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Improving water use efficiency using sensors and communication system for irrigation of greenhouse Tomato in Tulkarm, Palestine

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Section/Category:	Water management

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Abstract

This paper presents a six months experimental study on responsive changes in yield and water use efficiency (WUE) of tomato grown in greenhouse to different irrigation frequency and amount under drip irrigation depending on sensors and communication system. The study presents the use of innovative low cost technology to schedule irrigation interventions under different conditions. The irrigation scheduling was based on a sensor system sensitive to soil matric potential (SMP). Four irrigation treatments were applied, one is farmer custom based irrigation (control), the other three are sensor based irrigation depending on a preset threshold (-20 kPa, -40 kPa, and -60 kPa) in four different beds. Water consumption, plant growth parameters, and yield in each treatment were measured weekly. The 20 weeks results show that appropriate irrigation (frequency and amount) improve WUE without affecting the quantity and quality of tomato crop yield in an experimental greenhouse. Both yield and WUE were improved by applying irrigation depending on information system. Findings of the study shows that applying irrigation by using sensors sensitive to SMP and communication system can promote sustainable irrigation practices and may overcome water scarcity and even improves in the agriculture sector. It is recommended to schedule irrigation frequency for tomato grown in greenhouses using low cost communication system that uses sensors sensitive to SMP to save water without compromising yield in water scarce regions.

Keywords: Irrigation, Soil matric potential, Water Use Efficiency, Sensors and communication system

1. Introduction

Water scarcity in arid and semi-arid regions implies and even enforce the sustainable use of water, mainly in agriculture, using appropriate technologies for better economic viability and for better socioeconomic development. Innovations to face water scarcity and improve water use efficiency (WUE) and productivity in agriculture are required in irrigation management (Gençoğlan et al., 2006) especially in a climate change stresses that is affecting the globe increasingly. WUE is a ratio between plant production and the water amount consumed by crop (Al-Jamal et al., 2001; Perry, 2011; Rahil and Qanadillo, 2015; Zhang and Oweis, 1999). Appropriate irrigation scheduling improves WUE, water save, protect environment, and promote sustainable agriculture. These benefits can be enhanced and result in reduction in water losses by applying precision irrigation that allows applying irrigation according to the plant need, variability in weather, and crop properties and development (Daccache et al., 2015). Applying methods to improve irrigation that promote water saving is an important agriculture practices, especially in water sensitive regions. Sustainable use of water resources is one of the 17 Sustainable Development Goals: "*By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity"* (Ferri, 2010).
Palestine is mainly an agricultural area, however with limited water resources (McNeill et al., 2009; Shadeed and Almasri, 2010) and widely varying climatic conditions (Kitaneh et al., 2012). Meeting the water needs of a growing population and growing economies in Palestine is a huge challenge for a region struggling already with water scarcity, water supply deficit, and climate change (Saleh, 2016; Shetty, 2006). However, constrains never stopped Palestinian farmers continue their efforts to improve agricultural output (quantity and value) through the application

of drip irrigation and plasticulture in addition to other improvements that they can access. In Palestine, the agriculture sector contributes to the gross domestic product, food security and employment. In the year 2006, labor force in the agricultural sector constituted 16.7% of total labor force, however this percentage of contribution declined to 10.4% in 2014, and to 7.4 % in 2016 (Palestinian Central Bureau of Statistics, 2017). In the year 2011, the sector accounted for 5.5% of the Palestinian GDP and 11.9% of total employment (Palestinian Central Bureau of Statistics, 2017) but according to the Palestinian Monetary Authority (PMA) agriculture sector contributed about 3% of GDP in the year 2018, and the agriculture sector workers were 6.3% of the total work force in Palestine (Palestine Monetary Authority (PMA), 2019).

