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IRRIGATION MANAGEMENT WITH SALINE GROUNDWATER OF DATE PALM CULTIVARS IN THE HYPER-ARID UNITED ARAB EMIRATES

Ahmed Al-Muaini[1], Abdullah Dakheel[2], Steve Green[3], Al-Hareth Abdullah[2], Abdul Qader Abdul Rahman[2], Wasel Abdelwahid Abou Dahr[1], Steve Dixon[4], Brent Clothier[3].

[1] Environment Agency Abu Dhabi, United Arab Emirates
[2] International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates
[3] Plant & Food Research, Palmerston North, New Zealand
[4] Maven Consultants, Wellington, New Zealand
Email: almuaini@ead.ae

Abstract

Date palm (Phoenix dactylifera L) currently accounts for about one third of all groundwater allocated for agricultural irrigation in the United Arab Emirates. Anecdotal evidence suggests many farmers are applying excessive amounts of irrigation. More precise information on crop water use is needed to help farmers improve their irrigation practices by better matching irrigation supply to crop water demand. This paper presents results from a field experiment to determine the water requirements of mature date palm trees. We are investigating the combined effect of irrigation management and water salinity on the crop yield of dates and their fruit quality. Our experiments are assessing the impact of two different levels of water salinity (5 dS/m and 15 dS/m) on palm-tree water use, irrigation need and date production. We show how different varieties of date palm respond to altered irrigation volumes and salinity levels for three varieties of date palms: Lulu, Khalas & Shahlah. These 3 varieties were selected from a long-term date experiment at ICBA involving 18 varieties for they represent a range of salt-tolerances. Baseline results were established during 2015 using the current irrigation practices. New irrigation treatments were established in 2016. Information from our field experiments are being used to parameterize a decision support tool for Irrigation Allocation that is being developed for Environment Agency - Abu Dhabi (EAD) to manage groundwater usage in a sustainable way.

Introduction

The United Arab Emirates (UAE) has a hyper-arid climate with annual precipitation of well less than 100 mm/year, very high summer temperatures and no perennial surface water resources. Groundwater levels are falling rapidly due to pumping for agriculture greatly exceeding the natural recharge from the scant rainfall, making groundwater a non-renewable resource and presenting serious challenges in terms of its quantity and increasing salinity. (Figure 1)

