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Effect of Irrigation with Treated Wastewater Using Surface and Subsurface Drip Irrigation Systems and Different Irrigation Quantities on Pearl millet Productivity and Water Use Efficiency

تأثير الري بالمياه العادمة المعالجة باستخدام نظامي الري بالتنقيط السطحي وتحت السطحي وكميات ري مختلفة على انتاجية وكفاءة استخدام المياه لمحصول الدخن اللؤلؤي

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Abstract

A great challenge for the agricultural sector in Marj Ibn Amer as well as in Palestine is less water availability for agricultural purposes. This causes decrease in irrigated agricultural land and consequently make the agricultural sector more vulnerable and infeasible that lead to food insecurity. So, adoption of optimum water management practices considers prime importance for attaining national food and water security which can be achieved by producing more food from less water use. The productions of forage crops in Palestine cover around 20% of the fodder demand. Therefore, there is a strategic attitude by the MoA to increase the area cultivated by forage crops, irrigated by treated effluent. Due to the high nutritional value of Pearl millet and its tolerance to drought and salinity, the MoA encourages the farmers to cultivate it.

The main objective of this research is to find the highest aboveground biomass production of pearl millet per unit of water application using treated wastewater (TWW) in irrigation.

This research was carried out during summer season of 2017 where pearl millet seeds cultivated in clay soil in late of May in the field of Marj Ibn Amer as semi-arid area in Jenin governorate where secondary treated wastewater is generated from the adjacent wastewater treatment plant serving Jenin city used in irrigation. Crop water requirement (WR) for Pearl millet estimated based on CROPWAT model.

Field experiment was conducted based on a split plot design (SPD) with three replicates. The main plots consisted two irrigation systems including subsurface drip irrigation system (SSDI) and surface drip irrigation system (SDI). The sub-plot comprised three irrigation water quantities (100% water requirement (WR), 75% WR and 50% WR).

The results showed that the fresh weight, dry weight, plant height and water use efficiency (WUE) were the highest by SSDI compared to SDI for each cut. The results showed that the fresh weight, dry weight and plant height for the cuts were increased by increasing irrigation amount from 50% WR to 75% WR and 100% WR, respectively.

The results showed that the fresh forage productivity with SSDI was (5894 kg/dunum) higher and significant at confidence level ($p<0.05$) than SDI (4876 kg/dunum). Also, dry forage productivity was higher with SSDI (947 kg/dunum) than SDI (830 kg/dunum).

Under irrigation with 100% WR produced the highest fresh forage productivity (7134 kg/dunum) and significant at confidence level ($p < 0.05$) than 75% WR and 50% WR which were (5154 kg/dunum), (3872 kg/dunum), respectively. The dry forage productivity was the highest (1155 kg/dunum) and significant with 100% WR than 75% WR and 50% WR which were (853 kg/dunum), (658 kg/dunum), respectively.

WUE by applying 50% WR was the highest (15.43 kg/m^3) than 100% WR and 75% WR, which were (14.91 kg/m^3) and (14.14 kg/m^3), respectively. Also, WUE with SSDI was the highest (16.16 kg/m^3) and significant at confidence level ($P<$ 0.05) than SDI which was (13.5 kg/m^3).

It's recommended to disseminate the technology of SSDI among the farmers in order to increase the WUE in arid and semi-arid regions as well as applying 50% WR using TWW for irrigating Pearl millet.

الملخص

كما هو الحال في فلسطين، يواجه القطاع الزراعي في مرج ابن عامر تحديا كبيرا بسبب قلة توفر المياه الزراعية والذي بدوره أدى الى تناقص مساحات الزراعة المروية الذي اثر سلبا على هشاشة هذا القطاع وعلى الجدوى الإقتصادية منه الذي بدوره يؤدي الى انعدام الأمن الغذائي. وعليه فإن انتاج كميات كبيرة ما امكن من الغذاء من خلال إستخدام اقل ما يمكن من المياه هو أحد الممارسات المثلى التي من الممكن تبنيها وذلك لزيادة الأمن الغذائي و المائي على المستوى الوطني. يتم انتاج 20% من الاحتياج العلفي محليا، وعليه تبنت وزارة الزراعة من خلال استراتيجيتها زيادة المساحة المزروعة من المحاصيل العلفية باستخدام المياه المعالجة وقد شجعت وزارة الزراعة المزارعين على زراعة الدخن اللؤلؤي نظرا لقيمته الغذائية العالية وتحمله للجفاف والملوحة.

الهدف الرئيسي من هذا البحث هو ايجاد اعلى كمية محصول علفي من الدخن اللؤلؤي ممكن انتاجه من كل وحدة مياه معالجة مستخدمة.

اجري هذا البحث في صيف عام 2017 في نهاية شهر ايار حيث تمت زراعة بذور الدخن في حقل ذا تربة طينية و مناخ شبه جاف في سهل مرج ابن عامر التابع لمحافظة جنين، حيث يوجد هناك مصدر ري من المياه المعالجة الثنائية الخارجة من محطة جنين لمعالجة مياه الصرف الصحي العادمة. صممت التجربة على اساس نظام الالواح المنشقة بثلاثة مكررات لكل معاملة فكانت القطع الرئيسية تتكون من نظامي ري وهما نظام الري بالتنقيط السطحي ونظام الري بالتنقيط تحت السطحي اما القطع المنشقة فتمثل كميات المياه الثلاثة وهي (100%، 75%، 50%) من الاحتياج المائي لمحصول الدخن. تم تقدير الاحتياج المائي لمحصول الدخن اعتمادا على CROPWAT model .

اظهرت النتائج ان الوزن الاخضر، الوزن الجاف، طول النبات وكفاءة استخدام المياه كان الاعلى باستخدام نظام الري بالتنقيط تحت السطحي مقارنة بنظام الري بالتنقيط السطحي في كل القصات، كذلك اظهرت النتائج ان الوزن الاخضر، الوزن الجاف وطول النبات زاد بزيادة كميات الري من 50% من الاحتياج المائي الى (75% و 100%) من الاحتياج المائي على التوالي.

اظهرت النتائج ايضا ان انتاجية المحصول العلفي الاخضر باستخدام نظام الري بالتنقيط تحت السطحي كانت 5894 كغم/الدونم اعلى وذات اثر احصائي معنوي عند مستوى ثقة (P<0.05) مقارنة بنظام الري بالتنقيط السطحي 4876 كغم/ الدونم. ايضا كانت انتاجية المحصول العلفي الجاف اعلى باستخدام نظام الري بالتنقيط تحت السطحي (947 كغم/ الدونم) من نظام الري بالتنقيط السطحي (830 كغم/ الدونم).

الري بكمية 100% من الاحتياج المائي اعطى اعلى انتاجية محصول علفي اخضر (7134 كغم/ دونم) وذات اثر احصائي معنوي مقارنة مع ري (75% و 50%) من الاحتياج المائي للمحصول حيث كانت (5154 كغم/ الدونم ، 3872 كغم/ الدونم) على التوالي، كذلك كانت انتاجية المحصول العلفي الجاف اعلى باستخدام 100% من الاحتياج المائي وذات اثر احصائي معنوي مقارنة مع 75% و 50% من الاحتياج المائي اذ كانت (853، 658 كغم/ الدونم) على التوالي.

اعلى كفاءة استخدام للمياه كانت 15.43 كغم/متر مكعب بتطبيق 50% من الاحتياج المائي للمحصول مقارنة مع 100% و 75% من الاحتياج المائي للمحصول حيث كانت (14.91 و 14.14 كغم/متر مكعب) على التوالي. ايضا اعلى كفاءة استخدام للمياه كانت باستخدام نظام الري بالتنقيط تحت السطحي 16.16 كغم/متر مكعب وذات اثر احصائي معنوي عند مستوى ثقة (P<0.05) مقارنة بنظام الري بالتنقيط السطحي الذي كانت كفاءة استخدام المياه فيه 13.5 كغم/متر مكعب.

نوصي بنشر تقنية نظام الري بالتنقيط تحت السطحي بين المزارعين وتطبيق 50% من الاحتياج المائي لمحصول الدخن اللؤلؤي باستخدام المياه المعالجة بهدف زيادة كفاءة استخدام المياه في المناطق الجافة وشبه الجافة.

Abbreviations

Acronym	**Definition**
Ca	Calcium
DAS	Days After Sowing
EQA	Environmental Quality Authority
K	Potassium
Kg	Kilogram
Kg/m^3	Kilogram per cubic meter
KPa	Kilo Pascal
L/h	Liter per hour
LW	Leaves Weight
m^3	Cubic meter
MCM	Million Cubic Meter
MoA	Ministry of Agriculture
N	Nitrogen
ppm	Part per million
PSI	Palestinian Standard Institute
PWA	Palestinian Water Authority
SDI	Surface Drip Irrigation system
SSDI	Subsurface Drip Irrigation system
TSS	Total Suspended Solids
TWW	Treated Wastewater
WR	Water Requirement

WUE	Water Use Efficiency
WWT	Wastewater Treatment
FC	Fecal Coliform
Na	Sodium
NO_3	Nitrate
EC	Electrical Conductivity
ds	Desisemins
^oC	Degree Celsius
m	Meter
cm	Centimeter

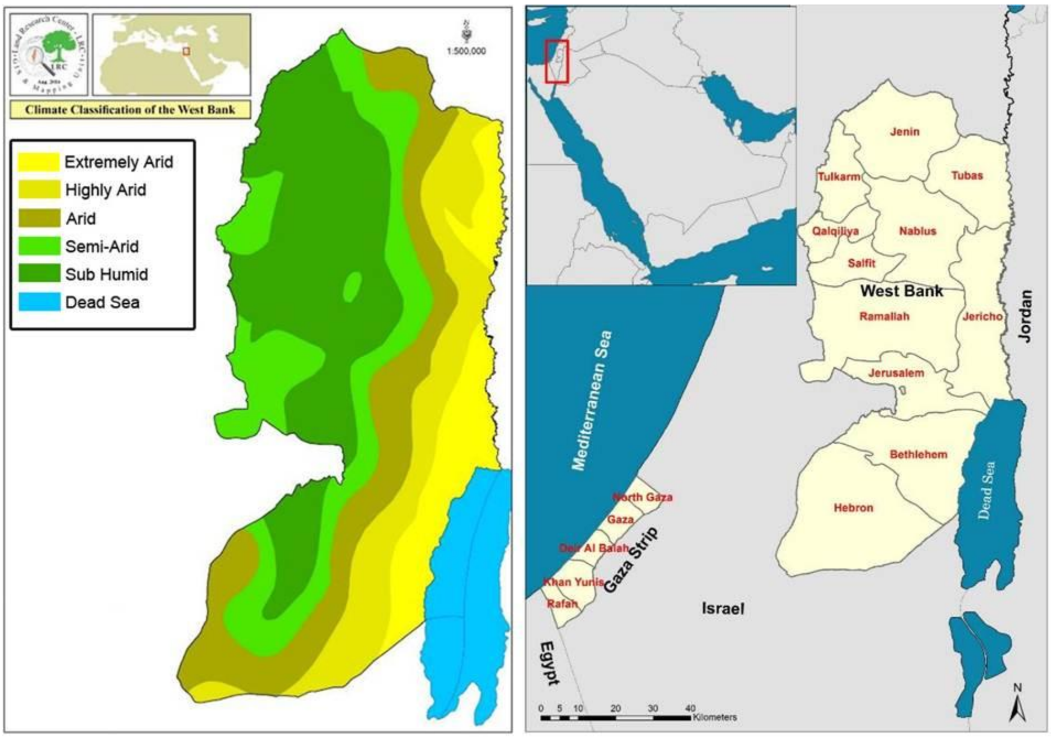
Chapter One: Introduction

1.1. Background

Water shortage is the most important environmental problem in the Mediterranean countries (Morugán-Coronado *et al*., 2011) and with increasing population growth will be exacerbated this problem with its negative effects on humanity. Whereas, the food demand will be increased causing food insecurity and wastewater production will be increased.

Irrigation plays a vital role in increasing crop yield which is essential factor for agricultural feasibility. Also, treated wastewater reuse is a common practice in Mediterranean countries (Pedrero *et al*., 2010) as in arid and semi-arid areas, and it is considerable source for many purposes (Moghadam *et al*., 2015; Bardhan *et al*., 2016) especially for irrigation (Balkhair *et al*., 2014; Elmeddahi *et al*., 2016) due to has fertilizing material such as N, P, soil fertility and soil organic matter which it enhances growth of forage crops (Babayan *et al*., 2012). Whereas, using of treated wastewater in irrigation increases the crop productivity (Mohammad and Ayadi, 2004; Hassanli *et al*., 2009; Alkhmisi *et al*., 2011; Khan *et al*., 2012), serves fresh water resources and reduces disposal of wastewater to the environment (Pedrero *et al*., 2010; Urbano *et al*., 2017).

Palestine is one of the MENA countries suffer from severe and growing water shortage and it has varied climate ranged from semi-arid in the west to extremely arid in the east and southeast Figure 1. Noticeably, Palestine has water shortage due to the Israeli occupation over pumping of groundwater that exceeds the total annual rainfall recharge rate and has water scarcity resulting from Israeli occupation obstacles where the access to more than 20% of water resources is not available for the Palestinian societies from water resources (PWA, 2012).



Aridity Classifications for the West Bank (LRC, 2014)   General location of the WBGS (FAO, 2014)

Figure 1: Aridity classification for the West Bank (LRC, 2014)

The main Palestinian water source is ground water which represents more than 90 % of the available sources. The total annual discharge from the groundwater aquifers is approximately 126.3 MCM for domestic uses and 118 MCM for agricultural uses in the west bank. Furthermore, about 15 MCM of the Palestinian wastewater production is treated inside Israel from all streams crossing the border to Israel and the Palestinian Authority pay around 42 million US$ yearly since 1996 for the Israeli occupation to treat the Palestinian wastewater then the Israeli occupation uses this treated wastewater without any compensation for this lost resource (PWA, 2012).

Due to the difficult situation of agricultural water the irrigated agricultural land represented around 19% of the total agricultural area in Palestine compared with 37% in Jordan and 59% in Israel. Moreover, the field crops represent around 24%, 23% from the total agricultural land in the West Bank and Gaza strip, respectively, which mostly cultivate as a rainfed (MoA, 2017). As in other countries agriculture in Palestine is the major sector of water use, which was reported to be 45% of the total water consumption, even though this quantity is not enough for irrigation demand (MoA, 2017), which represented the main restriction factor for developing the agricultural sector. Therefore, the fluctuation of agricultural sector has been attributed to the fluctuation of the water availability that has a negatively impact on the agricultural production (MoA, 2017).

Livestock sector is one of the important sectors in agriculture in the West Bank which represented around 47% from the agricultural activities. Also, the total contribution of cattle, sheep and goats estimated around 61% of the total livestock production which are feeding mainly on forage crops such as Clover, Parley, Wheat, Vetch and Alfalfa (MoA, 2016).

The feeding material cost represents around 85% of the livestock production cost (MoA, 2016), where 80% of the fodder is consumed has been imported from Israel which is subjected to the fodder supply and demand in the Israeli market resulting in more gradually increase of the fodder price (MoA and PWA, 2014).

Among the several types of fodder, Pearl millet crop is the superior for feeding livestock animals in the world due to its high nutritional value and phytochemicals with antioxidant properties (Rai *et al*., 2008). Furthermore, pearl millet are highly tolerant to drought, soil salinity and high air temperatures, which adapted under increasing severity of abiotic production constraints and make them more invulnerable to climatic change (Zegada-Lizarazu and Iijima, 2005; Rai *et al.*, 2008). On the other hand, pearl millet has higher nitrogen use efficiency which represents a vital farm factor for economic and environment sustainability (Thivierge *et al*., 2015) such as ground water quality.