The climate in Palestine is predominantly of the eastern Mediterranean type, cool and rainy in winter (October to April) but hot and dry in summer (May to September) with annual rainfall in the range of 100–700 mm (Frenken, 2009; Shadeed and Almasri, 2010). Irrigated agriculture (both greenhouses and open-fields) struggles mainly from restricted access to water and high water costs (Isaac and Hrimat, 2007; World Bank, 2009). Agriculture in Palestine consumes about 160-189 MCM/Year of available fresh water (Isaac and Hrimat, 2007; Palestine Monetary Authority (PMA), 2019; Palestinian Ministry of Agriculture, 2017; World Bank, 2009), this amount represents 45-75% of the total water consumption (Abu-Madi, 2009; Almasri and McNeill, 2009; Frenken, 2009; Palestinian Ministry of Agriculture, 2017). It is estimated that irrigation water consumption could increase to 552 MCM/Year in 2020 (Jayousi and Srouji, 2009). Farmers are paying high prices for irrigation water, in some cases it reaches up to 12 NIS/CM (~ $ 3.5) to irrigate plants in greenhouses, the average price is NIS 3-4/CM (~ $ 1). More groundwater mining is practiced in order to compete for basic living needs and agriculture in Palestine (Sbeih, 1996; World Bank, 2009). It is estimated that 740 CM/dunam/year are required for vegetables production (Palestinan Water Authority, 2013). Unsustainable use of groundwater resources to the limits of natural recharge capacities and even exceeding these mainly in irrigation under the sever constraints due to the political situation in Palestine leads for thinking better in WUE and water productivity (Abu Zahra, 2001). Palestinians extracts groundwater from available wells either private, Palestinian Water Authority owned, or municipal owned, but they even have to buy water from the Israeli water company Mekorot (Haddad, 1998; Palestinan Water Authority, 2013; World Bank, 2009). Since the current water availability for agriculture is limited in Palestine, a crucial way to substitute in the total water available is through improving on‑ farm application and water management practices. It is estimated that improvements in water management applications could reduce amount of water needed for irrigation by around 20 MCM/year (Frenken, 2009) and increase irrigated potential areas.

In the West Bank part of Palestine, 10% of the cultivated land produces vegetables with an average yield $ 2500/Dunam (Palestinian Central Bureau of Statistics, 2011; Palestinian Ministry of Agriculture, 2017). Tomatoes, mainly grown under irrigation, occupies 10 to 15% of land cultivated by vegetables (Frenken, 2009). Greenhouses are used mainly for vegetables cultivation in Palestine to allow good control of the climate that is allowing vegetables to be planted for the whole year length especially in areas of more climate variability and high possibility of severe cold or frost. In general drip and trickle irrigation systems are used to irrigate vegetables in Palestine, a small percentage of vegetables are still irrigated by traditional methods (Frenken, 2009). Generally significant part of the farmers irrigates their crops according to fixed interval and to some extent at fixed duration. Since crop water requirements vary over the growing season, the use of fixed intervals and/or fixed duration of irrigation (fixed amount of water) may result in either over irrigation or under irrigation, which will end with miss-management which may adversely affect

WUE and water productivity. Using a fixed irrigation scheme or farmers experience and traditions to estimate water need are not enough to reach a good WUE and productivity (Müller et al., 2016; Ranquet Bouleau et al., 2015). Estimating the plant water need using sensors based irrigation is hypothesized to lead to a better WUE and can increase the productivity too. This is possible by choosing a proper threshold for starting irrigation depending on the plant need or soil moisture status. This technology use can increase harvest as irrigation water can decrease.

Soil Matric Potential (SMP) is the term used to describe the water tendency to move in the soil, in other words it is a measure of the holding strength of the soil matrix for water(Müller et al., 2016; Ranquet Bouleau et al., 2015). The sensors used in this study were watermark soil moisture sensors, model 200SS. They measure resistivity to calculate the corresponding SMP-level. The electrodes that measure the resistivity are placed within the sensor, in a granular material where water moves like in a soil. Taking the measurement inside the sensor, where conditions are well defined, gives the advantage of not needing to recalibrate depending on soil properties. The sensors are furthermore internally compensated for common salinity levels found in agricultural soils (Isaksson, 2016; Ranquet Bouleau et al., 2015) .

"Info4Dourou 2.0 is one of the projects launched by the UNESCO Chair in Technologies for Development in the 'ICT for Development' sector." (Cooperation & Development Center (CODEV), 2019). The Info4dourou2.0 project main goal is to "*improve agriculture in semi-arid regions by the use of communication and sensing technologies"* (Cooperation & Development Center (CODEV), 2019). This project developed a sensing and communication system that allows data collection in the field and sent via the GPRS net to a webserver. The farmer can log in to a website for data but more easily the system can set alarms that allows for sending an SMS or other form of communication such as an email to the farmer when a chosen threshold is reached so to start an irrigation event. The system allows irrigation management using soil matric potential (SMP) threshold by applying simple sensors positioned in the subsurface at a suitable depth depending on the plant root system position since SMP thresholds are less dependent on the soil texture but directly linked to the root ability to use the water. The system in practical application in the field, allow farmers to use the system by choosing sensor position, effect of soil type, and suitable thresholds.