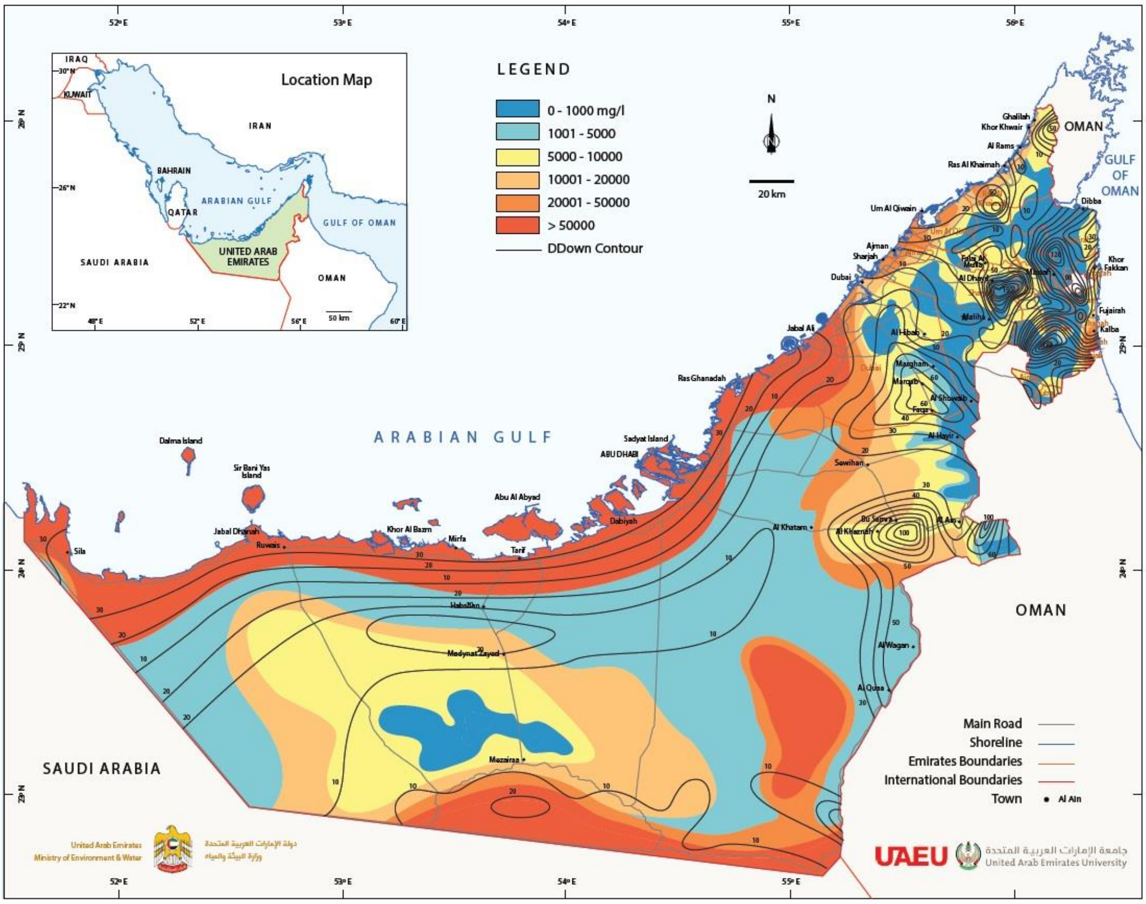

Figure 6.8 Salinity increases of the Surfacial /Quaternary aquifer in 1969-2012 with contours of decline in water table elevation

Figure 1. Salinity increases in the surficial /Quaternary aquifer in 1969-2012 with a contour of the decline in water-table elevation

The agricultural sector is the largest consumer of water in the UAE. The 2015 UAE State of the Environment Report indicates that the agriculture and landscape sectors consumed 57 % of the annual UAE water budget, followed by industrial, residential and other uses (Figure 2).

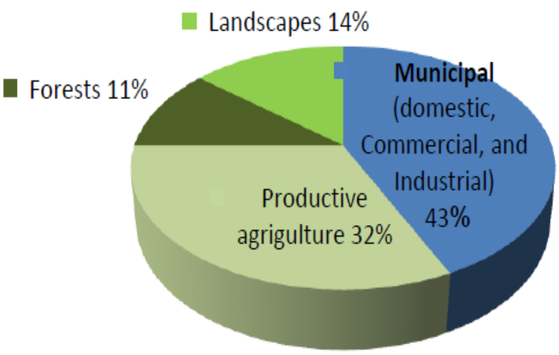

Figure 2. The breakdown of groundwater usage by sectors as presented in the 2015 UAE State of the Environment Report,

Date palm (Phoenix dactylifera L) currently accounts for about one third of all groundwater use. More precise information on crop water use (ETc) is needed to help farmers improve their irrigation practices by better matching irrigation supply to crop water demand. Plant and Food Research and Maven International are currently working to help Environment Agency - Abu Dhabi (EAD) refine their estimates of the water demands of date palms. We are using a soil water balance approach, to assess irrigation and drainage losses, combined with measurements of trunk sap flow to determine transpiration rates of palm trees. Information from our field experiments will be used to parameterize a decision support tool for irrigation allocation that we will develop for EAD.

Objectives

The main objectives of this paper are:

- To investigate ways to improve irrigation management and optimise water usage. Experiments on three varieties of date palms have been set up to apply daily replacement volumes equal to ETc + 50%; ETc + 75%; ETc + 100%. The two remaining trees from each treatment are receiving 'normal' irrigation volumes (ETc + 150%).
- To investigate the impact of different levels of water salinity on tree water use, irrigation need and date production. Replicated measurements of the tree water use and the soil water balance will be set up for two salinity levels (5 dS/m and 15 dS/m).
- To investigate how different varieties of date palm respond to altered irrigation volumes and salinity levels. Replicated experiments will be set up on the three of the most common varieties of date palms (i.e. Lulu, Khalas and Shahlah).
- To develop a date palm management tool, for planning purposes and for future proofing, so that growers are able to assess the likely impacts of changing groundwater quality on date production and irrigation needs.