A great challenge for the agricultural sector is to produce more food from less water use. So, adoption of optimum water management practices considers prime importance for attaining national food and water security which can be achieved by improving the (WUE) that will eventually improve the production. Thereafter, highly WUE will achieve by selection an efficient irrigation system (Sinobas and Rodríguez, 2012) and use an optimal crop water requirement (English and Raja, 1996; Kirda, 2002; Fereres and Soriano, 2007; Lorite *et al.*, 2007; Geerts and Raes, 2009). For the above reasons in Palestine it is highly important to explore an optimal irrigation management to enhance the water use efficiency.

Globally, the irrigation water quantities of pearl millet as grain production in terms of WUE had been investigated (Maman *et al*., 2003; Diouf *et al*., 2004; Seghatoleslami *et al*., 2008; Nagaz *et al*., 2009; Singh *et al*., 2010; Yadav *et al*., 2014). But none of them focused on fresh or dry forage yield with regards to WUE. Also, there are few studies that explored the effect of irrigation water quantities on pearl millet as green or dry forage yield of one cut at the end of cropping cycle in terms of WUE (Ibrahim *et al*., 1995; Payne and Sattelmacher, 2000; Zegada- Lizarazu and Iijima, 2005; Ismail, 2012; Jahansouz *et al*., 2014). Otherwise, there are very few studies that explore the effect of irrigation water quantities on pearl millet crop production as green or dry forage yield of many cuts through the cropping cycle in terms of WUE (Ismail, 2012; Ismail *et al*., 2018), but at the same time studies examining the effect of irrigation system on WUE in pearl millet fresh or dry production are very limited (Ismail, 2012; Hassanli *et al*., 2009; Ismail *et al*., 2018). None of the previous studies investigated the combining irrigation system with using TWW and irrigation quantities for irrigation of pearl millet fresh production. Therefore, this study is participating in the efforts of assessing the effect of irrigation system and irrigation water quantity on WUE using TWW in irrigating pearl millet.

In Palestine pearl millet is a potential crop that participates in fodders availability. Elaborating this aspect to the use of TWW as irrigation source in a sounded efficient management has a positive impact on the economic status of farmers and improves food security.

1.2 Objectives

The overall objective of this research is to find the highest aboveground biomass production of pearl millet per unit of water application. The study is focusing on using treated wastewater in irrigation. To achieve the overall objective, the following specific objectives are tested:-

1. Effect of using both surface and subsurface drip irrigation systems on pearl millet crop productivity as a forage crop.
2. Effect of using different irrigation water quantity on pearl millet crop productivity as a forage crop.
3. Effect of using both surface and subsurface drip irrigation systems on WUE.
4. Effect of using different irrigation water quantity on WUE.

1.3 Research questions

Research questions formulated as the following:-

- Which of the irrigation systems (surface or subsurface) can be used in order to get the highest yield of pearl millet production?
- Which of the irrigation water quantity can be used in order to get the highest yield of pearl millet production?
- Which of the irrigation systems (surface or subsurface) can be used in order to get the highest water use efficiency?
- Which of the irrigation water quantity can be used in order to get the highest water use efficiency?

Chapter Two: Literature Review

2.1. Palestinian treated wastewater status

Palestinian Agricultural sector facing a big challenge in agricultural water shortage resulted in reducing the irrigated agricultural land which becomes around 19% compared with the rainfed agricultural land (MoA, 2017).

Palestinian national climate change adaptation plan considered TWW as one of Agricultural water resource (EQA, 2016) and the Palestinian government push toward increase the amount of TWW to be reused in irrigation and other purposes since few years ago (PWA, 2014). The expected of TWW production from wastewater treatment plants that can be used in agriculture in West Bank by the year of 2022 shown in Table 1.

Table 1: Expected TWW production that can be used in the West Bank 2022

WWT plant	TWW production yearly (MCM)
West Nablus	4.38
Jenin	1.64
Jericho	2.33
Anza	0.1825
Biet-Dajan	0.1825
Al-Taybah and Rammon	0.1059
Hajja	0.1825
Sarra	0.1825
Mesylia	0.1825
Tayaseer	1.825
Hebron	5.11
Al-Teera	0.365
Rawabi	0.1825
Saeer	0.438
Total	20.1079

As shown in Table 1 the total TWW expected to be reused in irrigation annually by the year of 2022, around 20.1 MCM which can represent around 13 % of the current conventional agricultural water (MoA, 2017) and can be consider as additional agricultural water.

The second strategic objective for the National Agriculture Sector Strategy (2017-2022) is "Natural and agricultural resources sustainably managed and better adapted to climate change ". Therefore, MoA aimed to increase the availability of conventional and unconventional water resources for both crop producers and livestock breeders (MoA, 2017).

There is a possible to increase the amount of TWW by establish new WWT plants where 56 % of the residents are connection with sewerage network system (PCBS, 2018) while the existing WWT plants cover around 50 % of the total wastewater production in Palestine (PWA and MoA, 2014)

2.2. Palestinian treated wastewater and reuse regulations

MoA and Palestinian Water Authority (PWA), Palestinian Standards Institute (PSI), Palestinian Environmental Quality Authority and others are great interest for treated wastewater and the importance of treated wastewater reuse for the Palestinian situation. Since 2003, the Palestinian government has issued the Agricultural Law (No 2/2003) that defined the TWW as one a water source. As well, Palestinian Standards Institute has issued at that time a Treated Wastewater Standard (PSI 742-2003) which identifies the important parameters levels to be taken into consideration if deciding that the wastewater should be treated and the requirement needed for TWW production could be discharged or reused. Since 2011, MoA issued instructions for treated wastewater reuse in agriculture (MoA Technical Instructions/2011) based on the Agricultural Law (No 2/2003). Furthermore, Palestinian Standards Institute has issued the Obligatory Technical Regulations (PSI TR 34, 2012) Annex 1 that divided the quality of treated wastewater specialized for irrigation into 4 categories, high quality (A), good quality (B), moderate quality (C), and low quality (D) and it also contain the obligatory regulations and technical instructions requirement for controlling, permitting, conveying and reusing of TWW in irrigation.

Recently, Palestinian Standards Institute has issued the Treated wastewater – Treated Wastewater Effluent for Agricultural Purposes (Restricted) (PSI 742-2015) in 2015 to cope with the gradually increased the production of TWW. It is determining the classification of treated wastewater quality and the crops include fodder crops, fruits, ornamentals and others could be irrigated with the specific TWW quality produced and the number of barriers approach to utilize each treated wastewater quality in irrigation for different crops whereas the barriers include actions such as positioning the emitters at a distance far from crop canopy, utilizing subsurface drip irrigation system, utilizing filters for irrigation water, storing irrigation water, cutting off irrigation before harvesting and other possible actions that the farmer could be utilize in the farm to reduce the possibility of contamination the fruit with treated wastewater.

The key regulatory documents regarding with wastewater treatment and reuse in Palestine are the Water Law No. (3) of year 2002, the Agricultural law No. (2) of year 2003, the Agreements with Israel, particularly the Memorandum of Understanding of December 2003, the Environmental Law No. (7) of year 1999 and the Water Law No (14) of year 2014.

The following are the Palestinian laws and regulations related to treated wastewater and its reuse:-

- Law 7/1999: The Palestinian Environmental law, 1999.
- Law 3/2002: The Palestinian Water Law, 2002.
- Law 2/2003 : Agricultural Law, 2003.
- PS 742/2003: The Palestinian Treated Wastewater Standards, 2003.
- MoA Technical Instructions/2011: The Ministry of Agriculture technical instructions for treated wastewater reuse in agriculture, 2011.
- TR 34/2012: Technical Regulations for the reuse of treated wastewater in irrigation (PSI, TR-34, 2012) Annex 1.
- The Palestinian Water Law 2014.
- PS 742/2015: The Palestinian Amended Treated Wastewater Standards, 2015.
- MoA Reuse permission template/2016: MoA licensing procedures, 2016.

Accordingly the MoA is responsible for the reuse of TWW activities and provides guidance and advice to the farmers on cropping pattern and good agricultural practices, as well as marketing of produce. It serves as a permitting, monitoring and extension agency for reusing treated wastewater in irrigation.

2.3 Millet species

Millets are grass crops include five genera, *Panicum, Setaria, Echinochloa, Pennisetum, and Paspalum*. Wherever, all of the tribe *Paniceae*; one genus, *Eleusine*, in the tribe *Chlorideae*; and one genus, *Eragrostis,* in the tribe *Festuceae* included in millet group. The most important cultivated millet species are foxtail (*Setaria italica*), pearl or cattail millet (*Pennisetum glaucum*), proso (*Panicum miliaceum*), Japanese barnyard millet (*Echinochola crusgalli*), finger millet (*Eleusine coracana*), browntop millet (*Panicum ramosum*), koda or ditch millet (*Paspalum scrobiculatum*), and teff millet(*Eragrostis tef*) (Baker, 2003).

Pearl millet (*Pennisetum glaucum, P. typhoides*, *P. tyhpideum*, *P. americanum*) is the most widely grown of all millets which considered the biggest species cultivation for almost half of global millet production. It is also known as bulrush millet, babala, bajra, cumbu, dukhn, gero, sajje, sanio or souna (FAO and ICRISAT, 1996).

2.4 Pearl millet distribution

Pearl millet has a wide geographic distribution as in Western Africa, particularly in the Sahel; in Central, Eastern and Southern Africa; and in Asia, in India and Pakistan and along the southern coast of the Arabian Peninsula. Therefore, Pearl millet had been adopted as summer forage in the southeastern coastal plain of the United States as a grain crop (FAO and ICRISAT, 1996; ICRISAT, 2016).

2.4 Pearl millet crop description

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an erect annual grass, reaching up to 3 m high with a distribute root system. It considered as C4 plant which uses C4 carbon fixation (Andrews and Kumar, 1992). It can be grown between 14 and 32°, N and S, and in every dry tropical area. It thrives well where other C4 cereals (maize, sorghum) cannot grow because of drought or heat. It can be found in regions where annual rainfalls range from 125 to 900 mm. Ideal growth temperatures range from 21°C to 35°C. Pearl millet is known to tolerate acid sandy soils and is able to grow on saline soils (FAO, 2009). Furthermore; pearl millet is able to grow in scarce conditions (irrigation with high level of water salinity) without losing nutritive value (Fahmy *et al*., 2010). Where, Pearl millet is critically important for food security in some of the world's hottest and driest areas. As well, in some countries, millet is sown as a catch crop when sowing conditions for the main crop are unfavorable (FAO and ICRISAT, 1996).

Climate change is one of the most vulnerable issues affected on agricultural sustainability and it will cause increase about 10% of dry land areas in the world. while, Pearl millet is a hardy, climate smart grain crop, idyllic for environments prone to drought and heat stresses (O'Kennedy *et al*., 2009; Ullah *et al*., 2017), has high crop growth rate, large leaf area index and high radiation use efficiency that gives its high potential yield (Ullah *et al*., 2017). Therefore, it is best to adopt this crop within Palestinian agricultural fodder crop.

Pearl millet can be adapted on poor and sandy soils in dry areas that are unsuitable for maize, sorghum or finger millet. Where, Pearl millet had the highest yield of all millets under drought and heat stress. However, pearl millet is more efficient water use crop than sorghum or maize (FAO and ICRISAT, 1996). Moreover, the highest average value of water use efficiency (27 kg/m^3) was obtained by the application of improved management practices for pearl millet crop compared with Fodder beet, Egyptian clover and Barley crops where the WUE was 16, 20, and 21 kg/m^3, respectively (El Shaer and Al Dakheel, 2016).

According to above mentioned, Pearl millet has been introduced to Palestinian territories by Ministry of Agriculture to evaluate its suitability on the prevailing conditions due to it is highly tolerant crop to drought and soil salinity, and then to disseminate it as forage crop into the forage crops that are cultivated in Palestine which can be enhanced the livestock farmers by reducing livestock feeding material cost by making it available in the Palestinian market at affordable price due to the 85% of livestock feeding material imported from Israeli market at high price.

2.5 Pearl millet utilization

Pearl millet is grown as a staple food for human consumption in many parts of Africa and Asia because it has a high-energy and nutritious value (FAO and ICRISAT, 1996; O'Kennedy *et al*., 2009) and for feeding livestock as poultry, pigs, cattle and sheep (FAO and ICRISAT, 1996; Myers, 2002; Havilah, 2011)due to has high-energy and high-protein ingredient compared with maize and sorghum (FAO and ICRISAT, 1996; O'Kennedy *et al*., 2009).

On the other hand, Pearl millet can be offered to livestock as fresh forage, dry forage, pasture and silage (Cook *et al*., 2005; Teutsch, 2009). Nevertheless, pearl millet can be grazed at 40-50 days after sawing date, but it should be grazed above 15-30 cm (Lang, 2001; Teutsch, 2009). Grazing or cutting at boot stage is advisable, because it increases the productivity and the crop cycle by maintains high nutritive value (Andrews and Kumar, 1992; Morales *et al*., 2014). On the other hand, Pearl millet intended for dry matter should be cut at the boot stage with advisable interval between cuttings is 3-4-week and 2-3 cuts can be taken during the hot condition (Lang, 2001; Teutsch, 2009). Pearl millet can be ensiled at any crop cycle stage and maintain better nutritional value than hay at the soft dough stage (Morales *et al*., 2011). Moreover, Pearl millet silage yield is better than other silages crops in South Africa (Andrews and Kumar, 1992). In the same time, pearl millet silage making protein content more soluble than other forms (Hassanat, 2007; Guimarães *et al*., 2010).

Finally, pearl millet produced in developed country as a forage crop in order to feed animals (Basavaraj *et al*., 2010). Hence, the Palestinian Ministry of Agriculture is aiming to adopt this crop for livestock breeders as forage crop due to the forage unavailable and the grain is unknown in the foods of Palestinian society.

2.6 Pearl millet Nutritional Value

Pearl millet is palatable to livestock but its nutritive value depends on variety, growing conditions, stand management and preservation methods.

Among the several types of fodder, Pearl millet crop is the superior for feeding livestock animals in the world due to its high nutritional value include protein with more balanced amino acid profile, dietary energy, vitamins, several minerals especially micro nutrients such as iron and zinc, insoluble dietary fiber leading to lower glycemic index, and phytochemicals with antioxidant properties (Rai *et al*., 2008).

The pearl millet fresh forage is good digested by ruminants due to crude protein content varies from 6 to 20% with dry matter digestibility being about 66-69% (Guimarães *et al*., 2010).

Pearl millet fresh forage has 66.6% dry matter digestibility in vitro for sheep (Cherney *et al*., 1990a) but in form of hay varied between 73.9%-64.4% dry matter digestibility (Cherney *et al*., 1990a; Cherney *et al*., 1990b). while, Pearl millet offered to dairy cows as fresh is palatable for a period of three-years and it can gain medium to high milk yield (19.8 kg/day) and lower weight losses than both Sudan grass or Sorghum x Sudan grass hybrid (Clark *et al*., 1965). Also, it can maintain 13 to 15 kg milk daily by cow through the pre-dry season without additives (Benedetti, 1999).

Pearl millet is a considerable pasture for sheep through strong drought condition and it was able to support higher stocking rates than native grassland included four grasses (*Andropogon gayanus, Brachiaria decumbens, Panicum maximum* and *Pennisetum purpureum*) or improved native legumes (*Gliricidia sepium* and *Leucaena leucocephala*) whereas the average stocking rate was superior in (91.4

kg leaves weight(LW)/dunum of pearl millet versus 26.1 and 46.7 kg LW/dunum of native grassland and improved native legumes, respectively) and resulted in superior daily weight gains by fed on pearl millet (151g/d) versus native grassland (53 g/d) and improved native legumes (58g/d) (Brum *et al*., 2008).