The purpose of this study was to evaluate the possibility of using the low cost sensors through a cooperation between Al-Quds University (AQU) and Cooperation and Development Center (CODEV)-Ecole Polytechnique Federale de Lausanne (EPFL) within the framework of the Info4dourou2.0 project in Palestine as a management tool to supply water for irrigation of tomato in greenhouse using drip irrigation system to improve WUE, reduce water consumption, but at the same time keep and improve productivity.

2. Materials and Methods

2.1 Experimental Site and Field Design

The experiment was conducted in an experimental greenhouse at Palestine Technical University-Kadoorie (PTUK) Tulkarm, Palestine. Tulkarm is situated on the western edge of northern West Bank in Palestine (32°18'52.6"N 35°01'19.1"E). Tulkarm has a moderate climate, the average annual precipitation during winter (October to April) varies between 530 and 630 mm, which is the main water source for the groundwater aquifer, however its very dry during the summer (May to September) (Abu-Madi, 2009). The study was conducted at the experimental farm of PTUK from November, 2017 to April, 2018. Part of a greenhouse with an area of 1000 square meters was

used for the experiment. The soil of the experimental farm is classified as loam clay texture with bulk density in the upper 30 cm of 1.2 g cm^{-3}. Inorganic fertilizers were applied to all tomato plants equally through drip irrigation system according to the farmers' tradition in the area.
Tomato is a staple commercial vegetable grown mainly in greenhouse in many countries including Palestine to bridge the seasonal gap in its production (Li et al., 2017; Liu et al., 2013). The tomato (*Lycopersicon esculentum* L.) seedlings (FA#593 variety) planted in November 2017 in a raised-bed system cultivated with 520 tomato seedlings on 4 beds each bed 80 cm wide, the space between beds is 1.2 meter, each bed consist of two plant rows, 26 meter long, the space between rows and plant within rows were 60 and 40 cm respectively (**Figure 1**).