Materials and methods

Sap Flow Measurement

Being a monocotyledon, the date palm does not have a cambium layer. Rather, the trunk is composed of tough, fibrous vascular bundles cemented together in a matrix of cellular tissue which is mostly lignified near the outer part of the trunk. The outer 3-4 cm of trunk does not transport water while sap flow tends to be fastest towards the centre of the trunk (Zaid and Arias-Jimenez, 2002). Thus long probes were needed to ensure flow could be measured across the inner zone of the trunk (Figure 3). Data are collected at 30 min intervals (Figure 9). Sap flow (L/h) was calculated from measurements of t_Z using the approach outlined by Green et al. (2003, 2008). These calculations included a correction for the effect of wounding. Here we used a wound diameter of 2.8 mm for the 2.0 mm diameter drill holes. Sap velocity (SV) is deduced from the wound-corrected heat-pulse velocity (HPV) and measured volumetric fractions of wood and water within the sapwood. The fractions of wood (Fm) and water (Fl) in the sapwood were determined gravimetrically from core samples (Fm = 0.35 and Fl = 0.60). T was determined by multiplying SV by the conducting wood area using the simple annulus approach suggested by Hatton et al. (1990).

Study area

Field experiments are being carried out at the International Centre for Biosaline Agriculture (25.09° N; 55.39° E; 48 m a.s.l.) near Dubai City. Our observations for this experiment started in mid-winter (January) 2014. We are assessing the impact of two different levels of water salinity (5 dS/m and 15 dS/m) on palm-tree water use, irrigation need and date production. We show how different varieties of date palm respond to altered irrigation volumes and salinity levels for the three varieties of date palms: Lulu, Khalas & Shahlah. These 3 varieties were selected from a long-term date experiment at ICBA involving 18 varieties for they represent a range of salt-tolerances. Baseline results were established during 2015 using the current irrigation practices. Irrigation treatments were imposed in January 2016. The soil is described as a Typic Torriorthent sandy-skeletal hyperthermic soil (AD151; Abdelfattah, 2013) with a sand content > 90% and a bulk density in the range of 1.5-1.6 kg/L. Irrigation to each tree is supplied via two bubblers with a design flow rate of 10 L/min discharging water into a 2 m diameter basin. Irrigation is applied automatically, normally in one to three irrigation events daily between the times of 0900 and 1900. Irrigation volumes are being measured with a flow meter (Sensus 620, Raleigh, USA).