Pearl millet grown under a warm climate succeeded the needed requirement of metabolizable protein to gain high yielding dairy cows 30 liters milk daily by cow when they fed on 11.6 kg DM daily. While, pearl millet forage may not give the energy needs of lactating dairy cows (Fulkerson *et al*., 2008). Otherwise, Pearl millet taken up by lactating dairy cows as silage that either consist of 50% (DM) pearl millet in a lucerne concentrate-based diet silage or 36% (DM) of pearl millet in a concentrate-based diet maintain 24-26.3 liter of milk daily production (Messman *et al*., 1991; Kochapakdee *et al*., 2004) that contain 3.6% and 2.8% milk fat and protein content, respectively (Kochapakdee *et al*., 2004). On the other hand, the DM digestibility was 64.3% when the silage consisted 38.5% DM of pearl millet taken up by 325 kg dairy heifers resulting in increased 2.4% of body weight (Jaster *et al*., 1985).

Feeding older beef heifers 15 months aged with 250 kg weighting on pearl millet forage over 3 months reported that a growth rate was 0.8 kg daily (Montagner *et al*., 2009). Pearl millet pasture, either fertilized or unfertilized offered for 13-14 month aged steers with weighing 230 kg backed up live-weight daily gains 0.553 kg of unfertilized to 0.764 kg in fertilized pasture (Moojen *et al*., 1999).

The intake and digestibility of pearl millet forage crude protein as hay by goats are higher than Sudan grass, elephant grass or sorghum (Aguiar *et al*., 2006). Pearl millet hay compared with clover hay for feeding goat indicated that there was no differences on the propagation of female goats and the kids behavior (Hanafy *et al*., 2007).

Pearl millet has higher protein (8 to 60%) and lysine (40%) than corn. Also, pearl millet is much lower in tannin and hydrocianide than sorghum (Sedivec and Boyles, 1993; Myers, 2002) thus it can be suitable forage for livestock animals.

2.7 Effect of using treated wastewater with different irrigation systems and different water quantity on Pearl millet productivity and water use efficiency

2.7.1 Background

An agricultural sector facing an escalate challenge to cope with increasing food demand which is affected by water availability (Zwart and Bastiaanssen, 2004). Where, an arid and semi-arid region have forage deficiency resulting from water shortage and water scarcity (Rostamza *et al*., 2011) as well as, suffers from deficiency in food demand (Hassanli *et al*., 2009).

Adoption of optimum water management practices considers prime importance for attaining national food and water security. Therefore, many researchers have been trying to find the ways that can improve the water use efficiency that will eventually improve the production. So, selection an efficient irrigation system will be achieve the efficient water use (Sinobas& Rodríguez, 2012) in addition to use an optimal water quantities will achieve the efficient water use (English and Raja, 1996; Kirda, 2002; Lorite *et al.*, 2007; Fereres and Soriano, 2007; Geerts and Raes, 2009). As well as, selection an unconventional water resources for irrigation purpose will be decrease the growing pressure on freshwater resources in addition to alleviate the negative environmental impact of disposal wastewater to the environment.

2.7.2 Effect of irrigation system on crop productivity and water use efficiency

There are many irrigation systems using for forage production as pearl millet, corn, alfalfa, Turf grass, Sudan grass and Bermuda grass in the world including, SDI, SSDI, sprinkler irrigation system and furrow irrigation system. While, in Palestine they have a common irrigation systems which are represented by surface drip irrigation system and sprinkler irrigation system.

Recently, MoA recommended farmers to use SSDI for irrigation alfalfa using TWW to reduce the water losses resulting from evaporation which lead to less accumulation salts on the soil surface which consequently not threat the germination seeds. The recommendations of the Palestinian Ministry of Agriculture is not tested on the ground yet in terms of using this kind of irrigation system on pearl millet or alfalfa on WUE, but it is rising from the regulations which consider the SSDI as barrier for health protection.

SSDI refer to apply the irrigation water beneath the soil surface by drip irrigation system (ASAE, 2007).

WUE is a term referring to yield as weight divided by the water consumption, its term used for evaluating the efficiency of the agricultural practices used for crop production related to amount of irrigation water.

Using SSDI comparing with SDI and sprinkler irrigation system on sandy loam soil at arid region showed that the SSDI gave highest fresh and dry biomass which leads to higher WUE of pearl millet forage crop than the other irrigation systems (Ismail, 2012). Moreover, an experiment conducted during two consecutive growing seasons on sandy loam soil at arid region showed that the SSDI gave highest fresh and dry biomass and water use efficiency of Pearl millet and Sudan grass followed by surface drip irrigation and sprinkler irrigation in all cuts of both growing season (Ismail *et al*., 2018).

Furthermore, using SSDI compared with SDI and furrow irrigation in an experiment conducted in 2005/2006 on clay loam soil in an arid region revealed that the highest corn yield was obtained with SSD followed by SDI and furrow irrigation. As well, water use efficiency was highly significant difference where the highest WUE was obtained with the SSDI (2.12 kg/ m^3) and the lowest was obtained with the furrow irrigation system (1.43 kg/ m^3) (Hassanli *et al*., 2009).

Using an efficient irrigation system for pearl millet production is very important issues to sustain this forage cultivation in areas have water shortage and water scarcity. Wherever, SSDI is very efficient system for many crop production (Devasirvatham, 2009; Sinobas and Rodríguez, 2012; Lamm, 2016) resulting from reducing or eliminating soil evaporation (Sinobas and Rodríguez, 2012; Mali *et al*., 2016), surface runoff, deep percolation (Sinobas and Rodríguez, 2012) and salt accumulation at upper soil surface which if they occur will be threatened the germination seeds and leached the salt when rainfall precipitation occurred (Lamm, 2016). As well, SSDI reduce the harvesting restriction elements results from the wet surface area, harvesting equipment and their negative compaction impact, and drip line system arrangement which lead to increase the productivity and to eliminate the additional labor cost causing from withdrawing the drip lines and then reinstall them to avoid the harvesting process obstacles (Hutmacher *et al*., 2001; Lamm, 2016). Also, remain the soil moisture more stable relatively (Mali *et al*., 2016) as showed in maize production on sandy loam soil (Douh and Boujelben., 2011; Douh *et al.,* 2013), increase nutrient availability (Mali *et al*., 2016) and consequently increased WUE (Douh and Boujelben., 2011; Douh *et al.,* 2013). Moreover, irrigation with SSDI resulted in reducing soil salinity compared with SDI in arid region when irrigated with moderately saline water that has EC = 7 ds/m thus, the WUE is improved (El Mokh *et al*., 2014).

Many researchers studied the effects using different irrigation systems on yields of 30 crops which indicated that the yield had been increased by SSDI than or equal to other irrigation systems and it's required less water in most cases (Camp, 1998). Furthermore, an experiments for 15 years conducted at the USDA Water Management Research Laboratory concluded that yield and water use efficiency of crops include, tomato, cotton, sweet corn, alfalfa and cantaloupe had been increased significantly using subsurface drip irrigation system (Ayars *et al*., 1999).

Crop response to the irrigation system used varied in terms of productivity where there are many factors affecting including crop types, crop species, climate, soil type, dripline depth, dripline spacing, irrigation frequency, irrigation quantity and fertigation frequency as pointed out by Lamm (2016).

According to Lamm (2016) who reviewed several studies on the effect of using SSDI over other irrigation systems on many crops including corn, cotton and tomato, he concluded that the increment yield using SSDI than other irrigation systems ranged from (- 10% to + 65%) for cotton tile yield, from (-51% to + 38%) for corn grain yield and from (- 32% to +205) for tomato.

Moreover, according to the previous literature studies there are very few studies investigated the effects of irrigation systems on pearl millet forage productivity and WUE (Ismail, 2012; Ismail *et al*., 2018). As well, there are no studies examining the effect of irrigation systems on WUE of pearl millet irrigated with TWW neither globally nor locally.

As a result, it's important to test an effectiveness use of SSDI in irrigation in Palestine as a way to reduce irrigation water consumption and increase WUE in terms water shortage, less agricultural water availability and food insecurity.

2.7.3 Effect of water deficit on productivity and water use efficiency

Irrigation water amount that consumed for crop production is the key factor for evaluating the WUE and to achieve the efficient water use must be examine the effects of different irrigation water amount on crop productivity as a way in areas have water scarcity.

The effective management to obtain high WUE which ultimately achieves the desired economical returns and conserve the water by applying less water is main goals in the regions have water scarcity (Panda *et al*., 2004) and inefficient water use as in Palestinian territories. As well, under the drought conditions, more production per unit of irrigation water applied is the main concern (Zegada-Lizarazu and Iijima, 2005).

Studies on WUE of pearl millet cultivated in different soil types as sandy loam, sandy and clay loam soil showed that the WUE had been increased under deficit irrigation in arid and semi-arid regions (Nagaz *et al*., 2009; Rostamza *et al*., 2011; Ismail *et al*., 2018). Otherwise, plant height, fresh and dry yield of Pearl millet and Sudan grass had been decreased with increasing water deficit. In the same time, WUE had been increased with increasing water deficit using both SSDI and SDI (Ismail *et al*., 2018). As well, Pearl millet yield cultivated on sandy soil in arid region had been increased with decreasing water stress (Nagaz *et al*., 2009). Also, Pearl millet planted in sandy soil showed higher plant height, dry matter and fresh yield when irrigated than rainfed condition in semi-arid area (Yadav *et al*., 2014).

WUE of forage maze planted in loamy sand soil had been increased with increasing water deficit. While, the fresh forage yield was increased with increasing water application (Alkhamisi *et al*., 2011). Furthermore, in an experiment of alfalfa planted on sandy clay loam indicated that fresh and dry forage were increased by increasing applied water amount from 50%, 75% to 100% of crop water requirement, respectively, while the WUE decreased (Ismail and Almarshadi, 2011).

As well, WUE of wheat, rice, cotton and corn increased significantly with deficit irrigation as reviewed by (Zwart and Bastiaanssen, 2004). Moreover, Kang *et al.* (2017) reviewed several studies of the effect of deficit irrigation on WUE, and they concluded that the WUE had been increased with deficit irrigation compared with full irrigation.

Generally, many researchers studied the effects of deficit irrigation on pearl millet crop production as grain yield regarding to WUE and they found beneficial increments in WUE under deficit irrigation. Even though, water deficit is reduced grain yield of Pearl millet (Maman *et al*., 2003; Diouf *et al*., 2004; Seghatoleslami *et al*., 2008; Nagaz *et al*., 2009; Yadav *et al*., 2014). Besides that, those studies did not focus on fresh or dry forage yield with regards to WUE. On the other hand, the studies that explore the effect of deficit irrigation on pearl millet crop production as green or dry forage yield of one cut at the end of cropping cycle in terms of WUE are few (Ibrahim *et al*., 1995; Payne and Sattelmacher, 2000; Zegada- Lizarazu and Iijima, 2005; Ismail, 2012; Jahansouz *et al*., 2014) and they found increased in WUE under deficit irrigation except Ibrahim et al (1995) and Jahansouz *et al.* (2014) reported that the WUE of pearl millet had been decreased with deficit irrigation. Otherwise, there are very few studies that explore the effect of deficit irrigation on pearl millet crop production as green or dry forage yield of many cuts through the cropping cycle in terms of WUE for optimizing crop water use and they found that the WUE increased under deficit irrigation (Ismail *et al*., 2018) except Ismail (2012) showed that the WUE of pearl millet decreased with deficit irrigation.

As a result, the main concern in the Palestinian agricultural sector in terms of water unavailability is the production per unit of applied water rather than the absolute production which is the best option to deal with this raising challenge. So, the examination of WUE for irrigated crops is the most important role to conserve water.

2.7.4 Effect of using treated wastewater on crop productivity and water use efficiency

Irrigation plays a vital role in increasing crop yield which is essential for agricultural feasibility. And since Palestinian territories have water shortage and water scarcity that encouraged an exploration for finding an alternative water resources. TWW can be considered as alternative water resource for irrigation which will help to alleviate water shortage naturally (Capra and Scicobone, 2004; Elmeddahi *et al*., 2016). In addition to save fresh water resources reusing of treated municipal wastewater for irrigation will reduces disposal of wastewater to the environment (Pedrero *et al*., 2010; Urbano *et al*., 2017). Reuse of treated wastewater for irrigation purposes is exist in many countries (USEPA, 1992; Toze, 2006; Pedrero *et al*., 2010; Belaid *et al*., 2012; Lal *et al*., 2015; Schacht *et al*., 2016). Such as Mediterranean regions which it has been increased over the last decades to cope with water shortage and uneven rainfalls precipitation due to climate change (Lonigro *et al*., 2015) and in arid and semi-arid areas wastewater is considerable source of irrigation water (Balkhair *et al*., 2014; Bardhan *et al*., 2016) in addition to have fertilizing materials such as N, P, soil fertility and soil organic matter which enhance crop growth (Babayan *et al*., 2012; Lonigro *et al*., 2016) which leads to increase crop productivity (Mohammad and Ayadi, 2004; Hassanli *et al*., 2009; Alkhmisi *et al*., 2011; Khan *et al*., 2012; Minhas *et al*., 2015) and increase the concentration of the N, absorbable P and absorbable K in the soil (Kaboosi, 2016)

An exploring the effect of using TWW in irrigated different pearl millet genotype on fresh and dry yields indicated that fresh and dry yields had higher with TWW than freshwater without any negative impact on chemical characteristics neither in plant nor soil (Alkhamisi *et al*., 2016).

Moreover, using treated wastewater in irrigation of alfalfa crop comparing with saline ground water showed that treated wastewater is a suitable alternative irrigation source due to the NO_3^--N had been increased in soil irrigated with treated wastewater (Adrover *et al*., 2017).

Palestinian Agricultural sector suffering from freshwater unavailability for all purposes as well as forage production deficiency which consequently lead to food insecurity. So, to deal with this raising challenges the Ministry of Agricultural strategy define in one of those strategic goals that is increasing the quantity of conventional and unconventional water availability to the farmers and livestock breeders and raise its use efficiency (MoA, 2017). In order to achieve the above goal, reuse of TWW in irrigation is the most effective things to alleviate the water unavailability to provide more water for irrigation and to sustain agricultural productivity (Minhas *et al*., 2015). Taking into consideration that Pearl millet is remained agricultural answer for some countries have water scarcity and food insecurity (Satyavathi *et al*., 2015; Shukla *et al*., 2015; Ullah *et al*., 2017) that we are facing due to it is considered as water saving, drought tolerant and climate change compliant crop. Hence, it's important to explore the effect of irrigation quantity using TWW, to optimize pearl millet crop productivity in terms of WUE since there are a few studies globally mentioned above examining only the effect of TWW on pearl millet crop productivity and there is one study in Palestine focusing on pearl millet genotypes productivity with treated grey water which it is differ in their characteristic from TWW, as well, their experimental condition differ from my study condition which carried out in the field.

Chapter Three: Materials and Methods

3.1 Study area

The research was carried out in Marj Ibn Amer in Jenin governorate where secondary treated wastewater is generated from the adjacent wastewater treatment plant serving Jenin city.

Marj Ibn Amer is located in the north part of the West Bank North West Jenin governorate. Topography of the Marj is mainly flat with slightly undulating low hills. The elevations are about 100 meters above sea level. The soils are dark, heavy, deep and classified as clay throughout the Marj. These soils are fertile and have formed the basis for intensive agriculture. The irrigation water used there comes from groundwater wells which are limited in addition to the TWW generated from Jenin Wastewater Treatment (WWT) Plant which is exploited for Marj Ibn Amer irrigation scheme as shown in Figure 3.1 where this area is bordered by green - black dotted line.

This area has a Mediterranean semiarid climate, with an average monthly temperatures range from 9.1°C in January which is the coldest month to 33.8°C in August which is the hottest month. The average wind speed is about 113 km/day, and the average monthly of relative humidity has 66% with minimum values in the warmer months. Average annual rainfall throughout the Marj Ibn Amer is between 400 and 450 mm and the rainfall season starts mainly in October and extent to April and the maximum rain fall occur in Jan. /Feb. with 50 mm /month (www.pmd.ps).

The area is suitable to be cultivated by pearl millet crop according to the climatic condition.

