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SHORT COMMUNICATION

Evaluation the use of electronic wireless capacitive sensor in the irrigation of the main crops in Abu Dhabi

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ABSTRACT

Two obstacles are associated with most of Abu Dhabi efforts to deal with the water shortage to sustain its agricultural sector. These problems are unskilled labors and lack of accurate crop water requirements data. Accurate information on crop water requirements is needed to help farmers improve their irrigation practices by better matching irrigation supply to crop water demand. A wireless capacitive sensor was evaluated in the irrigation of greenhouse tomato and cucumber in order to develop irrigation scheduling program. Amount of irrigation, yield, and water use efficiency were used to compare between the capacitive sensor system and three other irrigation orders obtained from FAO Penman-Monteith method to calculate the potential evapotranspiration as climate-based irrigation treatments (125%, 100%, and 75%). The results showed that the capacitive sensor gave accurate irrigation amount and it had the best yield. In addition, the data of this system helped in the development of a suitable irrigation scheduling program for the two crops. Such a smart irrigation system is a promising tool to be implemented in the regions that suffer from water shortage.

Keywords: Irrigation requirement; Smart irrigation system; UAE

INTRODUCTION

Water scarcity and quality are serious issues facing countries in arid and semi-arid regions. Worldwide, agricultural sector is by far the biggest user of water accounting for almost 70% of all withdrawals. In the United Arab Emirates (UAE), the agricultural sector consumes about 48% of total water use where about 95% from groundwater and 5% desalinized water (Environment Agency, 2009) with tomato and cucumber are the top vegetables crops over Abu Dhabi farms. Therefore, it is primary essential to use water in agriculture more wisely and to regulate irrigation in a proper way. Ideal irrigation system information depends on the net amount of water applied by the system, which can be determined through measurements of irrigation application efficiency and system gross application rate (Alhammadi and Al-Shrouf, 2013).

Some of efforts which have been done to improve the irrigation scheduling techniques either were based on the measurement of soil moisture or based on the crop water needs which is highly affected by the climatic parameters (Shock et al., 2007).

Some challenges are connected with the Abu Dhabi endeavors to manage the water scarcity to support its agricultural production. These issues are low or no trained workers and lack of knowledge of exact crop water requirements. Therefore, another approach is expected to overcome these snags. Investment in a technology is one approach for Abu Dhabi emirate endeavor to overcome the water scarcity. So the urgency for defining the crop water requirement under Abu Dhabi Emirate conditions is highly needed, also the adapted technology is to be consider the labor interference factor. So the adaptation of a wireless self-operating irrigation system could be one of the good alternative. Since the last two decades in the previous century, an extensive variety of advancements have been addressed as 'the appropriate response for detecting soil water. A few reviews were led to assess these innovations (Damas et al.; 2001; Evett, 2001; Dane and Topp, 2002; Evett, 2003a, b; Wang et al., 2006; Evett, 2007; Kim et al.,

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2008; Chávez et al., 2009a and b; Kim and Evans, 2009; Wang et al., 2006).

A new wireless irrigation system that control the farm irrigation process through Bluetooth and wireless sensors network that measure the soil moisture and temperature. Those sensors has the ability to continuously detect the exact plant water requirements (Kim et al. 2008). Chávez et al. (2009a) used a new system using Linux operating system to control electrical valve connected to individual or group of drippers. The control panel connected to a sensor network radio, GPS unit, and Ethernet radio. Kim and Evans (2008) were able to design wireless in-field soil moisture sensing and control software application that record instantaneous measurements and control of both inputs and outputs data. Vellidis et al. (2007) developed a smart array of soil moisture sensor for cotton irrigation programming. Damas et al. (2001) developed and evaluated remotely self-controlled automatic irrigation system using wireless LAN network. They had been capable to save 30-60% of irrigation water. Evans and Bergman (2003) assisted irrigation scheduling using wireless sensors in three irrigation systems combined with on-site weather station, remote sensing data, and farmer preferences.