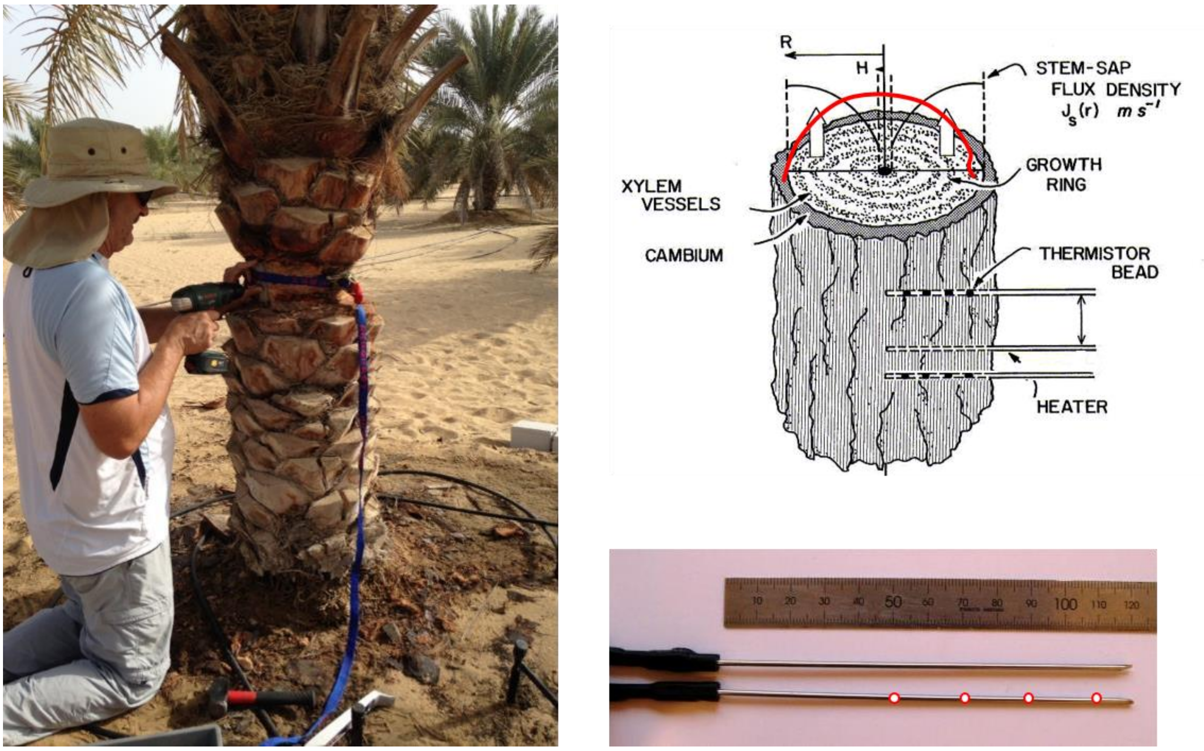

Figure 3. The pattern of sapflow in dicotyledons is greatest in the outer parts of the trunk, as shown in the diagram on the right. However, the flow in monocotyledons such as date palms is greatest near the centre (red line on the right). So long probes were built to enable measurement of the movement of sap flow in date palm trees (right bottom) where the location of the four temperature sensors is shown by the red dots.

Soil Salinity

A series of Campbell CS655 probes, which measure both soil salinity via electrical conductivity (EC) and soil water content, were installed into the root-zone of the Lulu trees. The CS655 TDR probes are working well, as shown for an irrigation cycle in both the S1 treatment (Figure 4) and the S3 treatment (Figure 5) of the Lulu trees. The trees are currently receiving two irrigations per day, except for Fridays when no irrigation is applied. For the S1 low-irrigation treatment, there is a good correspondence between soil water content and bulk soil EC. The same correspondence holds true for the S3 treatments under both low and high irrigation. This suggests there is unlikely to be a significant build-up of salinity in the surface layer of the root-zone (0-30 cm). Irrigation is most-likely leaching out the excess salts.

In contrast, for the S1 high-irrigation treatment, there was a marked increase in salinity during the hottest months of June and July. This latter result shows an increase of soil EC by a factor of two and with no significant change in water content of the top soil layer (0-30 cm) which is difficult to explain under the higher irrigation regime. Clearly, more ‘salt’ is remaining in the top soil of S1 treatment under the high irrigation regime. Increased surface evaporation during the very hot summer months could be causing the increase in salt content of the top soil layer, or the sensor’s location could be effecting the results, for example the probe could be in an area of the root zone that does not get the full watering. More detailed investigation of the data is needed to resolve this conundrum.

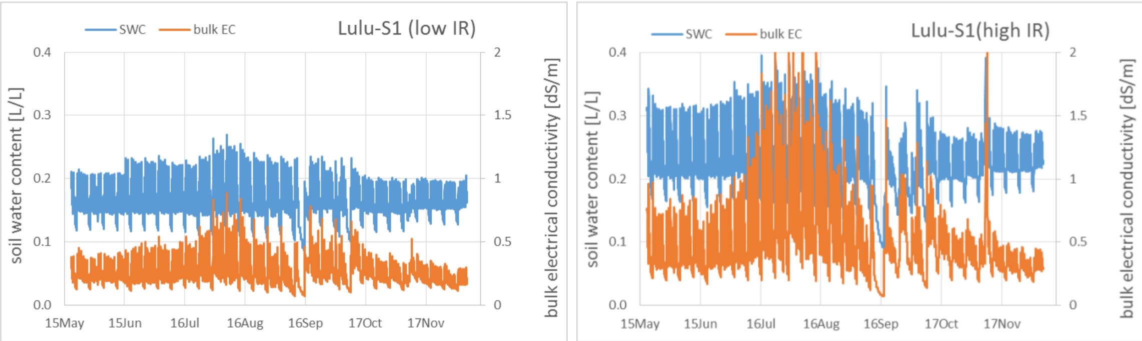

Figure 4. Left panel. The pattern of soil water content (SWC) and electrical conductivity (EC) measured before and during an irrigation event on a Lulu tree in the S1 (5dS/m) low irrigation treatment (150% of ETc). Right panel. As above, but for a high irrigation S1 treatment on a Lulu tree (200% of ETc).