Figure 3.1: Whole area designated for reusing treated wastewater in Marj Ibn Amer scheme (MoA, 2015)

3.2 Experimental Design

An experiment was conducted based on a split plot design with three replicate. The main plots consisted tow irrigation systems including (SSDI and SDI). The sub-plot comprised three irrigation water quantities (100% WR, 75% WR and 50% WR). As a result, there were six different treatments in the experiment including treatments (SSDI 1, SSDI 2, and SSDI 3) correspond to the SSDI with (50, 75 and100 % WR), respectively, and treatments (SDI 1, SDI 2, and SDI 3) correspond to the SDI system with equivalent water quantities. The experimental sub-sub plots were distributed throughout the research field which included 18 sub-sub plots as shown in Figure 3.2.

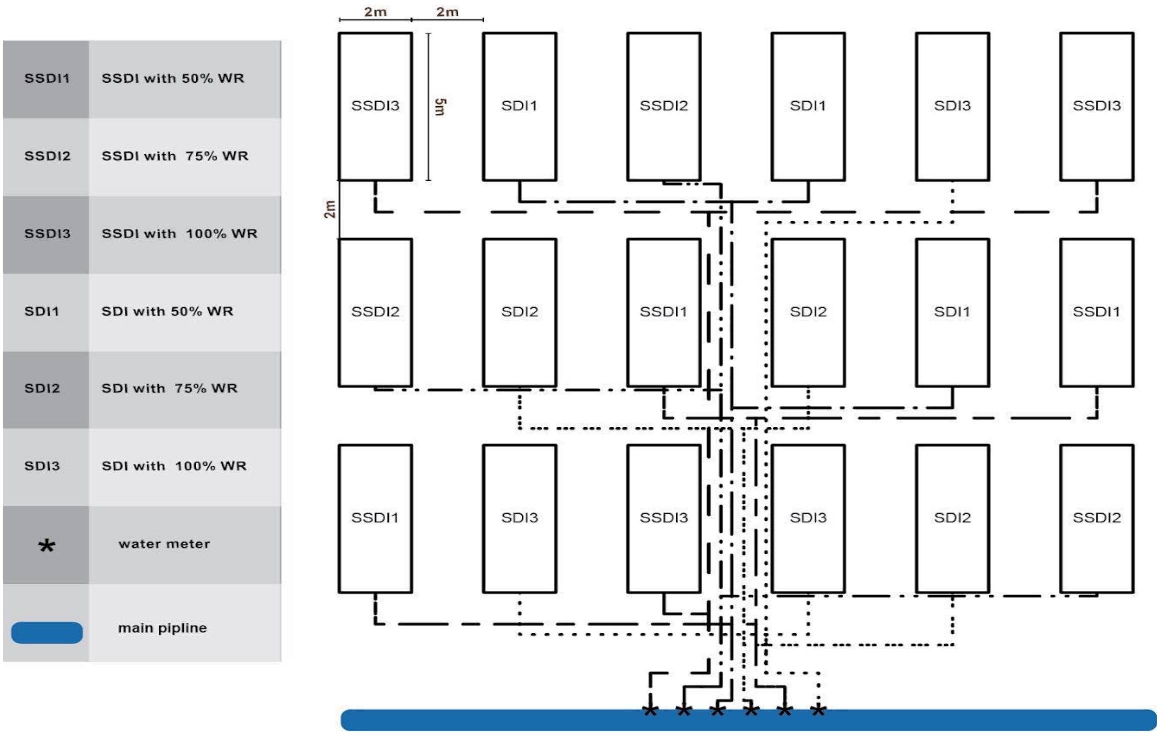


Figure 3.2: Field experiment design and irrigation system distribution; where, SDI: Surface drip irrigation; SSDI: subsurface drip irrigation system; WR: water requirements

3.3. Irrigation System Description

New pressure-compensating drippers with a working interval ranging from 80 to 430 kPa were installed in the irrigation sub-sub plots with dripper flow rate was 1.6 L/h. The sub-sub plots were a rectangular shape. They were composed of manifold pipe connected to the irrigation laterals. Both manifold and lateral pipes were made of polyethylene. There were four laterals per sub-sub plot with 0.5 m of spacing among laterals and 0.4 m spacing between drippers and 16 mm of external diameter. Lateral pipelines were installed 20 cm beneath the soil surface for all plots regarding to SSDI treatments. Lateral pipelines for all sub-sub plots in the experiment were installed at surface soil for the first 15 days after sowing days until the seeds well grown and well established without any stress. After that, the irrigation systems turned to surface and subsurface upon the treatments. The inlet pressure on the system was worked with 3 bars. The irrigation systems equipped with 125-micron disk filter before gate valve Figure 3.3.

Figure 3.3: TWW filtration by disc filter at gate valve

Additionally treatment for the effluent supplied to the irrigation system of the field experiment stored in storage reservoir, chlorinated and filtrated by sand filter at Jenin WWT plant (Figure 3.4).

Figure 3.4: Additional treatment for the effluent using storage reservoir and sand fiter

3.4. Irrigation Scheduling

An average 20-year monthly metrological data for the experimental area are presented in Table 2 which they were taken from Jenin meteorological station (www.pmd.ps). This station is located very close to the study area (32° 28 N, 35° 18 E). And its elevation is 178 m above sea level. It is equipped with rainfall, temperature, radiation, air humidity and wind-speed sensors.

Table 2: Monthly averaged of 20-years metrological data in the experimental area and the calculated ETo (www.pmd.ps)

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (Hours)	Rad ($MJ/m^2/day$)	ETo (mm/day)
January	9.1	17.5	72	103	5.6	10.5	1.54
February	10	18	74	120	5.3	12.1	1.88
March	12.2	21.9	67	112	7.5	17.4	2.91
April	15.1	26.3	62	120	8.5	21.2	4.08
May	18.6	28.9	60	129	9.7	24.2	5.04
June	22.7	31.7	62	138	11.6	27.3	5.99
July	25.4	33.4	64	138	11.5	26.9	6.2
August	26.5	33.8	66	138	10.8	24.8	5.87
September	24.7	32.4	65	103	9.4	20.7	4.68
October	21.2	30.1	62	86	8	16	3.44
November	14.8	24.1	66	77	6.7	12	2.16
December	11.2	19.2	70	86	5.7	9.9	1.54
Average	17.6	26.4	66	113	8.4	18.6	3.78

The crop water requirements estimated according to the Food and Agriculture Organization of the United Nations (Allen *et al*. 1998). The net crop water requirement including irrigation system efficiency at 100% for 100% WR was estimated by CROPWAT model version 8.0, using the monthly average of historical metrological data of the area for 20 years (Table 2). Based on the CROPWAT model, crop evapotranspiration (ETc) (mm /day) is calculated by the following equation:

$$ETc = ETo \times Kc$$

Where,

ETo = reference evapotranspiration (mm)

Kc = crop coefficient.

The reference evapotranspiration (ETo) has been calculated using CROPWAT model considering the Penman-Monteith equation as described by Allen *et al*. (1998). In addition, the crop coefficient values were used as listed by Allen *et al*. (1998) (Annex 2).

The irrigation efficiency was considered for calculating crop water requirement as 90% for both SDI and SSDI. Then the crop water requirements for each irrigation scheduling calculated for every treatment. The time interval between irrigations was the same for all treatments. Annex 3 explain the irrigation time intervals and irrigation amount of the sub-sub plots with (100% WR) and the deficit irrigation sub-sub plots, (75% WR) and (50% WR).

All the sub-sub plots received the same amount of water for the first 15 days after sowing (DAS) to achieve well germination and well establishment. Then the irrigation quantities treatments started for each distributed treatment as shown Figure 3.2 when the plants completely established and were at stage with around four leaves on their main stem by average.

3.5 Field and experimental details

In this field experiment the pearl millet [*Pennisetum glaucum* (L.) R.BR.] was sown after soil plowing Figure 3.5 and field preparations; the experimental area was divided into 18 sub subplots of 2 m × 5 m size.

Figure 3.5: Field preperation (Soil plowing)

A buffer of 2 m between adjacent plots in each replication and 2 m between replications were maintained Figure 3.2 and Figure 3.6. The seeds were sown on 25th of May in 2017 at a row spacing of 50 cm and the plant spacing of 15 cm on the rows. This gave a density of 13,333 plants per dunum. Plants were thinned to the desirable density 15 days after emergence. Forage cuts were made four times at 50, 78, 106 and 134 (DAS). The field experiment was designed as a 2×3 factorial in a split plot design with three replications. The first and second factors were drip irrigation system and irrigation scheduling, respectively.

Figure 3.6: Buffering zone between the sub sub plots

3.6 Treated wastewater sampling

Four treated wastewater samples were collected from the effluent of Jenin WWT plant during the experiment period, beginning in May 2017; Samples were collected from the distribution network at the gate valve and placed immediately inside a cold container of ice box to prevent any microbiological activities before reaching to the national agricultural research center laboratory where all analyzed parameters done. Common physical, chemical, and microbiological analysis of TWW parameters were carried out according to APHA analysis manual (Eaton *et al.*, 2005) (Table 3). Where, the pH was analyzed using the electronic pH meter method, the EC was analyzed using the conductivity bridge method, the Phosphorus and Nitrate were analyzed using spectrophotometric method, Potassium and Sodium were analyzed using the flame photometric method, the Calcium, Magnesium and Chloride were analyzed using the titration method, Total suspended solid was analyzed using filtration method, Chemical oxidation demand was analyzed using spectrophotometric method and Fecal coliform was analyzed using plate count method.

Table 3: Chemical, physical and biological parameters analysis of TWW used

Parameters	Unit	TWW
pH	--	7.33-7.5
EC	ds/m	1.45-1.75
COD	mg/l	57-90
TSS	mg/l	8-13
FC	CFU/100ml	40-71
NO_3 - N	mg/l	35-42
PO_4 - P	mg/l	6.2-8.5
K_2O	mg/l	35-75
Na	mg/l	45-60
Ca	mg/l	99-133
Mg	mg/l	39-55
Cl^-	mg/l	290-320

3.7 Crop Parameters (Agronomic Parameters)

Agronomic parameters like forage green yield, dry matter yield and plant height were determined in the field as well as in the laboratory. Four cuts were harvested during growing season from SDI and SSDI. The period of each cut was 50, 28, 28 and 28 days for the first, second, third and fourth cuts, respectively. The collected data in each cut included total water supply, plant height, and fresh and dry forage yields for each cut. The following procedures were adopted for collection of data on the above mentioned parameters in growing seasons.

- Plant height (cm**):** The plant height of three randomly selected plants from each middle plot was measured from base to the highest leaf tip with the help of a measuring tape and then their average was worked out.
- Fresh forage yield (kg/dunum) the plants from a well bordered area of 5 m^2 for each cut (the two central rows) were harvested by a scythe. After that the total sample from each plot at field weighed with the help of an electric balance. The harvested sample weight was recorded.
- Dry matter yield (kg/dunum) for calculating dry weight of forages, after measuring fresh weight of 5 plant, taken to the laboratory, plant parts were oven dried for 2 days at 75–80 °C and then total dry matter (TDM) of forage was calculated.
- Water use efficiency (Kg/m^3): The water use efficiency of the fodders was calculated by following formula:

$$\text{Water use efficiency} = \frac{Fresh\ yield\ (Kg)}{Water\ applied\ (m3)}$$

3.8. **Soil physical properties**

Soil samples were collected for determination of soil textural properties. The sex composite soil samples were analyzed according to ICARDA analysis manual (Estefan *et al*., 2013). Where, the hydrometer method was used to identify the soil particle percentage. Textural classes of soil were determined by USDA soil textural triangle as shown in Table 4.

Table 4: The field experiment soil textural class at three depths

Soil samples and depths(cm)	Soil texture			Soil textural class
	clay %	silt %	sand %	
1(0-20)	55	30	15	clay
2(0-20)	52.5	32.5	15	clay
3(20-40)	60	20	20	clay
4(20-40)	62.5	22.5	15	clay
5(40-60)	60	22.5	17.5	clay
6(40-60)	55	27.5	17.5	clay

2.9 Statistical Analysis

The collected data for each cut were statistically analyzed using analysis of variance procedure and mean separation using least significant differences (LSD) test by GenStat Software version 12. Analysis of variance, least significant differences of means (5% level), standard error and coefficient of variance listed in Annexes 4, 5, 6, 7 and 8 for each cuts, respectively.

Chapter Four: Results and Discussion

4.1 Effect of Irrigation System on Crop Parameters and WUE

The effects of investigated surface and subsurface drip irrigation systems on fresh weight, dry weight, plant height and WUE of pearl millet are presented in Table 5.

Table 5: Means of fresh weight, dry weight (kg/dunum), WUE (kg/m^3) and plant height (cm) of pearl millet under the effect of irrigation system as average of four cuts during experiment

Cut number	Treatment	Fresh weight	Dry weight	WUE	Plant height
1	subsurface	3247.22 [a*]	509.77 [a]	26.13 [a]	161.07 [a]
	surface	2491.66 [b]	444.54 [a]	20.37 [b]	153.81 [a]
2	subsurface	932.96 [a]	136.73 [a]	9.91 [a]	99 [a]
	surface	778.17 [b]	108.42 [b]	8.28 [b]	92.41 [a]
3	subsurface	1013.2 [a]	165.36 [a]	12.31 [a]	112.78 [a]
	surface	986.24 [a]	160.68 [a]	12 [a]	112.41 [a]
4	subsurface	704.11 [a]	135.16 [a]	10.42 [a]	112.52 [a]
	surface	619.58 [a]	116.75 [b]	9.27 [a]	100.7 [b]
All	subsurface	5894 [a]	947 [a]	16.16 [a]	
	surface	4876 [b]	830 [a]	13.50 [b]	

*Means followed by the same alphabetical letter in each characteristic/cut do not significantly different according to least significant differences (LSD) ($p < 0.05$).

The results showed that the fresh weight, dry weight, plant height and WUE were the highest by SSDI compared to SDI for each cuts as shown in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4. These results are similar to the results obtained by Ismail *et al*. (2018) and these results are attributed to many reasons causing SSDI superior than SDI including eliminating soil evaporation (Sinobas and Rodríguez, 2012; Mali *et al*., 2016), surface runoff, deep percolation (Sinobas and Rodríguez,

2012) and salt accumulation at upper soil surface (Lamm, 2016). In addition to remain the soil moisture more stable relatively (Mali *et al.*, 2016) as showed in maize production on sandy loam soil (Douh and Boujelben, 2011; Douh *et al.*, 2013) and increase nutrient availability (Mali *et al.*, 2016) and consequently increased WUE (Douh and Boujelben, 2011; Douh *et al.*, 2013; Mali *et al*., 2016).