Water commodity is a strategic asset in the agricultural sector of Abu Dhabi Emirate. It enables to the narrow the food security gap. To improve the irrigation use efficiency in Abu Dhabi after rehabilitation of the irrigation systems toward the drip irrigation, it is highly needed to adapt intelligent irrigation system as one approach the optimization of the irrigation water on Abu Dhabi Emirate. The selected smart system expected to be reliable, sustainable and accessible for the farmers. In this study, Abu Dhabi Food Control Authority research team evaluated one wireless, solar driven with an available smart phone application to help the farmer to monitor and manage their crop remotely without the regular labor interference. The system is self-irrigating system which could activate and deactivate the irrigation events based on availability of the water content in the soil root zone. The originality of this study is the determination of the real-time tomato and cucumber irrigation water requirement in Abu Dhabi Emirate as compared to the current on-farm irrigation practices with quit low water use efficiency due to inaccurate irrigation time or amount.

The objectives of this study are to test the efficiency of the wireless capacitive sensor in the irrigation of greenhouse tomato and cucumber. The sensor has the ability to detect soil moisture content between field capacity (FC) and welting point (WP) every 10 cm and send the reading to the computer via the satellite. In addition, this study is looking to develop an accurate irrigation scheduling for these two crops.

MATERIALS AND METHODS

Two greenhouses (each with an area of 252 m^2) were prepared at Al Salamat Research Station (24°12’56’’N 55°35’59’’E), Abu Dhabi Food Control Authority in UAE. In each greenhouse, four lines of automatic drip irrigation system were installed each with one flow meter. Flow meters were used to record the amount of water used on daily bases. The irrigation system in each greenhouse was design to be irrigated based on the order received from both DACOM system as well as (125% ET_o, 100% ET_o, 75% ET_o) FAO Penman-Monteith method to calculate the reference evapotranspiration as climate-based irrigation treatment. The irrigation treatments distributed in the experiments according to randomized complete block design (Fig. 1)

Daily reference evapotranspiration (ETo) which measure of the amount of water that is potentially lost to evaporation over a vegetated surface of some reference crop (grass or alfalfa) assuming no control on water supply. So the study adopted the FAO Penman–Monteith equation as the standard for ETo estimation, the independent variables for this method are the site weather parameters such as maximum and minimum daily air temperature, relative

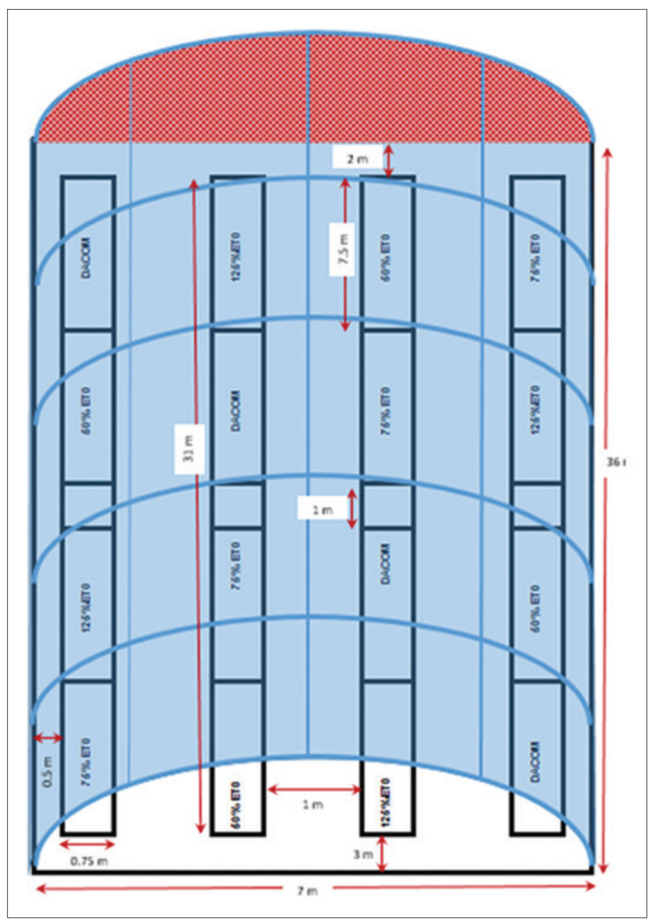

Fig 1. Experiment layout.