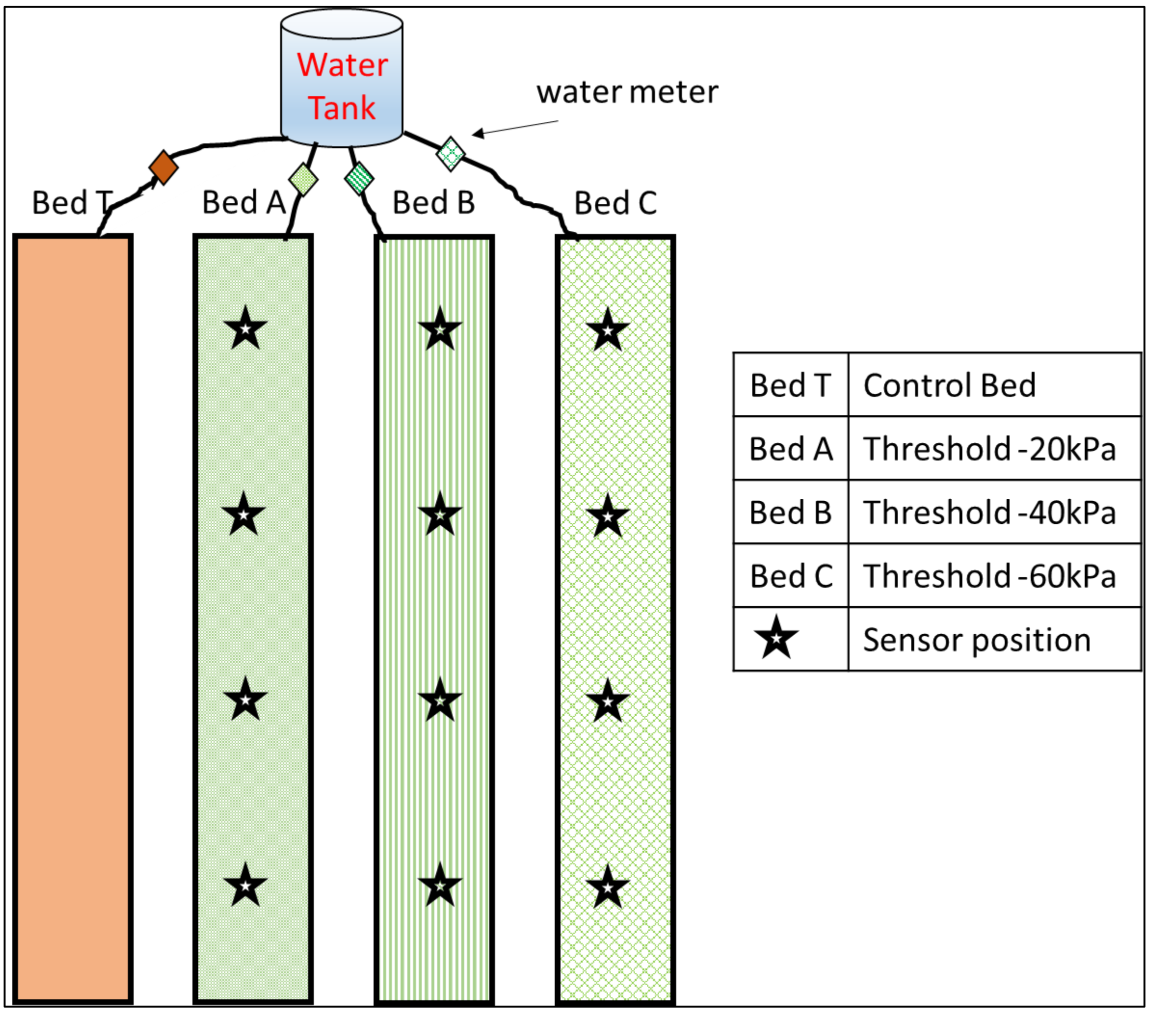

Figure 1. Schematic diagram showing the distribution and setup of the beds and sensors in the greenhouse

The parcel was divided into four subplots (Beds) (4 irrigation treatments). The four irrigation treatments were according to a preset threshold to each (Bed A -20 kPa, Bed B -40 kPa, and Bed C -60 kPa), Bed T was irrigated as it is practiced in the farmers' traditions in the area (a control). An average of 130 tomato plant per each subplot, 4 sensor per each subplot, each sensor placed few cm apart from the plant, at 25 cm depth. Soil is loam clay thus the depth of 25 cm would be sufficient and appropriate. Weeds were controlled by using mulch, hand removing, and when needed chemical control was used.

2.2 Irrigation System

The used drip irrigation system composed of PVC pipes with small holes in them every 40 cm. The hole was placed close to the plant. The pipes diameter next to the plants was 16 mm. The water source was the municipal distribution system. This water was groundwater from wells. Four water meters with an on/off handle were connected at the head of the four main irrigation pipes used to measure the water volume consumed in the irrigation.
The drip irrigation system discharge was tested before planting and it was at a rate of 4.66-5.58 L h^{-1} depending on the bed site (**Table 1**).

Table 1. Dripper flow at the planting beds

Measurement Replicate	Bed T (Control Bed)	Bed A (-20 kPa)	Bed B (-40 kPa)	Bed C (-60 kPa)
1	5.61	4.53	4.80	5.64
2	5.64	4.71	4.53	5.49
3	5.64	4.80	4.74	5.64
4	5.46	4.65	4.68	5.58
Average	5.58±0.08	4.67±0.11	4.68±0.11	5.58±0.07

2.3 Sensor Network and Data Collection

The system that was developed in the context of Info4dourou2.0 Project is based on measurements of Soil Matrix Potential (SMP). SMP sensors are placed in the subsurface at selected depth near plants roots (**Figure 1**) and connected to a station, which stores the data and sends it to a webserver. The station is designed to be used under extreme and harsh weather conditions and use easy and friendly. The basic components in a station are sensor cards connected to sensors and a solar panel used in charging rechargeable AA batteries to power the station. Master stations has a mother card that stores data and sends it to the webserver and equipped with a SIM card to transmit data. The data can be accessed through the website www.climaps.com. At this website it is possible to follow sensor data and the health status of the station including battery level and connection strength. This is also where the alarms are set for the preset thresholds. A full description of the system is more detailed in our previous publication (Isaksson, 2016; Müller et al., 2016; Ranquet Bouleau et al., 2015).

2.4 Plant Measurements

Weekly plant development measurements started one week after initial plants growth and vegetation for 18 plants from each bed. Each bed was divided into 3 areas, from each 6 plants were selected randomly to keep measuring during the experiment. Plant height, stem diameter (2 cm above the ground), leaves number and flowers were the factors measured to track the plants development in the four different irrigation treatments. After that when fruits started to appear we have measured fruits number and weight for the eighteen plants selected to monitor in each bed.

2.5 Water Consumption Measurement

Water consumed in irrigation for each experimental bed was measured using the water meters at the upper head of each bed water pipe. Also the drip flow and the irrigation time long was always monitored and matched with the water meter readings.

3. Results and Discussion

3.1 Crop Development

Different irrigation treatments effect on plants height, stem diameter, and number of leaves during 20 weeks of monitoring the plants development are shown in **Figures 2, 3, and 4**. The plants that were irrigated according to a preset threshold in Beds A, B attained a close height of the plants that were irrigated in the custom/traditional irrigation as farmers practice usually in Bed T, however, plants in Bed C where the irrigation was planned according to -60 kPa threshold attained less height especially after week 14 during the experiment.