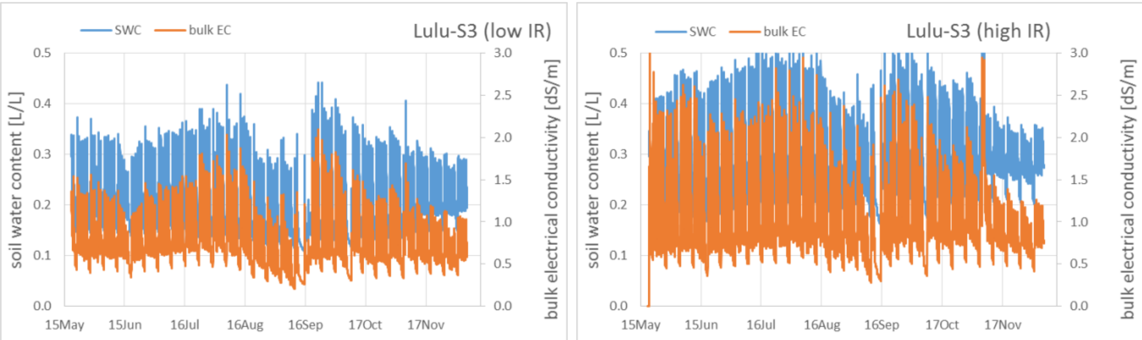

Figure 5. Left panel. The pattern of soil water content (SWC) and electrical conductivity (EC) measured before and during an irrigation event on a Lulu tree in the S3 (15dS/m) low irrigation treatment (150% of ETc). Right panel. Same as the left panel, but for a high irrigation S3 treatment on a Lulu tree (200% of ETc).

The pattern of SWC and EC shown in Figure 5 would suggest that even in the S3 treatment, after the irrigation treatment and subsequent root-water uptake, the soil’s EC is returning to its pre-irrigation value. This hints at the ability to reduce further the water applied in the S3 irrigation treatments.

In order to make this decision, we will continue to monitor this data over the coming season when transpiration rates increase again and when the irrigation volumes are greater.

Soil Water Content

Changes in volumetric soil water content (L/L) were measured using time-domain reflectometry (TDR). The centre rod of each waveguide was insulated using adhesive-lined heat-shrink tubing to minimise the effects of signal attenuation by the saline irrigation water. Each waveguide was connected via an RG58U coaxial cable to a multiplexer (model SDMX-

50, Campbell Scientific, USA). A data logger (model CR1000, Campbell Scientific, USA) was used to communicate with the TDR instrument (model TDR-100, Campbell Scientific Instruments, USA).

Soil moisture will tend to decrease when not enough water is being applied, and vice versa at times when the applied irrigation exceeds the tree's water demands. Figure 6 shows snap-shot of the soil water content (0-120 cm) measured in the middle and on the outer-edge of the basin under Lulu palms from the S1 treatment. This plot coincides with the period when irrigation problems occurred during late September. It shows that when we were under-irrigating, the size of the wetted zone around the irrigation basin contracted. There was a concomitant decline in the water content measured at the outside of the irrigation basin (see the left panel of Figure 7). The basin rewet almost immediately. But it took a month or so of more-regular irrigation to rewet the outside of the irrigation basin under the S1 low-irrigation treatment.