humidity, wind speed, and solar radiation. The ETo was calculated using an average of 30 years historical weather parameters. To evaluate the DACOM self-irrigation-system and for the comparison purpose, three different previously determined daily irrigation water levels (125% ETo, 100% ETo, 75% ETo) were used, those levels were chosen to represent the huge variability of the in UAE farms.

The capacitive sensor with 60 cm depth measures soil moisture content for 6 sublayers around root zone and send the data to the computer through the satellites. Once DACOM software analyzes the data, it sends the order to the irrigation system to start irrigating deciding the duration and the amount of water. The ability of sensors to measure soil water content accurately under identical soil depends on the weather, irrigation method, vegetation, and management using standard factory calibration.

A weather station in Al Salamat Research Station automatically collects and transmits a multitude of parameters in a flexible setup (i.e. temperature, relative humidity, rain, wind speed and wind direction and solar radiation). The data is transmitted via Radio Telemetry with a typical distance of 10 km. Optionally, the station can be fitted with a GPRS data unit for remote single point measurements.

Tomato (*Solanum lycopersicum*) seedlings of *Titan* var with 2.5 plants/m^2. were transplanted in the first greenhouse on Nov. 4, 2012 with a terraces of 4X2 m over two seasons, while cucumber (*Cucumis sativus) Zico* var. were transplanted with 2.5 plants/m^2 in the second greenhouse on Feb. 17, 2013 with a terraces of 4X2 m over four seasons. Soil moisture sensors with 60 cm long (DACOM Ins.) were installed near the root zone of the crop. Necessary data to feed to the software were measured including soil texture, field capacity, welting point, type of crop, root depth and fertigation. By the end of growing season, data were analyzed and finalized in order to develop an optimum irrigation scheduling program.

The experiments were designed with four planting double-lines distributed randomly in a half shape along the greenhouse with 0.5 m planting spacing in which each line served by one irrigation valve and flow meter. The four lines always got the same dose of fertilizers as well as any other agricultural practices except the irrigation amount. Irrigation was applied by one day irrigation intervals for 125% ETo, 100% ETo, 75% ETo treatments where the DACOM treatment was self-irrigating. An irrigation uniformity test has been done for the drippers to make sure that they are within the accepted level. Flow meter readings, yield, and the daily irrigation order given by the smart irrigation system were recorded regularly. The seasonal and daily irrigation amount per one plant are used to avoid the substantial variability between the UAE-farm's planting densities. To enhance the water productivity, crop water use efficiency (kg/m^3) was used as one of the evaluation parameters as a ratio between the crop-yield to the applied irrigation amount (Sinclair et al., 1984 and Cook et al., 2006).

RESULTS AND DISCUSSION

Amount of irrigation

Table 1 shows the amount of irrigation that was determined by DACOM system and the other irrigation amounts obtained from FAO for the different treatments. In the winter tomato, the results showed that the DACOM system had less seasonal irrigation amount (10,927.5 m^3/ha) than FAO 125% and100% irrigation treatments (14,732.5 and 11,767.5 m^3/ha, respectively) and higher than the 75% FAO irrigation treatment (8,992.5 m^3/ha). In consequence, FAO 75% had the lowest average irrigation per one plant (359.7 l) and per day (3.0 l/day and then DACOM came the second in both parameters (437.1 l as seasonal irrigation amount for one plant and 3.6 l as average daily irrigation amount per one plant). FAO 125% and then FAO 100% had the highest average seasonal irrigation amount for one plant (589.3 and 470.7 l, respectively) and daily irrigation amount per one plant (4.9 and 3.9 l, respectively).