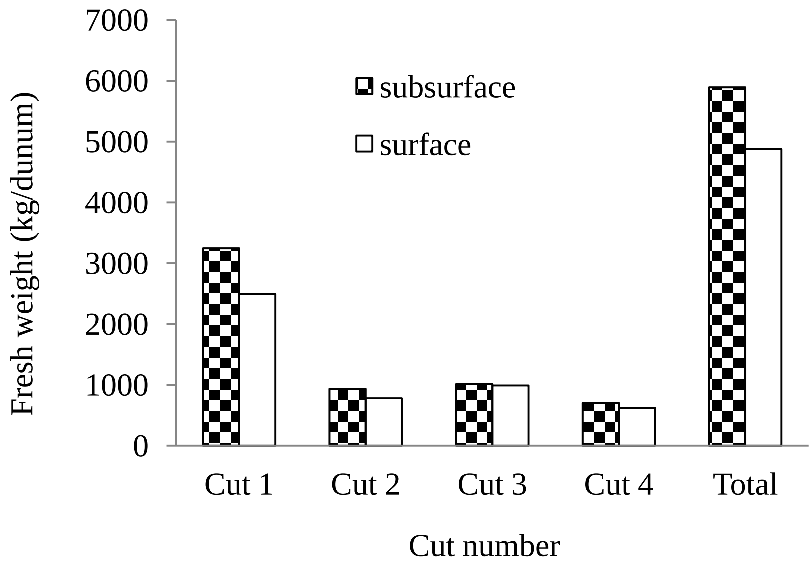


Figure 4.1: Comparison between surface and subsurface drip irrigation systems and fresh weight productivity (Kg/dunum) at each cut and whole cuts

In the first and second cuts, the fresh weight and WUE-fresh were affected significantly by SSDI compared to SDI for both cuts but not significantly in the third and fourth cuts. Nevertheless, there was significant difference in the total cuts. Crop growth basically depends on the weather and soil conditions, in case of the weather was typically for growth and the water available in the soil, the crop continue in growth first and second cuts implemented in July and august where the weather condition was the typical for growth, in case of subsurface the water was available in the root zone along the discharge of the dripper beneath the soil on the root zone and the evaporation rate close to zero. And most of the water can be abstracted by the roots. In case of surface drip irrigation system there was a high rate of evaporation and limited root zone which lead to reduce the transpiration (stomata closure) and consequently reduce photosynthesis due to crop water stress. Regarding with third and fourth cuts the crop inter in stress condition and these condition represented by flowering and senescence stage where the crop responding to the severity condition and start for flowering and producing seeds to survive itself which lead to reduce the vegetation growth.

Figure 4.2 shows that the WUE-fresh was the highest by SSDI compared to SDI for each cuts and for whole cuts similar to the results obtained for fresh weight and the reasons related to as mentioned above.

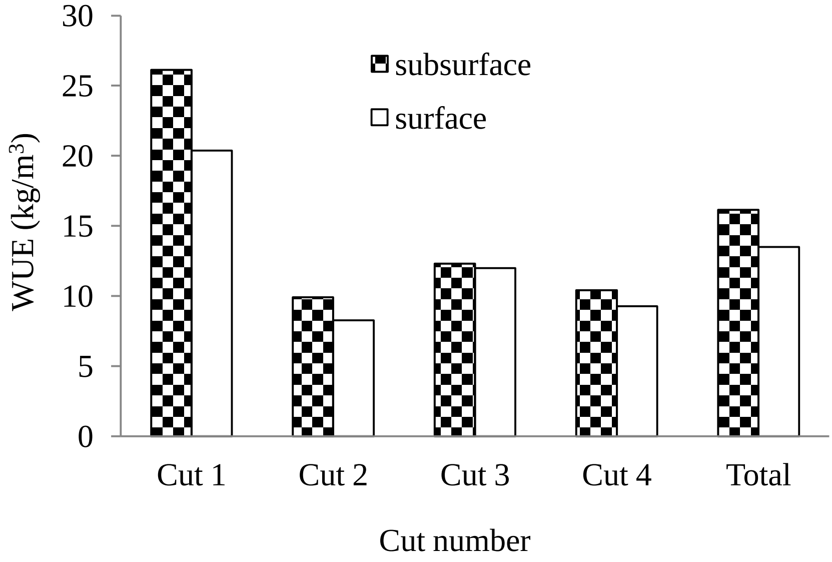


Figure 4.2: Comparison between surface and subsurface drip irrigation systems and water use efficiency (Kg/m^3) at each cut and whole cuts

Dry weight was the highest by SSDI compared to SDI for each cuts as shown in Figure 4.3 where the differences between them were significant in the second and fourth cuts but not significant in the first and third cuts. Generally, significant or not in dry weight results resemble to the results of fresh weight but the variance here results from the dry weight was carried out by measured 5 plants randomly then oven dried and the dry weight calculated proportionally with the fresh weight which was carried out by measuring all plants at middle of plots.

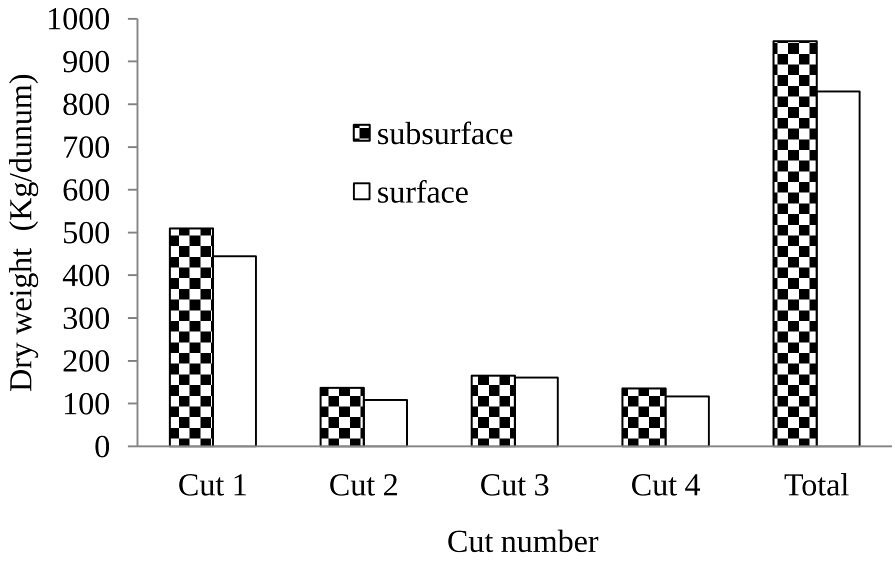


Figure 2: Comparison between surface and subsurface drip irrigation systems and dry weight productivity (Kg/dunum) at each cut and whole cuts

Plant height was the highest by SSDI compared to SDI for each cuts as shown in Figure 4.4. Where, the differences between them were significant in the fourth cut but not significant in the first, second and third cuts. Significant found in fourth cut due to the plants were chosen for measuring the tall carried out randomly and the plant growth at the fourth cut was stressed due to the weather and water availability conditions that lead to inter in senesce stage.

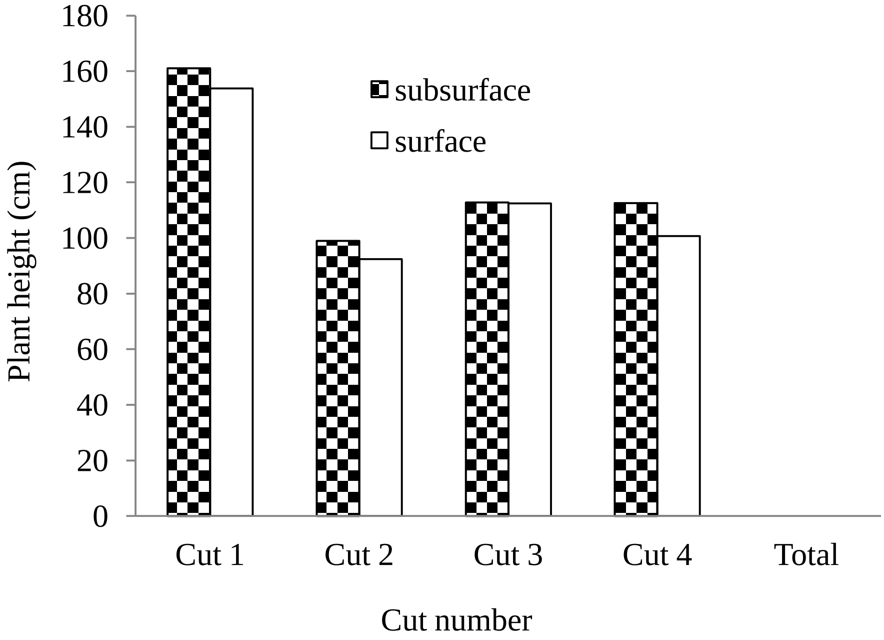


Figure 4.4: Comparison between surface and subsurface drip irrigation systems and plant height (cm) at each cut

4.2 Effect of Water application on productivity and WUE

The effects of investigated irrigation water applications on fresh weight, dry weight, plant height and WUE of pearl millet are presented in Table 6.

Table 6: Means of fresh weight, dry weight (kg/dunum), WUE (kg/m^3) and plant height (cm) of pearl millet under the effect of irrigation water application as average of four cuts during experiment

Cut number	Treatment	Fresh weight	Dry weight	WUE	Plant height
1	50%	2277.67 a*	403.52 a	25.05	145.89 a
	75%	2771.95 a	469.16 ab	22.24	155.78 ab
	100%	3558.73 b	558.8 b	22.48	170.67 b
2	50%	488.3 a	68.03 a	8.03 a	81.17 a
	75%	786.15 b	113.24 b	8.62 ab	95.17 ab
	100%	1292.23 c	186.44 c	10.63 b	110.78 b
3	50%	687.46 a	113.58 a	12.50 a	96.5 a
	75%	973.95 b	148.78 b	11.81 a	110.44 a
	100%	1337.76 c	226.71 c	12.16 a	130.83 b
4	50%	418.18 a	73.35 a	9.46 a	91.72 a
	75%	622.29 b	121.9 b	9.38 a	105.56 b
	100%	945.06 c	182.62 c	10.69 a	122.56 c
All	50%	3872 a	658 a	15.43 a	
	75%	5154 b	853 b	14.14 a	
	100%	7134 c	1155 c	14.91 a	

*Means followed by the same alphabetical letter in each characteristic/cut do not significantly different according to least significant differences (LSD) ($p < 0.05$)

The results showed that the fresh weight, dry weight and plant height for each cuts were increased by increasing irrigation amount at 50%, 75% and 100%, respectively as shown in Figures 4.5, 4.6 and 4.7, and these results are similar to the findings indicated by Ismail *et al*. (2018).

As shown in Figure 4.5 the highest fresh weight was obtained from plants irrigated with 100 % WR (3558.73 kg/du) at the first cut while the minimum fresh weight was in the fourth cut at 50% WR (418.18kg/du), the highest fresh weight production in the first cut at 100%WR attributed to the reasons of no deficit irrigation and to the typically growth conditions for pearl millet. Where, The first cut done on the mid of July. These results are similar to the results obtained by Ismail *et al*. (2018). The lowest fresh weight production in the fourth cut attributed to the reasons of deficit irrigation (50% WR) and to the stress growth conditions, where the fourth cut done on mid of October when the crop enter into the end stage. Whereas, the pearl millet crop in this stage tends to flower and produce seeds in order to keep the offspring and these results similar to the results gained by Ismail *et al*. (2018). The highly decrease of fresh weight in the second cut comparing with the first and the third cuts was caused by the highly increase of temperature after first cutting which lead to increase evaporation due to the canopy didn’t cover the exposure area and decrease transpiration and consequently decrease photosynthesis. So, growth rate was decreased. By the way the fresh weight improved in the third cut comparing with the second. Where, the temperature becomes closed to the typical of Pearl Millet growth.

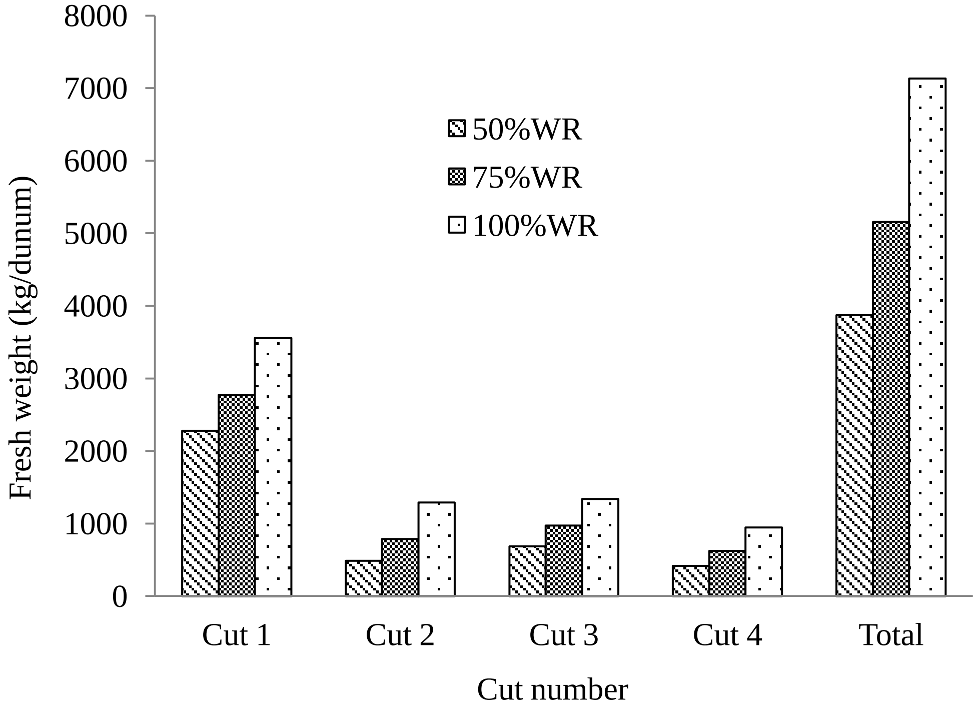


Figure 4.5: Comparison between irrigation amount at 50%, 75% and 100%, respectively, and fresh weight productivity (Kg/dunum) at each cut and whole cuts

The highest dry weight was obtained from plants irrigated with 100 % WR (558.8 kg/du) at the first cut while the minimum dry weight was in the second cut at 50% WR (68.03kg/du) followed by (73.35 kg/du) in the fourth cut at 50% WR as shown in Figure 4.6. The minimum dry weight was at the second cut due to the weather stress condition such as increased temperature that lead to decrease transpiration and increase evaporation which happened at soil surface of SDI system resulting in decrease photosynthesis thus decrease dry matter accumulation in above ground yield.

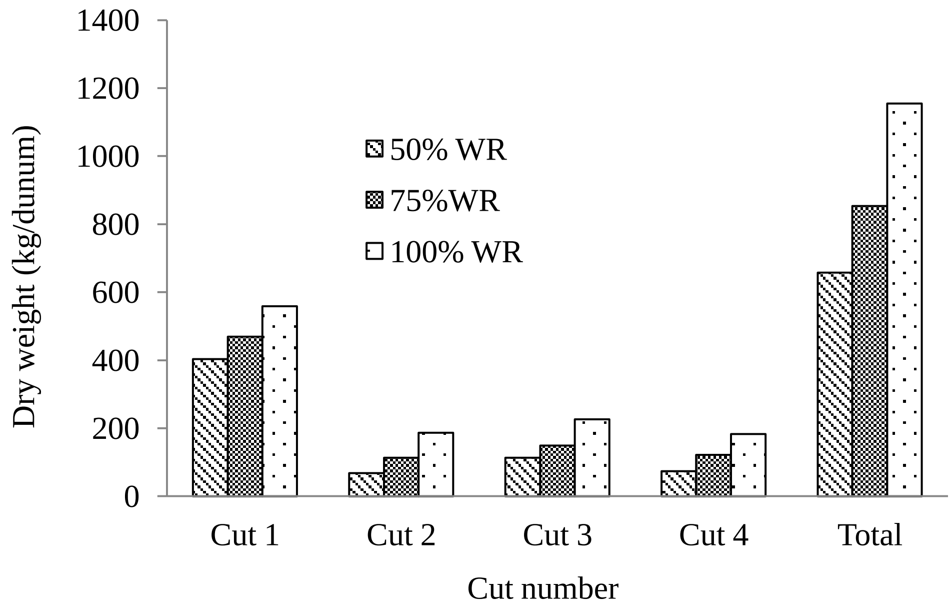


Figure 4.6: Comparison between irrigation amount at 50%, 75% and 100%, respectively, and dry weight productivity (Kg/dunum) at each cut and whole cut

In the first cut, fresh weight found no significant differences at confidence level 95 % ($p < 0.05$) between deficit irrigation at 75% and 50% WR treatments. In the same time it was significant difference in fresh weight at 50% WR comparing with the result obtained at 100% WR. While, at second, third and fourth cuts there were significance between 50% WR, 75% WR and 100% WR treatments.