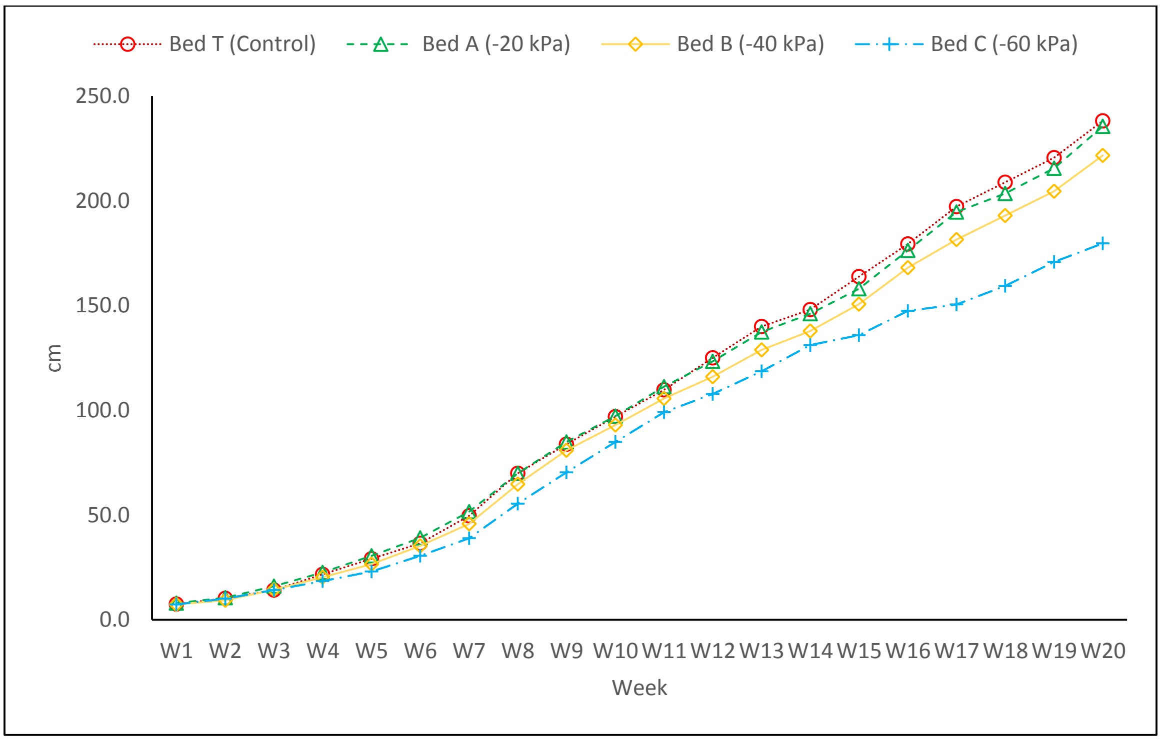

Figure 2. Average plant height (n= 18 plants in each bed) in cm of tomato plants under four irrigation treatments

The stem diameter (**Figure 3**) was more and comparable to each other in Bed T and Bed A (custom irrigation and the -20 kPa threshold treatment), but the stem diameter was less in Bed B and Bed C where less water was provided as thresholds were -40 and -60 kPa respectively.

