Integrating new technologies into the effective planning of irrigation schedules towards efficient water use and minimum loss

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Abstract

Irrigation consumes between 80 to 90% of total water resources in arid regions. Hence, on one hand it plays a vital role in food security in these regions, but on the other hand it is depleting their scarce natural water resources. Therefore, it is crucial to adopt a mechanism that can preserve the role of irrigation on food security, yet with minimal consumption of the already scarce water so that it can increase water productivity and conservation. This can be achieved not only by adopting proper modern irrigation systems but also by integrating new technologies into the effective planning of irrigation schedules so that plants can be supplied with efficient water and minimum loss. This vital approach is the main aim of this study. This study tests the idea of combining a sensors-based method with a simulation and adaptive controller. This idea is introduced on three farms using three different types of irrigation systems. One farm is planted by date palm and lime tress and irrigated by traditional "Aflaj" irrigation system. The second farm is also planted with date palm and lime trees but irrigated by modern "drip" irrigation system. The third farm is a fan and pad greenhouse planted with tomato and cucumber and irrigated by modern "drip" irrigation system. The electronic sensors used includes weather station sensors, crop water requirement sensors such as sap flow and leaf water potential meters, and soil properties sensors such as soil water content and potential, soil temperature, and electrical conductivity. These are used to assess water status and flow through the entire continuum of soil, plant and atmosphere. Those were connected to data loggers and remote communication via cellular network which added a new dimension to irrigation management by enabling near-continuous and near-real-time remote monitoring that contributed substantially in improving irrigation water use.

Keywords: sensors, irrigation scheduling, sap flow, irrigation systems, water productivity, moisture content, leaf water potential, real-time-monitoring, crop water requirements

INTRODUCTION

The annual mean water consumption per person in the Middle East and North Africa (MENA) area is 83% less than the mean water consumption of a person in other parts of the world (FAO, 2013). Moreover, irrigation practice alone consumes between 80 to 90% of total water resources in this region. Although irrigation plays a vital role in food security in this region, it is depleting their countries scarce natural water resources. Therefore, it is crucial to adopt mechanisms that can preserve the role of irrigation in food security yet with minimal consumption of the already scarce water. This can be achieved not only by adopting proper modern irrigation systems but also by integrating new technologies into the effective planning of irrigation schedules. In this way, plants can be irrigated efficiently and losses reduced to a minimum. In recent years important complementary technological advances in

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the area of soil and plant sensors come along with real time monitoring system for irrigation management. These have the potential to adjust irrigation management (Al-Mulla, 2004).

Scheduling irrigation requires the applying of the right amount of water in the right way and at the right time. A well-designed and properly installed irrigation system plays a key role in improving the efficiency of the irrigation system and hence the water productivity (White and Raine, 2008).

The main aim of this study was to analyze the water productivity in terms of better water use integrating new technologies into the effective planning of irrigation scheduling.

MATERIAL AND METHODS

Experimental site and crops

Different equipment to measure variables associated with irrigation water use and management was installed on representative farms in Oman. These variables include

- the status of water in the soil (water content, electrical conductivity and temperature);
- the movement of water through a crop (sap flow);
- the status of water in the crop (plant water potential).

An initial farm profile survey was carried out to select suitable sites that represented important crops and production systems in Oman, and that were also easily accessible and had cooperation and interest from the growers. Three farms in Al Halbaan (23.58 N; 58.03 E) were selected representing open field and protected agriculture. The two open field experiments were conducted on lime and date palm grown with both a drip irrigation system and a traditional flooded basin falaj irrigation system. Two seven-year-old uniform bearing trees of lime and date palm were selected in which both soil water and sap flow were measured on a near-continuous basis. In the greenhouse, the crops were tomato and sweet pepper which had been transplanted 6 weeks previously from the nursery and which had stem diameters of 1-2 cm. Soil water and stem water potential were monitored near-continuously.

Instrumentation description

1. SAP flow.

SAP flow was recorded with a SAP flow meter (SFM1 from ICT International, Australia). This device measures the plant transpiration through measuring the movement of water (sap flow) through it (Wilson et al., 2001; Köstner et al., 1998).

The SFM1 requires three 35-mm long probes and 1.3 mm in diameter. These probes consist of a heater which applies a known heat energy pulse and upstream and downstream thermocouple temperature sensors that measure the propagation of the pulse. The probes are radially inserted into the plant stem. The upstream thermocouple probe is located 5 mm below the heater probe while the downstream probe is located 10 mm above the heater probes. Short pulses of heat are periodically applied by the heater probe while the sensor probes continuously monitor temperature. Differences between the upstream and downstream temperatures are used in algorithms that estimate the velocity of the sap stream as it conducts heat in the direction of flow. The transpiration rate determines the velocity of the sap.