No significant differences for fresh weight at first cut between 50% WR, 75% WR attributed to the starting for its deficit after 2 weeks from sowing date to enhance and provide a well establish germination for seeds and ensure the root elongate to reach the water of subsurface irrigation system treatments. So, the amounts of irrigation water for the deficit treatments were higher than the assumptive 50% WR, 75% WR compared to 100% WR which stay as it.

And the significant difference of fresh weight shown at second, third and fourth cuts similar to that found by Ismail *et al*. (2018)

In the first cut, dry weight found no significant differences at confidence level 95 % ($p < 0.05$) between full irrigation (100% WR) and deficit irrigation at 75% WR or between 75% WR and 50% WR treatments as shown in Figure 4.6. In the same time it was significant in dry weight at 50% WR comparing with the result obtained at 100% WR. The significant difference found between 50% WR and 100% WR attributed to the reasons indicated at first cut related to fresh weight whereas the 75% WR treatment has well soil water available rather than 50 % WR.

In the second, third and fourth cuts, significant differences were shown in dry weight under 100% WR, 75% WR and 50% treatments as shown in fig7. Similar results revealed by Ismail *et al*. (2018).

The highest plant height was obtained from plants irrigated with 100 % WR (170.67 cm) at the first cut while the minimum plant height was in the second cut at 50% WR (81.17 cm) followed by (91.72 cm) at 50 % WR in the fourth cut as shown in Figure 4.7.

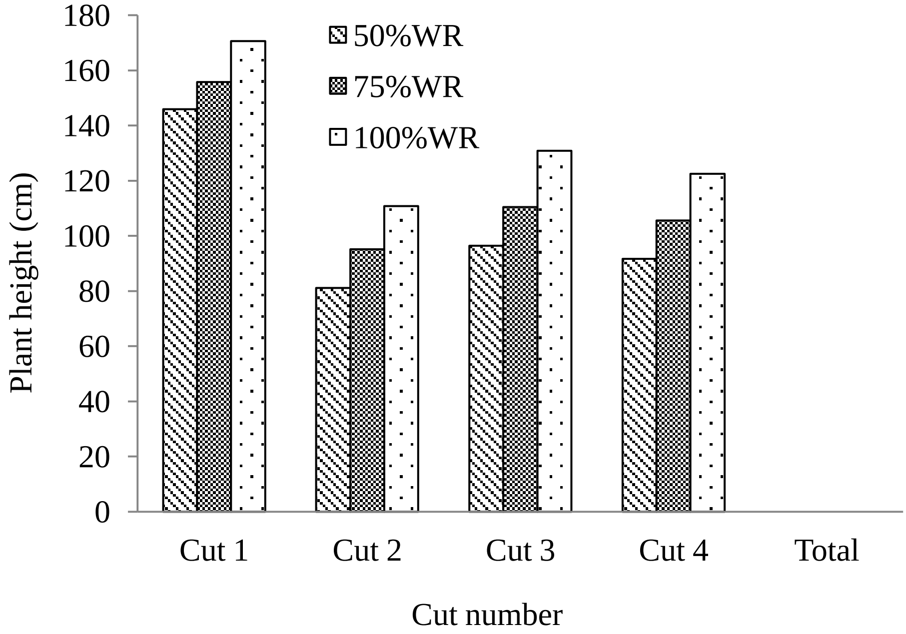


Figure 4.7: Comparison between irrigation amount at 50%, 75% and 100%, respectively, and plant height (cm) at each cut and whole cuts

There were no significant differences in dry weight between 75% WR and 100% WR treatments or 75% WR and 50% WR treatments in the first cut returned to the availability of irrigation water in 75% WR which achieved by the addition of irrigation water similarly to 2 weeks from sowing date to enhance well germination and planting that lead to increase photosynthesis rate resulting in increased dry matter accumulation.

In the first and second cuts, plant height found no significant differences at confidence level 95 % ($p < 0.05$) between full irrigation (100% WR) and deficit irrigation at 75% WR or between 75% WR and 50% WR treatments and it was significant decrease at 50% WR comparing with the result obtained at 100% WR.

While in the third cut, plant height found no significant differences between deficit irrigation at 75% and 50% WR treatments. But it was significant decrease in plant height at 50% WR comparing with the result obtained at 100% WR.

In the fourth cut, significant differences were shown in plant height under 100% WR, 75% WR and 50% treatments.

In the first, third and fourth cuts, no significant differences were shown in WUE-fresh at 100% WR, 75% WR and 50% treatments while WUE-fresh in the second cut found no significant differences between full irrigation (100% WR) and deficit irrigation at 75% WR or between 75% WR and 50% WR treatments but it was significant decrease at 50% WR comparing with the result obtained at 100% WR.

The highest WUE-fresh was obtained from plants irrigated with 50 % WR (25.04 kg/m3) at the first cut while the minimum plant height was in the second cut at 50% WR (8.03 kg/m3) as shown in Figure 4.8.

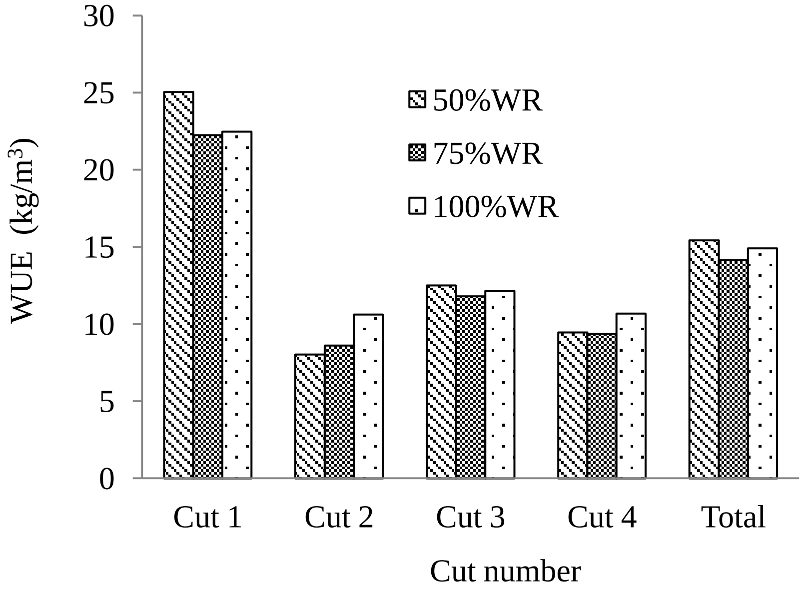


Figure 4.8: Comparison between irrigation amount at 50%, 75% and 100%, respectively, and water use efficiency (Kg/m^3) at each cut and whole cuts

4.3 Cost benefit analysis

The life span of the irrigation systems including its fittings estimated around five years for both subsurface and surface irrigation systems (this period usually adopted by the irrigation experts at MoA).

Machinery installation in case of SSDI and manually installation in case of SDI are considered as same cost in the first year, and it's neglected in case of SSDI for the following years because it is remain in the field along the period of life span.

For both systems, same treatment cost considered for operation and maintenance. The Pearl millet forage prices estimated according to the similar forage crops price. Cost benefit analysis taken in to consideration the costs and revenue items for 1 dunum (1000 m^2). Cost benefit analysis for both systems using in the experiment presented in Table 7.

Table 7: Cost benefit analysis for both SSDI and SDI used to irrigate 1000 m^2 of land cultivated with Pearl millet using treated effluent/ Marj Ibn Amer/Jenin

Surface drip irrigation system						
Item	Year1	Year2	Year3	Year4	Year5	Total
Irrigation system including fittings cost (US$)	530	0	0	0	0	530
Installation cost (US$)	50	50	50	50	50	250
Operation and maintenance (US$)	10	10	10	10	10	50
Labor, planting and harvesting (US$)	200	200	200	200	200	1000
TWW cost (US$)	66	66	66	66	66	330
Total cost						2160
Revenue of forage (US$)	1163	1163	1163	1163	1163	5815
Gross profit $	Total revenue - Total cost = 3665					
Subsurface drip irrigation systems						
Item	Year1	Year2	Year3	Year4	Year5	Total
Irrigation system including fittings cost (US$)	660	0	0	0	0	660
Installation cost (US$)	50	0	0	0	0	50
Operation and maintenance (US$)	10	10	10	10	10	50
Labor, planting and harvesting (US$)	200	200	200	200	200	1000
TWW cost (US$)	66	66	66	66	66	330
Total cost (US$)						2090
Revenue of forage (US$)	1770	1770	1770	1770	1770	8850
Gross profit (US$)	Total revenue - Total cost = 6760					

Calculations are based on: the life span of the irrigation network: 5 years; prices are fixed over 5 years; treated wastewater cost: 0.19 US$/$m^3$; mean water requirements: 365 m^3/dunum.year; mean Pearl millet production: for SSDI 5894 kg/dunum, and for SDI 4876 kg/dunum (based on this research results); fresh Pearl millet forage price: 0.27 US$/kg

As shown in Table 7 of the cost benefit analysis of cultivating 1 dunum with Pearl millet irrigated with treated wastewater, the gross profit of using SSDI (6760 US$) and it is higher than the gross profit obtained from SDI (3665 US$). As a result, using SSDI – from economical point- is efficient to be used for irrigation Pearl millet than the SDI using TWW.

Chapter five: Conclusions and Recommendations

5.1 Conclusions

The main conclusions of this research of Pearl millet cultivation in clay soil in the semi-arid area of Palestine irrigated with different quantities of treated wastewater using SDI and SSDI are:

1. The fresh forage productivity with SSDI (5894 kg/dunum) is significantly higher ($p<0.05$) than SDI (4876 kg/dunum); likewise, dry forage productivity with SSDI (947 kg/dunum) is higher than SDI (830 kg/dunum).
2. Water use efficiency (WUE) with SSDI (16.16 kg /m^3) is significantly higher than SDI (13.5 kg/m^3).
3. Fresh forage productivity produced by 100% WR (7134 kg/dunum) is significantly the highest as compared with 75% WR (5154 kg/dunum) and 50% WR (3872 kg/dunum).
4. Dry forage productivity produced with 100% WR (1155 kg/dunum) is significantly higher than 75% WR (853 kg/dunum) and 50% WR (658 kg/dunum).
5. WUE is the highest by 50% (15.43 kg/m^3) WR than 100% WR (14.91 kg/m^3) and 75% WR (14.14 kg/m^3), but the difference is not statistically significant ($p>0.05$).

5.2 Recommendations

1. The results of this thesis pointed that the problem of water scarcity can be addressed using SSDI in irrigation. It's important for the decision makers to take the right decision by adopting this irrigation technology in order to alleviate the water shortage as a way to increase the irrigated agricultural area.
2. It's recommended to start with adaptation plan with the same methodology on Pearl millet forage crop in arid and semi- arid area.
3. It's recommended to farmers pay attention for a WUE and water management by selection the suitable irrigation system and irrigation quantity for cultivation crop in areas have water scarcity and aridity.
4. It's recommended for other researcher to assess the impact of adopted methodology in this research on soil characteristics and groundwater quality for long period.
5. It's recommended to researcher to investigate the same methodology for other irrigated crop species can be cultivated using TWW according to the Palestinian TWW standard.

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Annexes

Annex (1): Technical Regulations for the reuse of treated wastewater in agricultural irrigation (PSI, TR-34, 2012):-

Introduction

These technical directions aim at the followings:

1. To put basics to use the treated water in agricultural irrigation in a way that will not affect badly the health of the human, animal, and plants.
2. Ensure that the treated sewage water in irrigation will not cause damage to any of the environmental elements including water soil, and air.

Article (1) The scope

The provisions of these regulations are for the treated sewage water that comes out of the treatment stations for using in agricultural irrigation.

Article (2) Definitions

For implementing the regulations of these directions, the following words and expressions have the stated meanings unless the context indicates otherwise:

2-1 The competent authority: is the party or the parties that determined by the cabinet in order to implement the regulations of these directions according to article (23) of the law of Standard Institution and other related applicable regulations.

2-2 User: a person, a contractor, or governmental, private, or civil institution that use or get benefit from the treated sewage water for agricultural irrigation.

2-3 Wastewater: the contaminated water with physical, chemical, biological, or radiological materials that resulted from the use of the domestic, industrial, commercial, or agricultural uses and becomes dangerous when being reused or discharged contrary to the provisions of relevant laws and regulations.

2-4 The Maximum Limits: Is the maximum concentration of a pollutant allowed to exist in treated sewage water, according to the limit mentioned in these instructions.

2-5 Treated sewage water: Is sewage water that has been clarified from some or all its suspended, sediment and dissolved materials by natural or mechanical, chemical or biological methods, whether individually or collectively, which do not exceed the maximum levels listed in these instructions.

2-6 Wastewater treatment station: group of facilities and equipment prepared to treat the wastewater by natural, chemical, mechanical, or biological methods, in order to improve the characteristics of wastewater to be reused it or discharged without any health or environment damages.

Article (3) The waste water for agricultural irrigation classified according to its quality to classifications mentioned in the Table (1)

Article (4) The following conditions should be implemented to use the treated water for agricultural irrigation:

a) To be in accordance to these directions especially to the Table (1)

b) Approval of the concerned authority on this agricultural irrigation use in accordance with permits issued by it for this purpose, consistent with the requirements of these instructions.

Article (5)

1-5 To transport the treated wastewater for agricultural irrigation in closed appropriate pipes and colored in purple and applicable to the Palestinian specifications.

2-5 if the treated wastewater is transferred by using a vehicle tanks, these tanks should be colored in purple and write on it with a clear obvious font visual from both sides (treated water for agricultural irrigation).

Article (6) The relevant authority shall set instructions explaining protective measures to be taken within the farm when dealing with the treated wastewater for agricultural irrigation

Article (7) The relevant authority shall monitor the quality of treated wastewater for agricultural irrigation by applying the control system described in Palestinian Standard No. 742

Article (8) Its prevented to use the treated wastewater for agricultural irrigation in the followings:

a) Watering of livestock and poultry

b) Irrigation for all types of vegetables

c) Groundwater recharge by direct injection

d) Fish farming

Article (9) User should not use the treated wastewater for irrigation in uses other than those identified by relevant agricultural irrigation party.

Article (10) When there is a conflict with the official documents issued by other parties, these documents should be modified to become in line with these instructions.

Article (11) These instructions are applicable from the date of the approval, and advertising.

Article (12) In case of any dispute in the interpretation of any text of these instructions, the interpretation of the regulations of the Technical Commission should be adopted.

Article (13) The concerned authority should develop a plan to implement all provisions of these regulations to include the stages of application and resources required to implement them, and should not exceed the duration of this plan for three years from the date of application of these regulations.