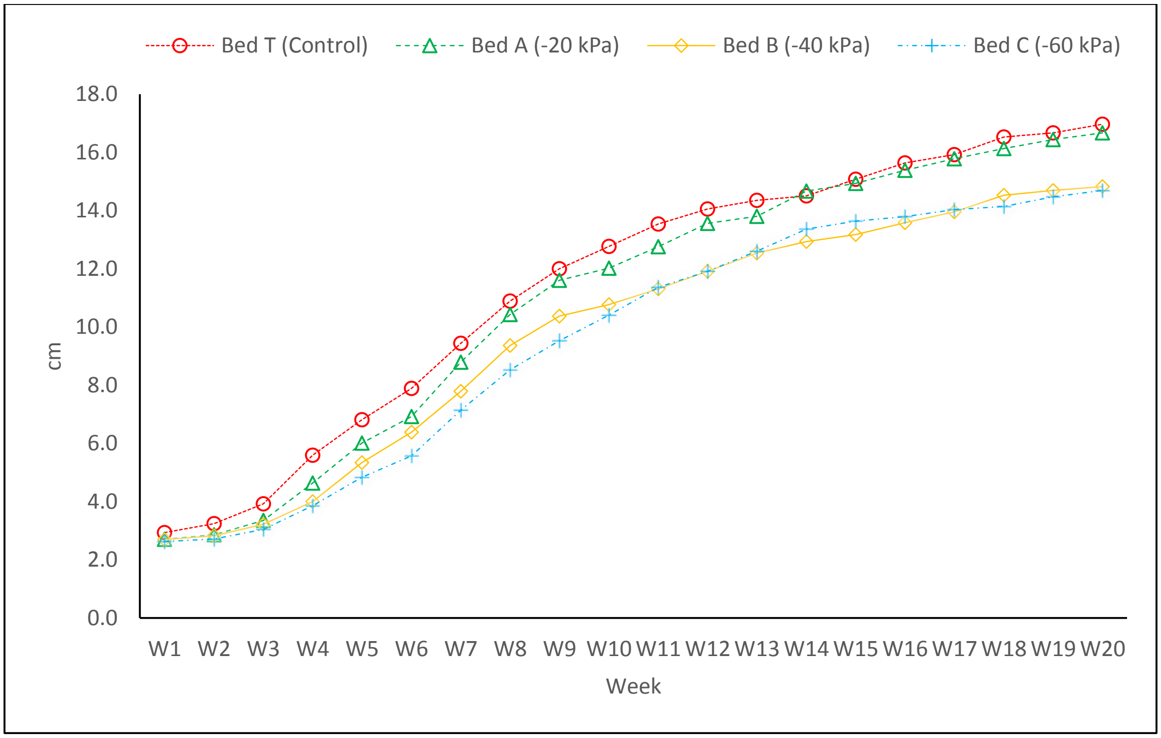

Figure 3. Average plant stem diameter (n= 18 plants in each bed) in cm of tomato plants above ground under four irrigation treatments

This implies that over or less irrigation effect on plant growth is negligible when the preset threshold was -20 and -40 kPa compared to farmers' traditional irrigation.

At the beginning the leaves number in all treatments were so close (**Figure 4**), but after week 15 less leaves were counted in plants in Bed C (-60 kPa).

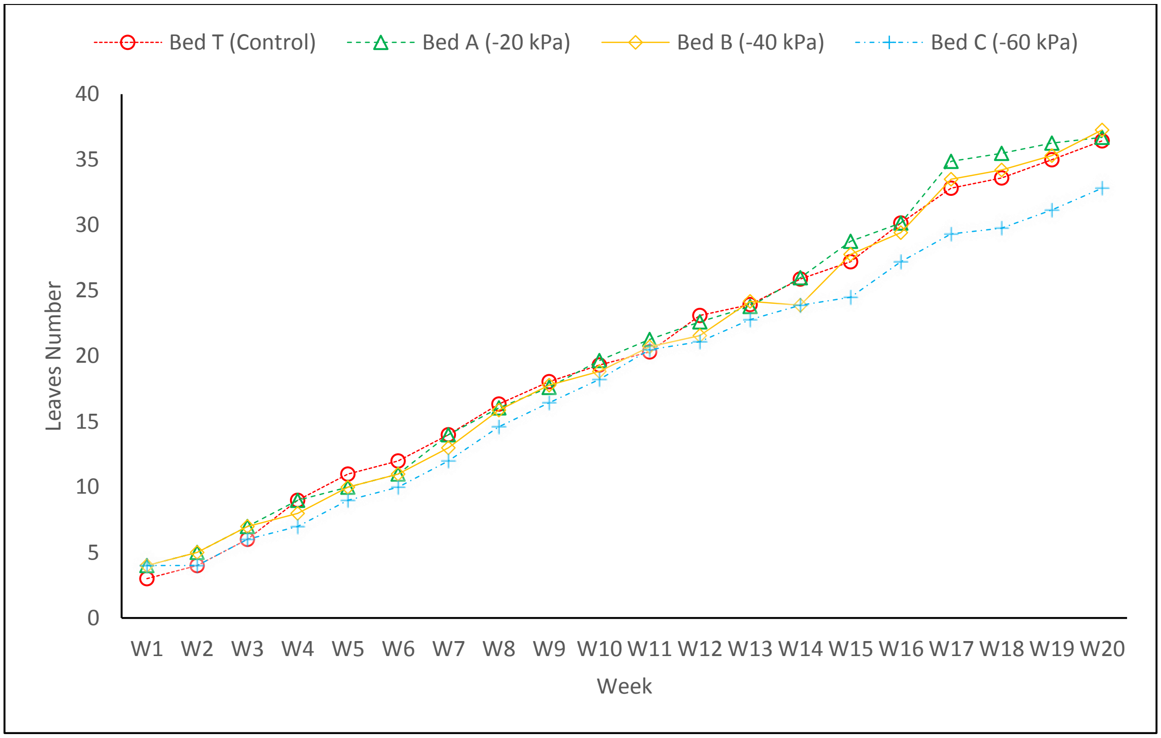

Figure 4. Average leaves number (n= 18 plants) of tomato plants under four irrigation treatments