In the winter cucumber, the results showed that DACOM system had less seasonal irrigation amount (1,892.5 m^3/ha)

Table 1: Seasonal irrigation treatments amount (m^3/ha), seasonal and the average daily irrigation amount for one plant (l) of DACOM system and the other irrigation treatments obtained from FAO for tomato and cucumber

Irrigation order	Seasonal (m^3/ha)	Average irrigation for one plant	
		Per season (l/plant)	Per day (l/plant)
Tomato[a]			
FAO 125%	14,732.5	589.3	4.9
FAO 100%	11,767.5	470.7	3.9
FAO 75%	8,992.5	359.7	3.0
DACOM	10,927.5	437.1	3.6
Winter cucumber[b]			
FAO 125%	3,050.0	122.0	1.0
FAO 100%	2,450.0	98.0	0.8
FAO 75%	1,845.0	73.8	0.6
DACOM	1,892.5	75.7	0.6
Spring cucumber[c]			
FAO 125%	11,355.0	454.2	3.8
FAO 100%	9,115.0	364.6	3.0
FAO 75%	6,985.0	279.4	2.3
DACOM	7,235.0	289.4	2.4

[a]Length of growing season (213 days), number of plants (120), [b]Length of growing season (105 days), number of plants (120), [c]Length of growing season (108 days), number of plants (120)

than FAO 125% & 100% irrigation treatments (3,050.0 and 2,450.0 m^3/ha, respectively) and higher than 75% FAO irrigation treatment (1,845.0 m^3/ha). In consequence, FAO 75% had the lowest seasonal irrigation amount for one plant (73.8 l) and then DACOM came the second (75.7 l). While both DACOM & 75% FAO had the lowest average daily irrigation amount for one plant (0.6 l). FAO 125% and then FAO 75% had the highest seasonal irrigation amount for one plant (122 & 98 l respectively) and average daily irrigation amount for one plant (1.0 & 0.8 l respectively).

In the spring cucumber, the results showed that FAO 75% had the lowest values in all amount of irrigation parameters (seasonal irrigation amount 6,985.0 m^3/ha, average plant irrigation per season 279.4 l, and average plant irrigation per season per day 2.3 l). Then DACOM came the second in all amount of irrigation parameters of 7,235.0 m^3/ha and 289.4 l for one plant seasonal irrigation amount, and 2.4 l as average daily irrigation amount per one plant). While 125% irrigation treatment had the highest values in all amount of irrigation parameters (seasonal irrigation amount 11,355.0 m^3/ha, seasonal irrigation amount for one plant 454.2 l, and average daily irrigation amount for one plant 3.8 l).

When amount of irrigation was compared between all crops based on length of the growing season, data confirmed that both DACOM system and FAO 75% irrigation treatment gave the lowest amount of irrigation the average daily irrigation per one plant (0.6 l) in winter cucumber. This is true due to the fact that winter cucumber has shorter season compare to the tomato and grow in the winter time where the temperature is much lower compare to spring cucumber. One of the most important aspects of irrigation management is to know the right amount of water that plant needs (Jorge et al., 2008).

Yield

The crop yield of DACOM system and the other FAO irrigation treatments obtained for the two crops are shown in Table 2. In the tomato, the results showed that DACOM and FAO 125% irrigation treatments showed gave the highest significant yield (184.1, 183.3 ton/ha respectively) compare to the other irrigation treatments, and then came the yield of, 100% of about 166.2 ton/ha, and the lowest significant yield was at FAO 75% of about 114.2 ton/ha.

In the winter cucumber, the results showed that DACOM and FAO 100% irrigation treatments gave the second highest significant yield (91.9, 91.7 ton/ha respectively) which are coming after the FAO 125% irrigation order (117.2 ton/ha). While the results showed the lowest significant yield was for FAO 75% irrigation treatments of about 83.0 ton/ha.