Table 1: Classification of the treated wastewater according to its quality (PSI, TR-34, 2012)

Maximum limits for physical, chemical and biological properties *)		Quality of Treated Wastewater			
		High quality (A)	Good quality (B)	Medium quality (C)	Low quality (D)
1.	Potential of Hydrogen pH	6-9	6-9	6-9	6-9
2.	Dissolved Oxygen DO	> 1	> 1	> 1	> 1
3.	Biochemical Oxygen Demand BOD_5	20	20	40	60
4.	Chemical Oxygen Demand COD	50	50	100	150
5.	Total Suspended Solids TSS	30	30	50	90
6.	Total Dissolved Solids TDS	1200	1500	1500	1500
7.	Nitrate Nitrogen NO_3-N	20	20	30	40
8.	Ammonium Nitrogen NH_4-N	5	5	10	15
9.	Total Nitrogen T-N	30	30	45	60
10.	Phosphate Phosphorus PO_4-P	30	30	30	30
11.	Fat, Oil and Grease	5	5	5	5
12.	Phenol	0.002	0.002	0.002	0.002
13.	Detergents MBAS	15	15	15	25
14.	Chloride Cl	400	400	400	400
15.	Sulfate SO_4	300	300	300	300
16.	Sodium Na	200	200	200	200
17.	Magnesium Mg	60	60	60	60
18.	Calcium Ca	300	300	300	300
19.	Sodium adsorption ratio SAR	5.83	5.83	5.83	5.83
20.	Aluminum Al	5	5	5	5
21.	Arsenic As	0.1	0.1	0.1	0.1
22.	Copper Cu	0.2	0.2	0.2	0.2

23.	Iron Fe	5	5	5	5
24.	Manganese Mn	0.2	0.2	0.2	0.2
25.	Nickel Ni	0.2	0.2	0.2	0.2
26.	Lead Pb	0.2	0.2	0.2	0.2
27.	Selenium Se	0.02	0.02	0.02	0.02
28.	Cadmium Cd	0.01	0.01	0.01	0.01
29.	Zinc Zn	2	2	2	2
30.	Chrome Cr	0.1	0.1	0.1	0.1
31.	Mercury Hg	0.001	0.001	0.001	0.001
32.	Cobalt Co	0.05	0.05	0.05	0.05
33.	Boron B	0.7	0.7	0.7	0.7
34.	Cyanide CN	0.05	0.05	0.05	0.05
35.	Fecal coliforms (colony/100 mL)	200	1000	1000	1000
36.	Bacteria E. coli (Colony/100 mL)	100	1000	1000	1000
37.	Nematodes (Eggs/L)	≤ 1	≤ 1	≤ 1	≤ 1

*) All units are in mg/l otherwise stated.

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- Law 7/1999: The Palestinian Environmental law, 1999.
- Law 3/2002: The Palestinian Water Law, 2002.
- Law 2/2003 : Agricultural Law ,2003
- Agreements with Israel, particularly the Memorandum of Understanding (MOU) of December 2003
- PS 742/2003: The Palestinian Treated Wastewater Standards, 2003.
- MoA Instructions/2011: The Ministry of Agriculture instructions for treated wastewater reuse in agriculture, 2011.
- TR 34/2012: Technical Regulations for the reuse treated wastewater in agricultural irrigation (PSI, TR-34, 2012)
- The Palestinian Water Law 2014.

Annex 2: Value of the crop factor (Kc) for various crops and growth stages.

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50
Lettuce/Spinach	0.45	0.60	1.00	0.90
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	0.40	0.80	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion, green	0.50	0.70	1.00	1.00
Onion, dry	0.50	0.75	1.05	0.85
Peanut/Groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sugarbeet	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

Annex 3: Irrigation water quantities during the experiment

Date	Day	Stage	Rain	Net Irr	Gross Irr	100%WR	75%WR	50%WR
			mm	mm	mm	m3/dunum	m3/dunum	m3/dunum
26-May	1	Init	0	1.9	2.1	2.1	2.1	2.1
29-May	4	Init	0	5.6	6.2	6.2	6.2	6.2
02-Jun	8	Init	0	7.7	8.6	8.6	8.6	8.6
05-Jun	11	Init	0	6	6.7	6.7	6.7	6.7
09-Jun	15	Init	0	7.9	8.8	8.8	6.6	4.4
12-Jun	18	Init	0	6.7	7.4	7.4	5.6	3.7
16-Jun	22	Dev	0	9.5	10.6	10.6	7.9	5.3
19-Jun	25	Dev	0	7.1	7.9	7.9	5.9	3.9
23-Jun	29	Dev	0	13.4	14.9	14.9	11.2	7.4
26-Jun	32	Dev	0	11	12.2	12.2	9.2	6.1
30-Jun	36	Dev	0	14.7	16.3	16.3	12.3	8.2
03-Jul	39	Dev	0	15.3	17.0	17.0	12.8	8.5
07-Jul	43	Dev	0	20.4	22.7	22.7	17.0	11.3
10-Jul	46	Dev	0	15.3	17.0	17.0	12.8	8.5
14-Jul	50	Init	0	10.1	11.2	11.2	8.4	5.6
17-Jul	53	Dev	0	7.6	8.4	8.4	6.3	4.2
21-Jul	57	Dev	0	11.6	12.9	12.9	9.7	6.4
24-Jul	60	Dev	0	12.2	13.6	13.6	10.2	6.8
28-Jul	64	Dev	0	16.3	18.1	18.1	13.6	9.1
31-Jul	67	Dev	0	12.2	13.6	13.6	10.2	6.8
04-Aug	71	Dev	0	22.5	25.0	25.0	18.8	12.5
07-Aug	74	Dev	0	16.9	18.8	18.8	14.1	9.4
11-Aug	78	Init	0	9	10.0	10.0	7.5	5.0
14-Aug	81	Dev	0	8.3	9.2	9.2	6.9	4.6
18-Aug	85	Dev	0	11	12.2	12.2	9.2	6.1
21-Aug	88	Dev	0	9.6	10.7	10.7	8.0	5.3
25-Aug	92	Dev	0	16.4	18.2	18.2	13.7	9.1
28-Aug	95	Dev	0	12.3	13.7	13.7	10.3	6.8
01-Sep	99	Dev	0	17.3	19.2	19.2	14.4	9.6
04-Sep	102	Dev	0	15.1	16.8	16.8	12.6	8.4
08-Sep	106	Init	0	7.3	8.1	8.1	6.1	4.1
11-Sep	109	Dev	0	6.2	6.9	6.9	5.2	3.4
15-Sep	113	Dev	0	10.3	11.4	11.4	8.6	5.7
18-Sep	116	Dev	0	7.8	8.7	8.7	6.5	4.3
22-Sep	120	Dev	0	12.2	13.6	13.6	10.2	6.8
25-Sep	123	Dev	0	10.5	11.7	11.7	8.8	5.8
29-Sep	127	Dev	0	14	15.6	15.6	11.7	7.8
02-Oct	130	Dev	0	11.3	12.6	12.6	9.4	6.3
				SUM	478.3	478.3	364.6	250.9

Annex 4: GenStat data results of all parameters at the first cut

All gained data were subjected to analysis of variance (ANOVA) at p 0.05, and mean separation was conducted using Least Significant Differences by (GenStat) software.

Analysis of Variance					
Variate: Dry weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	19144	19144	1.12	0.351
Water quantity	2	72914	36457	2.12	0.235
Residual	4	68669	17167		
Total	17	246284			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	171.5	210

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
4	131	27.5

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Fresh weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	2568922	2568922	10.85	0.03
Water quantity	2	5008873	2504437	10.58	0.025
Residual	4	947214	236804		
Total	17	11819651			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irr_system	W_APPLICATION
rep.	9	6
d.f.	4	4
l.s.d.	636.9	780

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
4	486.6	17

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: plant height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	237.14	237.14	2.41	0.195
Water quantity	2	1866.81	933.41	9.5	0.03
Residual	4	392.88	98.22		
Total	17	3839.33			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irr_system	W_APPLICATION
rep.	9	6
d.f.	4	4
l.s.d.	12.97	15.89

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: plant height		
d.f.	s.e.	cv%
4	9.91	6.3

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: WUE					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	149.41	149.41	10.64	0.031
Water quantity	2	29.04	14.52	1.03	0.434
Residual	4	56.15	14.04		
Total	17	385.35			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irr_system	W_APPLICATION
rep.	9	6
d.f.	4	4
l.s.d.	4.904	6.006

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: WUE		
d.f.	s.e.	cv%
4	3.747	16.1

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Annex 5: GenStat data results of all parameters at the second cut

Analysis of Variance					
Variate: Dry weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	3605.1	3605.1	8.45	0.044
Water quantity	2	42846.6	21423.3	50.24	0.001
Residual	4	1705.6	426.4		
Total	17	64490.2			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	27.03	33.1

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
4	20.65	16.8

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Fresh weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	107814	107814	7.19	0.05
Water quantity	2	1982309	991154	66.1	<.001
Residual	4	59979	14995		
Total	17	2628367			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	160.3	196.3

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Fresh weight		
d.f.	s.e.	cv%
4	122.5	14.3

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: plant height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	195.6	195.6	1.88	0.242
Water quantity	2	2633	1316.5	12.69	0.019
Residual	4	415	103.8		
Total	17	3948.6			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	13.33	16.33

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: plant height		
d.f.	s.e.	cv%
4	10.19	10.6

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: WUE					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	11.988	11.988	7.49	0.049
Water quantity	2	22.24	11.12	6.94	0.05
Residual	4	6.405	1.601		
Total	17	82.112			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	1.656	2.028

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: WUE		
d.f.	s.e.	cv%
4	1.265	13.9

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Annex 6: GenStat data results of all parameters at the third cut

Analysis of Variance					
Variate: Dry weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	98.5	98.5	0.36	0.581
Water quantity	2	40219.3	20109.6	73.6	<.001
Residual	4	1093	273.2		
Total	17	46084.7			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	21.63	26.5

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
4	16.53	10.1

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Fresh weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	3272	3272	0.12	0.749
Water quantity	2	1274638	637319	22.98	0.006
Residual	4	110932	27733		
Total	17	1584375			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	218	266.9

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Fresh weight		
d.f.	s.e.	cv%
4	166.5	16.7

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: plant height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	0.6	0.6	0	0.95
Water quantity	2	3577.9	1788.9	12.92	0.018
Residual	4	554	138.5		
Total	17	5279.7			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	15.4	18.86

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: plant height		
d.f.	s.e.	cv%
4	11.77	10.5

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: WUE					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	0.458	0.458	0.15	0.722
Water quantity	2	1.445	0.722	0.23	0.805
Residual	4	12.616	3.154		
Total	17	31.301			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	2.324	2.847

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: WUE		
d.f.	s.e.	cv%
4	1.776	14.6

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Annex 7: GenStat data results of all parameters at the forth cut

Analysis of Variance					
Variate: Dry weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	1525.3	1525.3	7.66	0.05
Water quantity	2	35969.8	17984.9	90.37	<.001
Residual	4	796.1	199		
Total	17	41738.6			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	18.46	22.61

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
4	14.11	11.2

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Fresh weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	32154	32154	2.5	0.189
Water quantity	2	846903	423452	32.88	0.003
Residual	4	51508	12877		
Total	17	1058794			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	148.5	181.9

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Fresh weight		
d.f.	s.e.	cv%
4	113.5	17.1

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: plant height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	628.15	628.15	10.24	0.033
Water quantity	2	2862.11	1431.06	23.32	0.006
Residual	4	245.47	61.37		
Total	17	5253.61			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	10.25	12.56

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: plant height		
d.f.	s.e.	cv%
4	7.83	7.3

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: WUE					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	5.935	5.935	2.68	0.177
Water quantity	2	6.434	3.217	1.45	0.335
Residual	4	8.855	2.214		
Total	17	43.796			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	4	4
l.s.d.	1.947	2.385

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: WUE		
d.f.	s.e.	cv%
4	1.488	15.1

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Annex 8: GenStat data results of all parameters for total production cuts

Analysis of Variance					
Variate: Fresh weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	4698706	4698706	7.38	0.019
Water quantity	2	32410848	16205424	25.45	<.001
Residual	12	7642261	636855		
Total	17	45609435			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	12	12
l.s.d.	819.7	1003.9

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Fresh weight		
d.f.	s.e.	cv%
12	798	14.8

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: WUE					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	31.84	31.84	8.73	0.012
Water quantity	2	5.072	2.536	0.69	0.518
Residual	12	43.787	3.649		
Total	17	82.563			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	12	12
l.s.d.	1.962	2.403

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: WUE		
d.f.	s.e.	cv%
12	1.91	12.9

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Dry weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	61201	61201	3.85	0.073
Water quantity	2	749755	374878	23.6	<.001
Residual	12	190650	15887		
Total	17	1021730			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	12	12
l.s.d.	129.5	158.6

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Dry weight		
d.f.	s.e.	cv%
12	126	14.2

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Analysis of Variance					
Variate: Plant height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation system	1	3050.6	3050.6	4.48	0.05
Water quantity	2	43143.4	21571.7	31.68	<.001
Residual	12	8171.8	681		
Total	17	56691.2			

d.f.=degree of freedom, s.s.= sum of square ,m.s.= Mean of square, v.r.= F statistic, F pr.= P value

Least significant differences of means (5% level)		
Table	Irrigation system	Water quantity
rep.	9	6
d.f.	12	12
l.s.d.	26.8	32.83

rep.= Replication, d.f.=Degree of freedom, l.s.d.= Least significant differences

Stratum standard errors and coefficients of variation		
Variate: Plant height		
d.f.	s.e.	cv%
12	26.1	5.5

d.f.=Degree of freedom, s.e.= Standard error, cv= Coefficient of variance

Annex 9: Metrological data during the experimental period 2017 (www.pmd.ps).

May 2017

Element / Day	Max	Min	Evap.	sun shine	PST	Dry	Wet	PMS	RH	D.P	WS
01	31	18.4	6.6	7.2	992.6	22.4	17.4	1,008.5	62	13.7	2.8
02	27.2	15	6.3	10	995.7	22.1	17.5	1,011.6	63	14.4	3.1
03	25.2	15.8	5.1	9.5	996.7	20.4	16.2	1,012.8	64	13	1.9
04		16.8	5.8	11.1	996.9	19.6	16.7	1,012.8	74	14.7	1.8
05	25.2	16	7.8	11.5	998	20.4	16.8	1,013.3	69	14.4	2.4
06	26.2	16.4	4.5	9	997.7	21.5	18	1,013.1	69	15.2	3.4
07	28.8	16.8	6.2	12	996.8	21.9	16.8	1,012.7	61	13.1	3.8
08	34	18	8	10.7	997.5	24.3	16.6	1,012.8	46	10.8	2.3
09	40	24	9	11.2	993.9	29.3	19	1,008.3	36	11.9	2.8
10	37	19.4	10.5	11.6	992.6	29.8	18.8	1,006.6	33	11.1	2.9
11	28	18.4	8.7	10.7	995.8	23	17.9	1,011.6	61	14.1	4.5
12	29	18.8	7	10.2	997.4	22.7	19	1,012.7	71	16.9	3.1
13	32	19.4	9.3	11.5	997.5	24.7	18.6	1,012.7	56	14.5	3.8
14	34	21	10.4	11.8	996.5	26.3	18.8	1,012.1	45	13.5	2.1
15	30.6	20	11.6	11.5	994.6	26.4	19.3	1,010.1	51	14.6	7
16	32	19.2	6.5	11.5	995.1	24.6	20.5	1,010.1	70	18.1	3.8
17	31.4	21	9.2	10.8	993.8	24.8	20.3	1,009.1	67	17.6	2.4
18	32	22	7	10.6	991.5	26.4	20.3	1,006.4	57	16.4	3.3
19	27	19.4	8.3	11	991.7	23.7	19.4	1,007.1	67	16.7	4.5
20	24.4	17.2	4.5	10	996.2	21.1	18.2	1,012.1	75	16.3	6
21		15.4	6.7	11	996.6	21	16.7	1,012.3	64	13.6	5.1
22	32	19	7.8	10.5	993.5	24.3	18.1	1,008.6	55	13.9	2.1
23	25	18	7.6	10	995.5	22.3	18.3	1,011.1	68	15.5	5.9
24	27	16.4	7.9	12	999	22.1	17.9	1,014.6	69	15.1	3.4
25	30	19.2	6.4	12	997.6	22.6	18.8	1,013	70	16.3	3.1
26	27	17	7.7	12	996.4	22.7	18.4	1,011.9	66	15.6	3
27	35	21	9.1	11.6	994.2	26.7	18.9	1,009.5	49	13.1	1
28	30	18.6	9.6	9.5	995.4	25.7	19.1	1,010.3	54	14.7	4.5
29	34	20.4	8.3	12.2	996.6	25.5	19.1	1,011.8	54	15.5	1.8
30	31.2	19.4	8.4	11.8	1,000.2	25	19.3	1,015.1	59	15.4	2.5
31		18.6	7.3	12.5	999.7	24.3	19.2	1,015.4	62	15.6	1.6
Avg	30.2	18.6	7.7	10.9	995.9	23.8	18.4	1,011.3	60	14.7	3.3
Min	24.4	15	4.5	7.2	991.5	19.6	16.2	1,006.4	33	10.8	1
Max	40	24	11.6	12.5	1,000.2	29.8	20.5	1,015.4	75	18.1	7
Count	28	31	31	31	31	31	31	31	31	31	31