3.2 Water Use and WUE

Amounts of water that were applied in irrigation according to different water treatments in the four beds are shown in **table 2**. The amount of irrigation water applied according to farmer based irrigation in Bed T (custom irrigation) was 3.6, 7.5, and 9.4 times the amount of water used in irrigation in Bed A, B, and C respectively.

Table 2. Irrigation treatments, water save, yield, and WUE

Bed	Average Water Used (m^3)	Average Water Saved (m^3)	Yield (kg/Bed)	WUE (kg/m^3)
Bed T (Control)	11.3	-	146.5	13
Bed A (-20 kPa)	3.1	8.2	196.0	63
Bed B (-40 kPa)	1.5	9.8	250.5	167
Bed C (-60 kPa)	1.2	10.1	144.4	120

WUE: Water use efficiency

Using sensors and preset threshold for irrigation events saved 8.2, 9.8, and 10.1 m^3 of water in the irrigation treatments in Bed A, B, and C respectively. More yield (fruits in kg per bed) was recorded in Bed A (threshold -20 kPa) and B (threshold -40 kPa) compared to Bed T (custom irrigation) and Bed C (threshold -60kPa).

WUE (**Figure 5**) in this experiment is expressed as a ratio of tomato yield (kg) in each bed to irrigation water amount (m^3) used for each bed (irrigation treatment). The highest WUE was in Bed B while the lowest was in Bed T (custom irrigation) which can be interpreted by, a large amount of water is applied in irrigation improperly in custom irrigation.

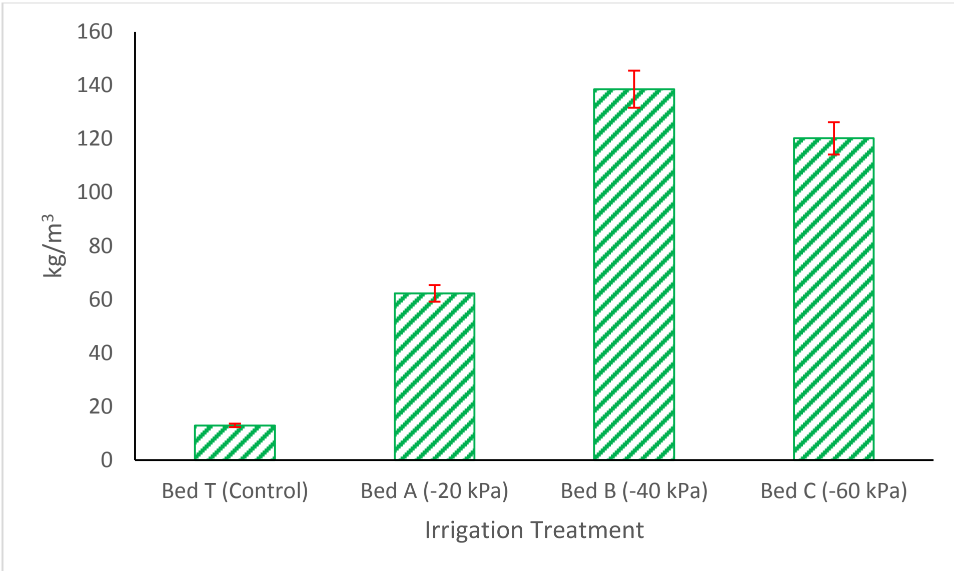

Figure 5. WUE of tomato plants under four different irrigation treatments

The yield was the lowest in both Bed T (custom irrigation) and Bed C with the lowest threshold (-60 kPa). The lowest WUE is when water irrigation used according to farmers custom on fixed amounts and defined time schedule. Higher WUE is recorded in this study in all cases where sensors were used to start irrigation and to follow the threshold of soil matric potential (SMP). Similar results of WUE were shown by Rahil and Qanadilo (Rahil and Qanadillo, 2015) when they applied different irrigation regime depending on farmer irrigation, crop evapotranspiration, and tensiometer in irrigating cucumber crop in similar experimental field in Tulkarm, Palestine.