Table 2: Yield (kg), water use efficiency (kg m^{-3}) of DACOM system and the other FAO irrigation treatments for tomato and cucumber

Irrigation order	Yield (Ton ha^{-1})	WUE (kg m^{-3})
Tomato[a]		
FAO 125%	183.3 A	12.44 C
FAO 100%	166.2 B	14.13 B
FAO 75%	114.2 C	12.70 C
DACOM	184.1 A	16.85 A
LSD (α = 0.05)	4.92	0.3974
Winter cucumber[b]		
FAO 125%	117.2 A	38.43 C
FAO 100%	91.7 B	37.46 C
FAO 75%	83.0 C	44.99 B
DACOM	91.9 B	48.53 A
LSD (α = 0.05)	5.85	3.15
Spring cucumber[c]		
FAO 125%	164.0 A	14.44 D
FAO 100%	150.0 B	16.46 C
FAO 75%	134.8 C	19.30 B
DACOM	169.5 A	23.43 A
LSD (α = 0.05)	9.02	1.06

[a]Length of growing season (213 days), number of plants (120), [b]Length of growing season (105 days), number of plants (120), [c]Length of growing season (108 days), number of plants (120)

In the spring cucumber, the results showed that DACOM and FAO 125% irrigation treatments indicated the highest significant yield (169.5, 164.0 ton/ha respectively), then the FAO 100%, and 75% irrigation treatments of 164.0, 150.0, and 134.8 ton/ha respectively with significant differences between both of them).

The results showed a strong correspondence between the amount of the irrigation water and the crop yield for the treatments which were irrigated based on FAO Penman Monteith method, however DACOM treatment showed less amount of irrigation water and more crop yield.

The results clearly indicated that DACOM treatment showed a more accurate determination for the seasonal irrigation schedule by supplying exact water amount according to the water needs of the crops through determining the correct frequency and duration of watering. Therefore, we were able to maximizes irrigation efficiency compared to other irrigation treatments through reducing the deep percolation since it is applied the irrigation water in the right amounts at the right time so the crop yield could be maximized

Water use efficiency

Table 2 shows the water use efficiency (WUE) of DACOM system and the other irrigation treatments obtained from FAO for the two crops with the statistical analysis. The results illustrated that DACOM system had the highest significant WUE in all type of crops and seasons (16.85 kg m^{-3} in the winter tomato, 48.53 kg m^{-3} in the winter

Table 3: Percentage increase in water use efficiency (WUE) between DACOM and both 75% and 100% FAO irrigation treatments

Crop Type	DACOM WUE (kg m^{-3})	FAO 75%		FAO 100%	
		WUE (kg m^{-3})	Increase (%)	WUE (kg m^{-3})	Increase (%)
Tomato	16.85	12.70	24.63	14.13	16.14
Winter cucumber	48.53	44.99	7.29	37.46	22.81
Spring cucumber	23.43	19.30	17.63	16.46	29.75

cucumber, and 23.43 kg m^{-3} in the spring cucumber) and FAO 125% showed the absolute significant lowest WUE in the tomato and spring cucumber experiment with 12.44 and 14.44 kg m^{-3} respectively. Then FAO 100% irrigation treatment came as a second significant WUE (14.13 Kg m^{-3}) in the winter tomato, FAO 75% in both winter and spring cucumber (44.99 & 19.3 Kg m^{-3}, respectively). In the winter cucumber experiment, the lowest significant WUE was found 37.46, 38.43 kg m^{-3} with no statistical significant differences for FAO 100% and FAO 125% respectively.

In general, when WUE was obtained by comparing yield with amount of irrigation being consumed by plant, DACOM appeared the most promising system because it gave the highest significant WUE. Table 3 shows percentage increase in WUE when DACOM system was used in comparison with both FAO 75% and 100% treatments. It was found that DACOM system always gave the significantly highest WUE ranging from a minimum of 7.29% increase in tomato with FAO% to a maximum of 29.75% increase in spring cucumber with FAO 100%. This leads to the conclusion that smart irrigation systems use less water as was documented in Alhammadi and Al-Shrouf, 2013.