The velocity of heat pulse is determined by using a default thermal diffusivity value along with gathered measurements of the movement of affected heat amount by the plant's inside and outside factors such as light and moisture deficit (Burgess and Downey, 2014). The sap flow calculations were based on HRM or the heat ratio method (Burgess et al., 2001).

The SAP flow meter remained intact with the plant continuously throughout the cropping season.

2. Plant water potential.

Plant water potential was measured near continuously with a stem psychrometer (PSY1 from ICT International, Australia). The device is attached directly to the stem. The bare xylem was covered with a silicon grease to avoid any gain or loss of water to or from the stem. To minimize the outside environmental impact on the instrument, grease was also applied around the attachment junction and the stem The psychrometers were tightly covered with plastic insulation foam material.

The PSY1 instrument measures in-situ water potential with a range of -0.01 to -10 MPa. The instrument contains a chromel/constantan thermocouple that is located inside it and used to be cooled down to water condensation level. Another chromel/constantan thermocouple also exists in this device but located at its surface contacting the plant stem. The difference between the temperatures of these two thermocouples provides the mean of measuring stem water potential (Dixon and Downey, 2015).

3. Soil water content, electrical conductivity and temperature.

Two types of sensor were used, the GS3 and 5TE (Decagon Devices, Pullman, WA, USA). These sensors measure the dielectric permittivity of the bulk soil which comprises solid material, air and water. As the permittivity of water is much higher than that of the solid material and air, it can be used to estimate soil water content. Temperature is measured using a thermistor, and electrical conductivity is measured between two electrodes within the sensor.

The 5TE sensors were used for the open field tree crops. While the GS3 sensors were used in the greenhouse. Two 5TE sensors were installed in root zone of lime tree at 25 and 50 cm depth while three 5TE sensors were installed in root zone of date palm at 25, 50 and 75 cm depth.

Three GS3 moisture sensors were installed in the greenhouse (tomato and sweet pepper) grown in soil less media (organic). Two of the GS3 sensors were inserted in the soilless media in which the plant was also equipped with a stem psychrometer. The remaining GS3 sensor was inserted in the soilless media in which tomato plant was not equipped with a stem psychrometer.

The sensors were connected to a Em50G data logger (Decagon Devices, USA) which measured and stored data every 15 min and which could upload the data to the internet using GSM cellular telephone network technology from which it could be remotely downloaded.

RESULTS AND DISCUSSION

The climate data for the period of the study are presented in Figure 1. It can be noticed that the coldest days of the year were at the third week of January where the temperature went down to 18°C while vapor pressure deficit then was 0.57 kPa. On the other hand, the hottest days were so far at the second week of May where the temperature and vapor pressure deficit reached 36°C and 4.47 kPa, respectively.

Two of the three EM50G data loggers worked perfectly in both collecting and uploading the data. However, the remote connection on the third logger did not function, and so the logger had to be downloaded on site. Figure 2 provides the soilless based measurements in greenhouse sung GS3 sensors including water content (m^3 m^{-3}), temperature (°C), and electrical conductivity (mS cm^{-1}). Figures 3 provides seven days of soil profile data retrieved online from the modern (drip) irrigated farm.

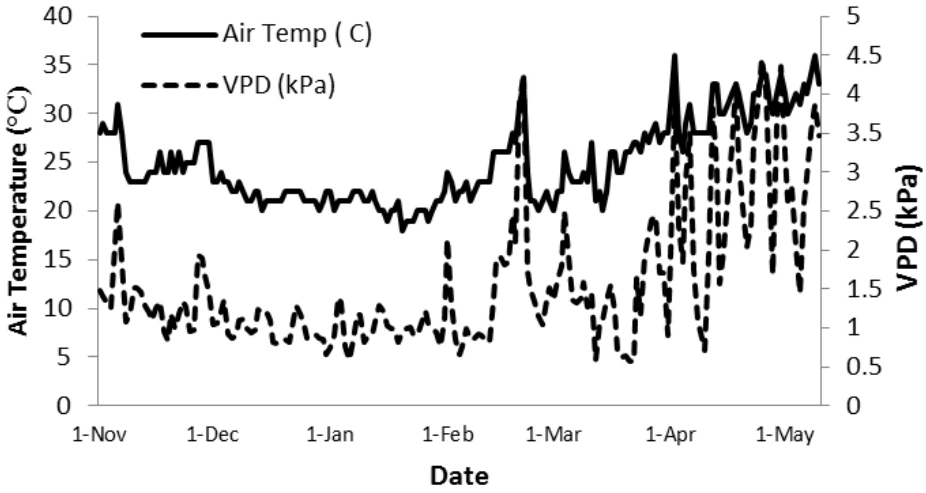

Figure 1. Atmospheric data (air temperature (°C), and vapor pressure deficit (kPa)).

