم. بينما في فلسطين ومع ان هذه التقنية تم إدخالها منذ سنوات الا أنها غير واسعة الاستخدام رغم انها من الحلول التقنية الواعدة في فلسطين لعدة أسباب منها انتشار القرى متوسطة وصغيرة الحجم، وانخفاض تكاليف تأسيس وتشغيل وصيانة وحدات المعالجة التي تعمل بهذه التقنية.

تم انشاء وحدة معالجة بتقنية الأرض الرطبة في المركز الوطني للبحوث الزراعية في موقعه بقباطية – جنين. وتعمل هذه الوحدة بنظام الجريان المهجن (السطحي الافقي (HSFW) بالإضافة الى الجريان العمودي (VSFW). خلال تنفيذ التجربة تمت زراعة هذه الوحدة بنباتات القصاب حيث أن التجربة تهدف الى تقييم اثر استخدام المياه المعالجة الخارجة من وحدة المعالجة على نمو وانتاج ثلاثة محاصيل علفية هي الشعير و الجلبانة والبرسيم المصري، كما أنها تهدف من ناحية أخرى الى تقييم استخدام نبات القصاب على كفاءة وحدة المعالجة وعلى جودة المياه الخارجة منها.

بينت النتائج أن كفاءة وحدة المعالجة كانت متوسطة حيث انخفض الاكسجين المطلوب بيولوجيا (BOD) والأكسجين المطلوب كيماويا (COD) بمعدل 77% و 78% على التوالي. بينما تمت إزالة 18% من النيتروجين فقط. وقد تمت إزالة 42% من محتوى المياه من الاملاح بواسطة النباتات.

أظهرت النتائج تحسن وزيادة كفاءة استخدام المياه من قبل المحاصيل الثلاثة، حيث ارتفعت كفاءة استخدام المياه من 9.9 الى 14.25 كغم/ م^3 للشعير، ومن 9.9 الى 22.8 كغم/ م^3 في الجلبانة،

ومن 31.46 لتصبح 49.83 كغم/ م^{3} من المياه في البرسيم مقارنة مع النباتات المروية بالمياه العذبة. وبرغم هذه الزيادة في كفاءة استخدام المياه الا ان النتائج بينت عدم وجود فروق إحصائية في الوزن الأخضر للمحاصيل الثلاثة نتيجة تغيير نوعية المياه.

أشارت النتائج الى تراجع محتوى النبات من البروتين الخام لمحصولي الشعير والبرسيم بينما ارتفع مستوى البروتين الخام في الجلبانة عند استخدام المياه المعالجة الناتجة من المحطة. وبرغم الانخفاض النسبي الحاصل الا أن محتوى النبات من البروتين الخام بقي ضمن مستويات مقبولة وتقع ضمن النطاق المنشور في الأبحاث.

بينت التجربة أن محطات المعالجة بتقنية الأراضي الرطبة قابلة وبشكل كبير للاستخدام تحت الظروف الفلسطينية، كما أن استخدام المياه الناتجة منها تزيد في انتتاج المحاصيل العلفية التي تم فحصها دون التأثير على الجودة الغذائية للأعلاف الناتجة.