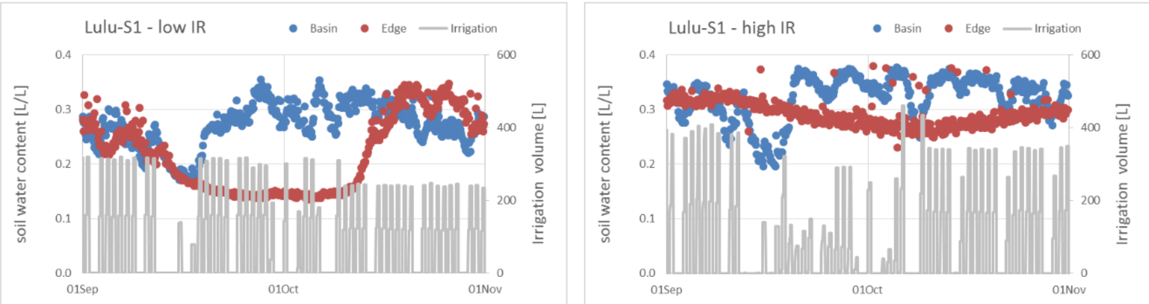

Figure 6. Left panel. The blue line shows the pattern of soil water content (0-120 cm) measured in the irrigation basin under the Lulu date palms from the S1 (5 dS/m) irrigation treatment. The red line shows the corresponding pattern of soil water content (0-120 cm) measured by TDR sensors placed on the 'edge' of the irrigation basin. The grey line shows the daily irrigation volume that was applied, in two aliquots, at 10:00 am and 3:00 pm each day, except for Fridays. Right panel. Same as the left panel, but for a high irrigation S1 treatment on a Lulu tree (200% of ETc).

Figures 7 and 8 show the complete time series of our records of soil moisture contents and these date back to May 2015 for the Lulu S1 and S3 treatments, respectively.

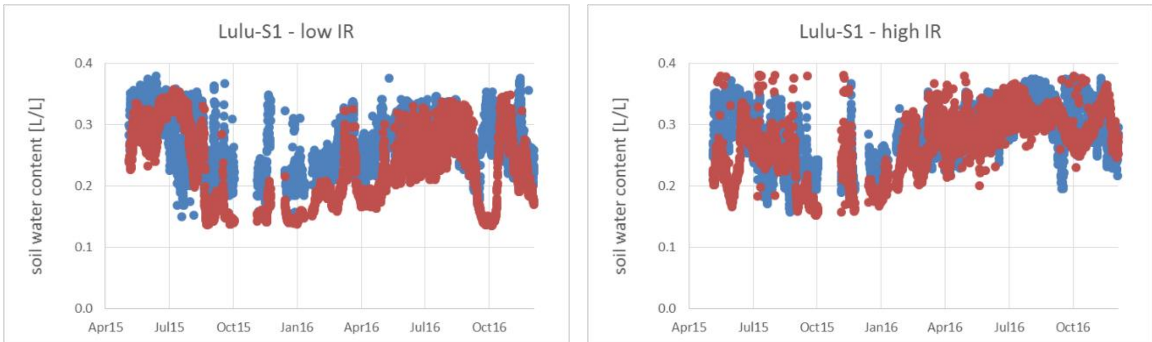

Figure 7. Left panel. The blue line shows the seasonal pattern of soil water content (0-120 cm) measured in the irrigation basin under the Lulu date palms from the S1 (5 dS/m) irrigation treatment from May 2015 until December 2016. The red line shows the corresponding pattern of soil water content (0-120 cm) measured by TDR sensors placed on the 'outer edge' of the irrigation basin. Right panel. Same as the left panel, but for a high irrigation S1 treatment on a Lulu tree (200% of ETc).