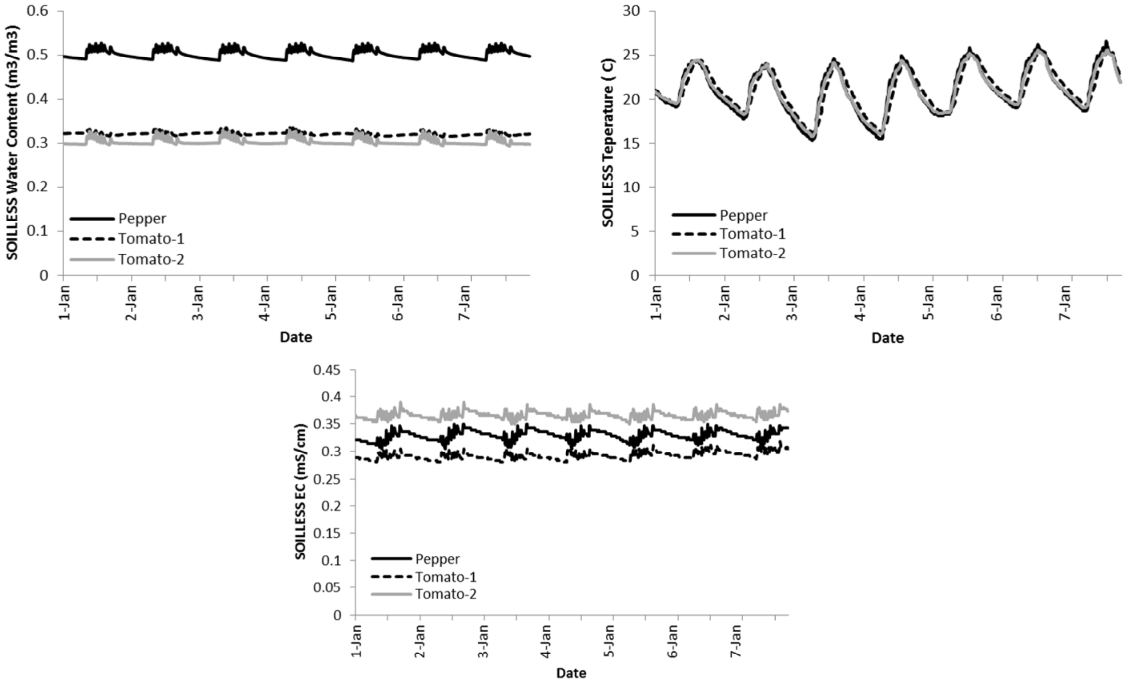

Figure 2. Soilless media conditions (water content, temperature and EC) inside a greenhouse.