Developing irrigation scheduling program

Developing irrigation scheduling program was one of the major outcomes of this study (Tables 4-6). The effort was aimed to increase WUE in Abu Dhabi farms due to lack of labors' knowledge and training. Thus, the irrigation scheduling program had been developed for the tomato, winter cucumber and spring cucumber greenhouse according to unified style design for Abu Dhabi farms.

The model that is used in the program focused to most closely simulate the DACOM irrigation system to address the crop water requirements. It depends on duration (in minutes) for one day irrigation interval on 10-day basis of the month using drippers with discharge of 4 liter $hour^{-1}$ for each plant.

Good irrigation scheduling means applying the right amount of water at the right time. In other words, making sure water is available when the crop needs it. In this study, the irrigation scheduling was developed in consideration of the proper amount of irrigation that maintains or increases the average yields while minimizing environmental impacts

Table 4: Irrigation duration (minutes) on 10-days basis (first, second, third) of the month for tomato[a] crop under a greenhouse cultivation

Month	Irrigation duration (minutes)		
	First	Second	Third
December	10.0	10.0	11.0
January	11.0	15.0	15.0
February	23.0	26.0	25.0
March	37.0	35.0	39.0
April	46.0	50.0	55.0
May	58.0	53.0	42.0
June	43.0	45.0	

[a]Planting date: Dec. 3, 2013, Ending date: June 11, 2014

Table 5: Irrigation duration (minutes) on 10-days basis (first, second, third) of the month for winter cucumber[a] crop under a greenhouse cultivation

Month	Irrigation duration (minutes)		
	First	Second	Third
November		6.0	6.0
December	6.0	6.0	9.0
January	10.0	12.0	10.0
February	14.0	12.0	10.0
March	15.0		

[a]Planting date: Nov. 18, 2013, Ending date: March 4, 2014

Table 6: Irrigation duration (minutes) on 10-days basis (first, second, third) of the month for spring cucumber[a] crop under a greenhouse cultivation

Month	Irrigation duration (minutes)		
	First	Second	Third
March		8.0	7.0
April	11.0	11.0	16.0
May	22.0	23.0	23.0
June	24.0	19.0	18.0

[a]Planting date: Mar. 13, 2014, Ending date: June 30, 2014

caused by excess applied water and subsequent agrichemical leaching. It maximizes irrigation efficiency by minimizing runoff and percolation losses. This irrigation scheduling program could be used as a part of the national effort to minimize the water losses and to protect the limited water resources. The irrigation management concept in future can be enhanced in the county by integrating the GSM technology through special sensors and phone application.

CONCLUSION

The DACOM irrigation system was evaluated as a wireless system to irrigate two main crops in Abu Dhabi. DACOM irrigation was compared with three other irrigation orders obtained from FAO Penman-Monteith method to calculate the reference evapotranspiration as climate-based irrigation treatment. The overall results of this work demonstrated that DACOM system showed excellent performance and successfully was able to provide accurate amount of irrigation as per crop needs with the advantage of maintaining better yield. Furthermore, we were able to develop irrigation scheduling for the greenhouse tomato and cucumber in Abu Dhabi using the data and results obtained from DACOM system during two growing seasons. Such smart irrigation system has a good potential to be implemented in regions that suffer from water shortage with a characteristic of its ability to be operated without a need for labors.

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Author's contributions

MSA carried out all the managerial work sharing with AK with field supervision by AAS. Also AAS wrote the 1st draft of the manuscript which subjected to a critical revision and editing by himself and MSA. AAF also carried out the study conception and design with continuous quality control for the data before doing the data analysis and interpretation. MA follow the daily monitoring of the software. AZ was responsible on the continuous checking for the work of the field hardware like the soil sensors, folowmeter reading in addition to field data entry. SAH & MAR were responsible for cucumber and tomato fertilization program respectively. AAK & AAA were responsible for the all of the green house cultural practices from planting till harvesting.

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