3.3 Irrigation frequency-reaching the thresholds

An example of SMP decrease patterns for Bed A that was preset to a threshold (- 20 kPa) is shown in **Figure 6**. Irrigation was initiated according to the time of reaching the preset threshold. The pattern in fig. 6 shows that irrigation was not time dependent but it was according to the information collected from sensors as the preset threshold is reached as shown in **Figure 6**. This information collected via an SMS decreased the irrigation frequency and as discussed above was efficient in decreasing water use without affecting plant growth, development, or yield.

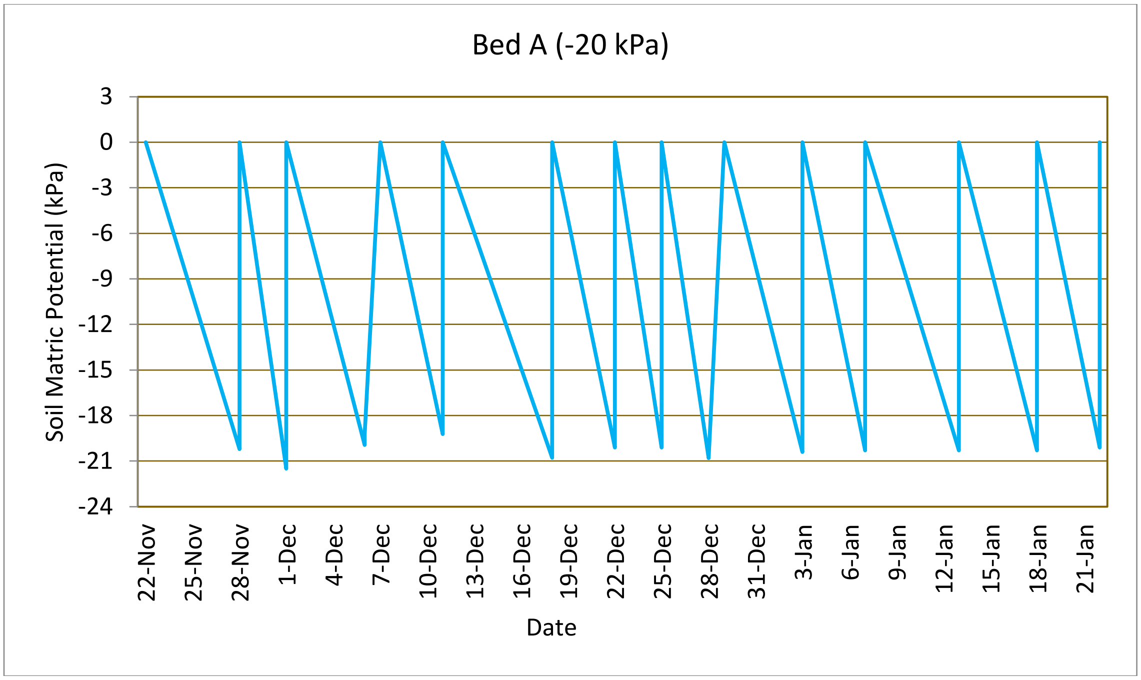

Figure 6. Graph of soil matric potential (SMP) data collected via the system for Bed A from Nov 22 to Jan 21

4. Conclusion

Results of this field study using low cost sensors and a simple communication system in an experimental greenhouse field and applying four different irrigation treatments on tomato plants were investigated. The use of the system by applying irrigation according to soil matric potentials (SMP) result in water save and better WUE compared to custom irrigation that apply water irrigation at fixed amounts and time intervals along the cultivation period. The system performance and improvements are attributed more to water saving, however the impact on the yield was minor and less evident. Plant growth was not highly affected by applying less water for irrigation, while the yield and WUE was improved when irrigation was applied according to preset thresholds that were triggering irrigation through an SMS to the field worker. Results show that the highest WUE was obtained when sensors were preset to a threshold -40 kPa. This implies that more water application in irrigation is improper for both productivity and water management. These innovations are simple, friendly to use, and are not expensive especially when water save and better water management and productivity is necessary in the context of climate change and water scarcity over wide range of the globe. Further future experiments and application of the system is required to optimize its use and validate the results either for tomato or other water consuming vegetables in Palestine and other similar agricultural practices in the area.

5. Declaration of Conflict Interest

There are no conflicts of interest to declare.

6. Acknowledgment and Fund Source

This study is part of the project Info4Dourou2.0 managed by the Cooperation & Development Center (CODEV) based at the EcolePolytechnique Fédérale de Lausanne (EPFL) which aims to improve water management by the use of simple low-cost wireless sensor networks. We also thank Al-Quds University (AQU) and PTUK for hosting and supporting the experimental work in Palestine

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