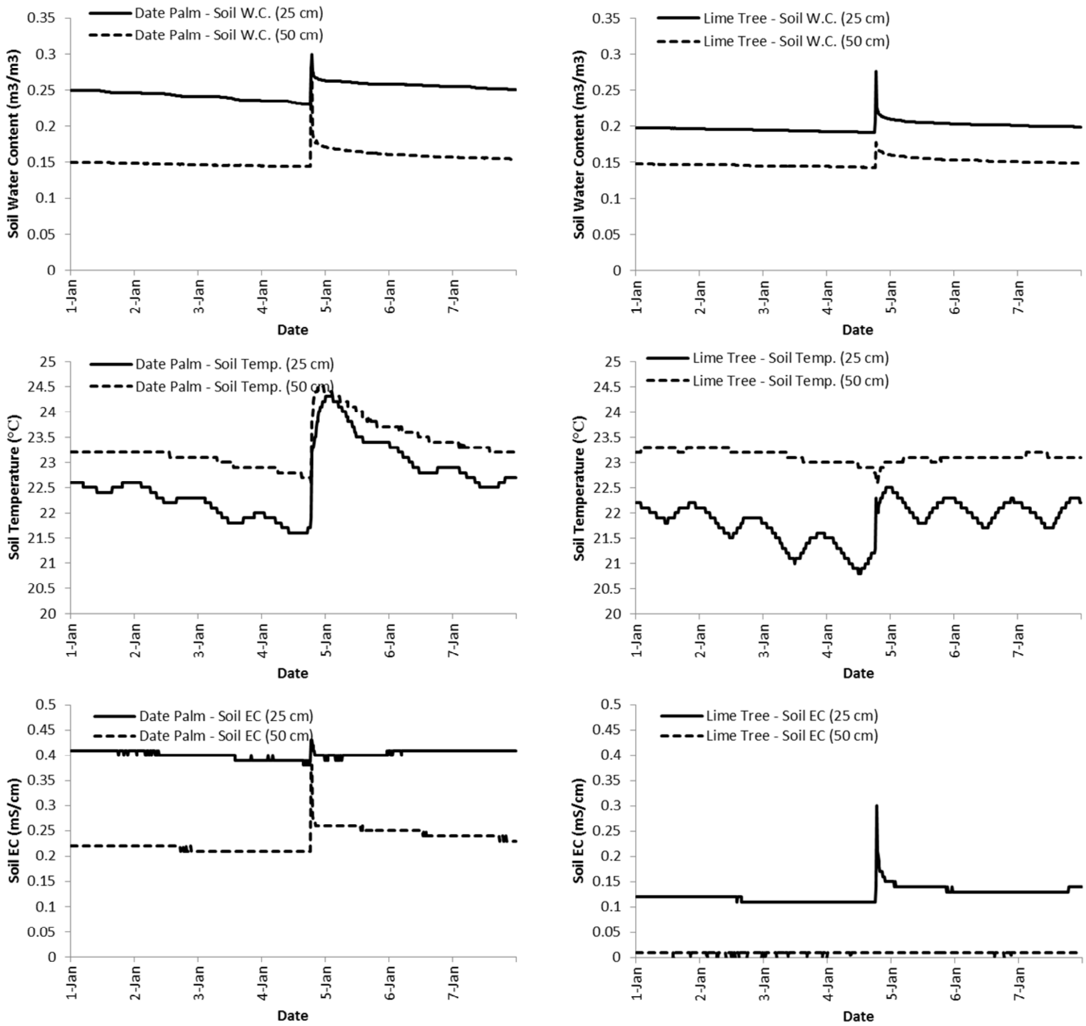

Figure 3. Modern irrigation farms 7-d online retrieved soil profile data.

The variation of climate conditions during the year had affected the behavior of all monitored plants towards there nutrients uptake (Figure 4). This behavior was detected by the sap flow sensors. The amount of sap density taken up by the lime tree under modern (drip) irrigation decreased from the month of January to April. The sap flow for lime tree under modern (drip) irrigation started reaching its maximum values at around 8 am and stayed at its maximum values for the whole day until 8 pm when it declined reaching its minimum values and remained as that for the rest of the night. The behavior of the lime tree under Aflaj irrigation was similar to the one under the modern irrigation. However, the maximum sap flaw showed two peaks a day; at 8:00 am and at 8:00 pm, while the amount of sap flow remained high during the day time and reached minimum during the night time.

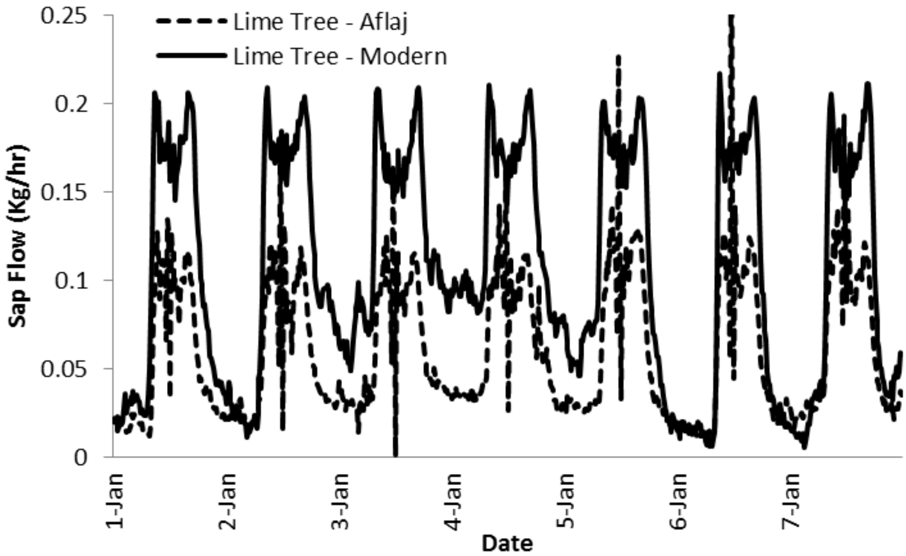

Figure 4. Sap flow measurements (kg h^{-1}) in lime tree under modern (drip) and Aflaj irrigation systems.

The behavior of sap uptake by the date palm tree was different under both irrigation systems than it was the case with the lime tree. The amount of sap flow up taken by the tree started to increase at 6:45 am until it reached its maximum amount at around 11:00 am, and from then, it started to decline. The sap amount up taken by this tree during the night time was always zero.

CONCLUSIONS

Integrating new technologies into the effective planning of irrigation schedules towards efficient water use and minimum water loss is very important to achieve a goal of preserving food security while maintaining minimal water consumption from the already scarce water. This study has combined sensors-based methods along with utilization of the latest technology in determining the exact crop water needs in three farms using three different types of irrigation systems. The preliminary results showed very good results that can open to further development in this field.

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