June 2017

Element / Day	Max	Min	Evap.	sun shine	PST	Dry	Wet	PMS	RH	D.P	WS
01	26.4	19	8.5	12	999.2	22.6	19.2	1,014.9	72	17.2	3.1
02	28.6	20	6	12.2	998.2	24	20.3	1,013.6	72	18.1	2.4
03	34	20.8	7.9	11.9	996.7	25.4	21.4	1,011.5	72	19	2
04	33	21	8.3	11	994.9	26.4	21.2	1,010.3	64	18.2	2.3
05	31.2	19	9.6	12	995.5	25.9	20.6	1,011	62	17.4	2.1
06	32	19.6	8.1	12.5	995.6	26.1	20	1,010.9	59	16.2	1.9
07	32	21	9	12.5	995.1	26.8	19.6	1,009.9	49	14.8	1.6
08	37	23	9.1	11.8	993.9	28.4	21.3	1,008.8	54	17.2	1.8
09	36	21	8.4	12	993.3	28.2	22.5	1,008.1	61	19.5	2.3
10	33	21.4	9	12	995.3	25.3	21.1	1,010.1	69	18.9	2.8
11	30.6	21	8.5	11.7	994.1	24.9	20.6	1,009.1	68	17.9	3.4
12	30	22	8.5	10.2	993.2	25.3	21.1	1,008.3	69	18.8	3.1
13	31	21	7.6	12	994.6	25.7	21.1	1,009.4	65	18.4	2.1
14	31.6	21.6	8.9	12.2	991.7	25.9	21	1,006.8	65	18.1	2.3
15	31.2	21.4	7.7	12.5	994.5	25.7	21.4	1,009.3	68	18.9	1.4
16	32	23	9.2	12	995.5	26.4	22.1	1,010.4	69	19.9	2.8
17	32.4	22.4	8.5	12	993.6	26.6	22.7	1,008.2	73	19.9	3.3
18	33.4	23.4	9	12.4	992.8	28	22.2	1,007.8	62	19	1.4
19	33.4	22.4	8.1	11.8	992.5	28	22	1,007.3	61	18.7	2.5
20		20	6.2	11.6	994.7	25.7	21.5	1,009.6	69	19.1	3.3
21	29.2	21.2	9.8	11.5	994.6	24.8	20.1	1,010.2	65	17.8	3.4
22	30.2	22.4	8.2	9.8	995.4	25.5	20.9	1,010.5	67	18.3	3.1
23	31.4	22	7.7	12.4	996.2	26.8	22.4	1,011	69	20.1	1.7
24	33	23	8.9	12	994.5	27.8	23	1,009.3	67	20.5	2.4
25	34.6	22.6	8.9	12	993.2	28	22.9	1,008	65	19.7	3.3
26	36	24	7.3	12	991.2	28.8	22.9	1,006	61	20	2
27	35.6	23.8	10.5	12	991.2	29.6	23.4	1,005.7	60	20.2	2.5
28	34	22	8.4	11.5	991.7	28.8	22.6	1,006.2	66	19.7	2.5
29	33.2	24.8	10.5	12	991.7	27.6	21.2	1,006.5	57	17.5	3.1
30	33	25	9.1	11	988.9	28.5	22.7	1,004.7	59	19.5	4.1
Avg	32.4	21.8	8.5	11.8	994.1	26.6	21.5	1,009.1	65	18.6	2.5
Min	26.4	19	6	9.8	988.9	22.6	19.2	1,004.7	49	14.8	1.4
Max	37	25	10.5	12.5	999.2	29.6	23.4	1,014.9	73	20.5	4.1
Count	29	30	30	30	30	30	30	30	30	30	30

July2017

Element / Day	Max	Min	Evap.	sun shine	PST	Dry	Wet	PMS	RH	D.P	WS
01	37	23.8	9.4	12	984.3	30.2	24	1,002.5	62	21.4	1.6
02		25.6	9	11.9	985.4	31.5	23.8	998.6	54	19.5	1.1
03	38.8	27	10.9	9.8	986.1	32.3	22.8	1,000.3	45	17.6	1.3
04	37.4	24.6	10.8	11	989.1	31.6	22.8	1,003.2	47	17.8	2.8
05	34	23.8	10.3	11	990.9	28.7	23.9	1,005.3	67	21.4	3
06	31.5	25	7.9	10.6	992	27.6	22.9	1,006.8	67	20.4	3
07	31.4	24.8	9.6	11.5	989.6	27.6	22.2	1,004.4	62	19.2	3.5
08	33.5	24.2	8.9	11.5	989.9	28.4	23.6	1,004.7	67	21.2	2.6
09	35	24	8	12	991.6	29.6	23.9	1,006.2	60	20.3	2
10	36.4	25.4	9.4	11.9	991.2	29.9	21.5	1,005.4	49	15.4	2.5
11	36.6	25	10.9	9.1	991.8	30.9	23.5	1,005.9	54	18.6	2.5
12	35	25.4	10.5	9.8	990.4	30.2	24.3	1,004.4	63	21.3	2.5
13	34	25	8.1	11.5	987.1	29.3	24.6	1,000	65	21.4	2.6
14	36.4	25	10.4	12.1	986.6	30.6	22.4	1,000.5	53	17.6	1.8
15	37.6	23.4	12.7	10.5	989.6	30.8	22.8	1,001.9	53	18.3	2.9
16	39	25.4	7.8	12.5	989.5	31.4	22.7	1,003.5	50	18	1.1
17	39	24.6	9.4	11.5	991.6	30.7	23.7	1,005.8	55	20.1	1.9
18	36.2	25	9.4	11.8	992.8	29.4	24	1,007	64	20.9	2.3
19	34.6	24.6	8.6	12	992.3	29.5	24.5	1,006.3	66	22.1	2.1
20	33	25	9.2	11.5	989.3	28.7	23.3	1,003.3	64	20.2	1.6
21	33.4	25	6.8	10.5	988.7	28.5	23.8	1,002.9	67	21.4	2.5
22	32.6	25	9.2	11.5	991.3	28.4	23.8	1,005.4	68	21.6	3
23	33.6	25	7.3	11.3	991.4	28.8	23.3	1,005.7	64	20.9	2.5
24	35	25	8.3	11.7	989.4	29.4	24.9	1,003.6	70	23.1	3.1
25	37.2	26	9.2	11.5	987.9	30.5	24.8	1,002.1	64	22.5	1.9
26	38	27	9	11.5	988.1	31	24.1	1,002	58	20.5	2.3
27	36.6	26.6	9	11.5	990	30.9	25.1	1,004.2	62	22.3	2.6
28	34.6	25	9.5	11.5	993.9	29.3	24	1,007.9	65	21.4	2.4
29	33	23.6	9.5	12	995.6	28.4	21.8	1,010.4	55	18	2.1
30	34	24.4	9.8	12	997.2	28.7	22.6	1,012.4	59	19.7	2.1
31	37	25	8.2	11.6	992.5	29.9	24.6	1,006.6	62	21.8	2
Avg	35.4	25.0	9.3	11.4	990.2	29.8	23.5	1,004.5	60	20.2	2.3
Min	31.4	23.4	6.8	9.1	984.3	27.6	21.5	998.6	45	15.4	1.1
Max	39	27	12.7	12.5	997.2	32.3	25.1	1,012.4	70	23.1	3.5
Count	30	31	31	31	31	31	31	31	31	31	31

August 2017

Element / Day	Max	Min	Evap.	sun shine	PST	Dry	Wet	PMS	RH	D.P	WS
01	36	24	10.2	12	993.2	30.4	24.2	1,006.7	61	21.2	2.3
02	34	25	10.9	12	996.3	29	23.4	1,010.2	63	20.6	3.4
03	33	25	7.8	11	996.5	28.8	23.5	1,011.3	64	20.9	2.1
04					992.6	27.8	23.1	1,007.4	68	20.5	1.8
05	33.2	23.4	8.4	11.5	990.7	29.8	22.7	1,004.8	54	18.8	3.2
06	35.2	24.6	8	12	994.1	29.4	23.3	1,008.8	60	20.2	1.9
07	35.2	25	9	11	996.3	29.5	24.4	1,011	66	22	1.1
08	35.2	25	8.7	9.6	995.2	29.7	24.7	1,009.8	66	22.3	2.8
09	35.2	25	10.2	11	993.6	29.4	24.5	1,007.9	67	22.3	2.5
10	33.6	25	6.8	10	992.3	28.6	23.9	1,007.1	66	21.5	3.3
11	35	25	7.9	10.5	991.3	29.1	24	1,006.1	65	21.4	1.4
12	35	25.6	8.3	11	990.2	29.7	24.2	1,004.3	64	19.8	1.4
13	35	25	9.6	11.6	990.8	29.8	24.9	1,004.6	67	22.6	2.3
14	34	25	7.4	11		29.5	24.8		69	22.6	2.4
15	33.6	24.6	7.7	11.6		29.3	24.6		64	22.2	2.8
16	33	24.8	7.9	11		28.5	23.9		68	21.7	2.3
17	34	24.5	7.9	11		28.5	23.8		67	21.5	2.5
18	33	24	8.6	11		28.2	23		64	20.4	3.6
19	35.3	24.6	9	11		29.2	22.6		51	18.8	2.5
20	35.4	25	8	11		29.4	22.9		58	19.5	2
21	33	24.6	8.7	11.2		28.7	24		67	22.1	2.9
22	32	25	7.8	10.7		28.4	23.7		68	21.3	2.9
23	33.4	23.6	7.7	11.4		28.7	23.7		66	21.2	2.1
24						27.8	23.5		66	21.3	1.5
25	35	26	6.6	11		30.8	25		62	22.5	3.3
26						29	24.7		71	22.6	2
27	35	25	9.5	11.5		30.6	22.3		53	18	1.5
28	31.8	23.6	8.8	11		27.8	22.8		65	20.1	1.8
29	33	22.6	9.8	11.6		27.5	21.7		59	18.4	2.8
30	33	22.6	7.2	11.2		27.5	21.8		60	18.6	2.3
31	31.8	24	8.3	11.2		27.4	21.5		60	18.4	1.3
Avg	34.0	24.5	8.5	11.1	993.3	29.0	23.6	1,007.7	64	20.8	2.3
Min	31.8	22.6	6.6	9.6	990.2	27.4	21.5	1,004.3	51	18	1.1
Max	36	26	10.9	12	996.5	30.8	25	1,011.3	71	22.6	3.6
Count	28	28	28	28	13	31	31	13	31	31	31

September 2017

Element / Day	Max	Min	Evap.	sun shine	Dry	Wet	RH	D.P	WS
01					25	21.3	74	19.4	0.3
02	34	26	8.2	11.8	30.3	24.7	63	22.1	2.8
03	36	26.4	6.5	10.5	30	24.6	65	22	3.8
04					30.1	24.7	64	22.3	2.5
05	34.6	24	7.6	10.5	30.8	23.2	52	19.1	2.8
06	32				27.7	21.9	60	18.5	2.5
07	32.6	22.6	8.4	11	27.7	21.9	60	18.6	2.6
08		25	7	10.5	26.3	22.1	69	19.9	1
09	37	25	8.6	9	29.1	24.5	69	22.7	1.9
10	35	23.6	7	9.7	29	23.6	63	21	2.9
11	36.2	21.4	9.6	9.5	29	23.2	63	20.4	1.3
12	38	23.2	6.4	10.2	29	23.1	61	20.1	1.5
13	36.4	24.2	6	10	29.4	23.6	61	20.6	2
14	35	24.6	7.2	9.5	29.1	24.9	71	23	2.4
15	31.2	24	7	5.5	27.4	23.8	76	22.1	2
16	32	22.6	4.6	9.2	26.7	22.5	69	20.3	2.4
17	32.4	21	5	10	26.9	22.5	68	20.2	2.6
18	33.6	23	6.6	10	27.1	22.4	67	19.9	1.5
19	32.4	22.6	7.4	10	26.9	22.7	69	20.5	1
20	33	23	4.3	5.8	26.5	22.7	72	20.7	1.8
21	31.4	24.6	5.2	9.3	27	23	71	21	2.1
22	31.2	23	6.4	9.3	26.8	22.8	71	20.9	2.6
23	30.4	22.6	7.3	10	25.8	20.9	65	18	2.5
24	30	21.6	7.6	9.2	25.6	20.6	64	18	2.8
25	31.6	22	5.4	9.2	26.3	21.8	67	19.5	2
26	31.4	22	7.8		26	21.7	67	19.3	2
27	30				25.3	21.3	70	19.1	2.5
30		21.6	7.5	10					
Avg	33.2	23.3	6.9	9.6	27.7	22.8	66	20.3	2.2
Min	30	21	4.3	5.5	25	20.6	52	18	0.3
Max	38	26.4	9.6	11.8	30.8	24.9	76	23	3.8
Count	24	24	24	23	27	27	27	27	27

October 2017

Element / Day	Max	Min	Rain	Evap.	sun shine	Dry	Wet	RH	D.P	WS
01	33.2	20.2		5.6	10	25.3	20.7	67	17.9	1.6
02	36.8	22.4		6.1		27.2	20.5	54	16.6	1.9
03	30	20.6		6.3	10	26.4	22	67	19.6	3
04	29.6	21		6	10	24.8	21.2	72	19.2	1.9
05	29	20		5.8	8	24.6	21.3	75	19.7	2.9
06	31	19.8		6.3	9.7	24.8	20.2	67	17.3	1.3
07	31	20		4.5	6.7	24.6	20.2	67	17.8	2.1
08	30	21		5.6	8	24.9	21.2	72	19.2	3
09	25.4	19.6	16	4.6	1.7	22.8	20.3	79	18.9	1.8
10	26	19		5.5	10	22.2	18.8	73	16.6	2.8
11	28	19		4.6	9.8	23.1	19	68	16.6	1.9
12	28	19		5.1	10	22.7	18.9	69	16.6	1.8
13	28	19		7	9	23.4	19	65	16.3	1.9
14	28	17		4.2	10	23.6	19	64	16.1	1.6
15	28	19		5.5	10	22.8	18.9	68	16.5	2.4
16	28	18		6.2	9	22.3	17.7	63	14.7	1.4
17	30	17		5.2	10	23.6	18.5	62	15.2	1.8
18	32	18		4.6	9	23.3	17.8	51	13.2	1.3
19	33.2	21		5	8.5	25.4	16.5	39	9.1	1.3
20	32	20		4.7	9.5	24.4	20	67	17.3	1.5
21	28	18		4.5	8	23.3	19.8	72	17.6	2
22	27	17		4.1	8.5	21.8	17.7	67	15	2.4
23	28.8	17		5.4	9.5	21.9	17.4	63	14.2	1.1
24	28	17		3.4	8.5	23.7	18.6	60	15.2	1.7
25	29	18		4.4	9.5	22.6	18.2	65	15.5	0.8
26	31.4	17		5.2	9.8	22.2	17.8	65	14.9	1.4
27	32.4	21		6.1	9.5	24.2	17	51	11.5	2.1
28	25	18		3.6	6	22.5	17.8	60	14	3.1
29	27.5	19		4.8	9	22	16.5	56	12.2	2.1
30	23.6	17	2.2	3.3	5.5	21.1	17.1	66	14.3	2.9
31	25.8	17.6		4.6	7	21.6	17.8	68	15.1	3.1
Avg	29.2	18.9	9.1	5.1	8.7	23.5	18.9	65	15.9	2.0
Min	23.6	17	2.2	3.3	1.7	21.1	16.5	39	9.1	0.8
Max	36.8	22.4	16	7	10	27.2	22	79	19.7	3.1
Count	31	31	2	31	30	31	31	31	31	31