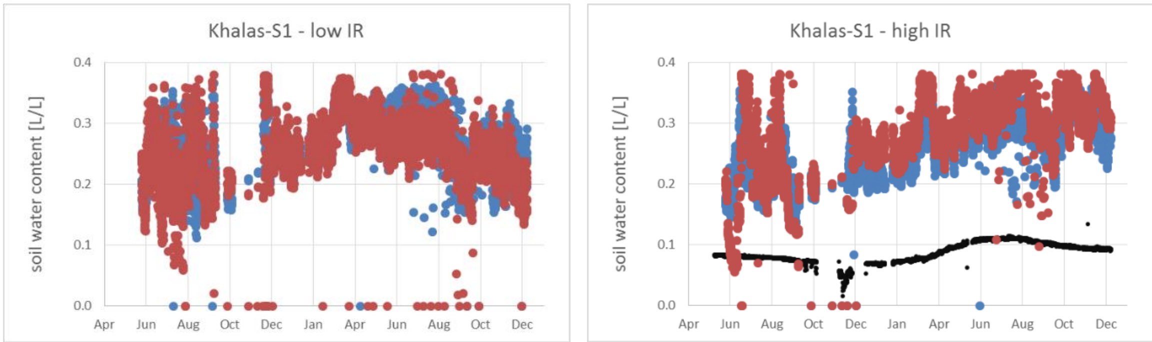

Figure 8. Left panel. The blue line shows the seasonal pattern of soil water content (0-120 cm) measured in the irrigation basin under the Khalas date palms from the S1 (5 dS/m) irrigation treatment. The red line shows the corresponding pattern of soil water content (0-120 cm) measured by TDR sensors placed on the 'outer edge' of the irrigation basin. Right panel. Same as the left panel, but for a high irrigation S3 treatment on a Lulu tree (200% of ETc). The black line is the soil water content (0-120 cm) measured by TDR sensors place in 'dry' sand at the location mid-way between four neighbouring trees.

Irrigation Treatments

Superimposed on these two salinity treatments are four irrigation treatments so that we can use these results to minimise the use of irrigation water, yet maintain a salt-leaching fraction to flush excess salts from the rootzone in order to maintain date production. The irrigation treatments are set in relation to the date palms' water use, ETc. They are 2.5 ETc which is the current practice, plus 2 ETc, 1.75 ETc and 1.5 ETc. A SCADA controlled irrigation system was installed and the treatments initiated during January 2016. Heat-pulse sapflow sensors monitor tree water-use.

Two years' data on the measured ETc of the Khalas S1 treatment are shown in Figure 9, along with lines showing an add-on of a 25% safety factor.

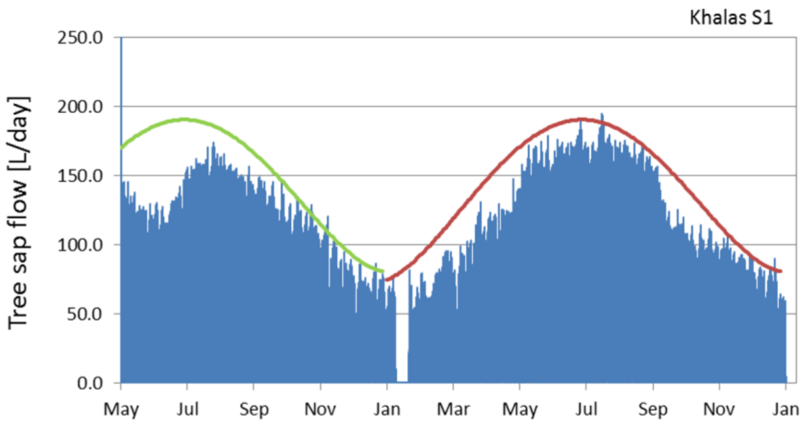

Figure 9. Measured water use by Khalas palm trees under the S1 salinity treatment (5 dS/m). The red line represents the upper bound of the estimated tree water use as determined during the pilot study (2014), with a 25% additional margin of safety added to these values (1.25 * ETc). The sudden drop in sap flow during May 2015 is due to intermittent irrigation when the new system was being installed. The palm trees are very sensitive to a lack of water.

Beginning on January 24th 2016, irrigation treatments were established across the two salinities and three cultivars using the SCADA system. All the S1 treatments were referenced to the ETc of the Lulu tree. All S3 treatments were referenced to the water use ETc of the Lulu S3 tree. Four trees were used to assess the impact of different irrigation amounts. An un-instrumented guard tree under SCADA control was used to maintain the standard 2.5 ETc rate for the daily water application. Then instrumented trees within each experimental plot were allocated either daily aliquots of 2.0 ETc, 1.75 ETc, or 1.5 ETc.

Using our Year-1 results to define an irrigation schedule that replaces water use and allows additional water for a margin of error and a leaching fraction.

The dotted lines in Figure 10 below shows the seasonal progression of the various amounts of water, L/day, that will be applied to the three instrumented trees based on the measured Lulu S1 ETc measured during 2014 by sapflow devices (black circle), and the predictions using *K*c.ETc (red dots), with *K*c = 0.38.

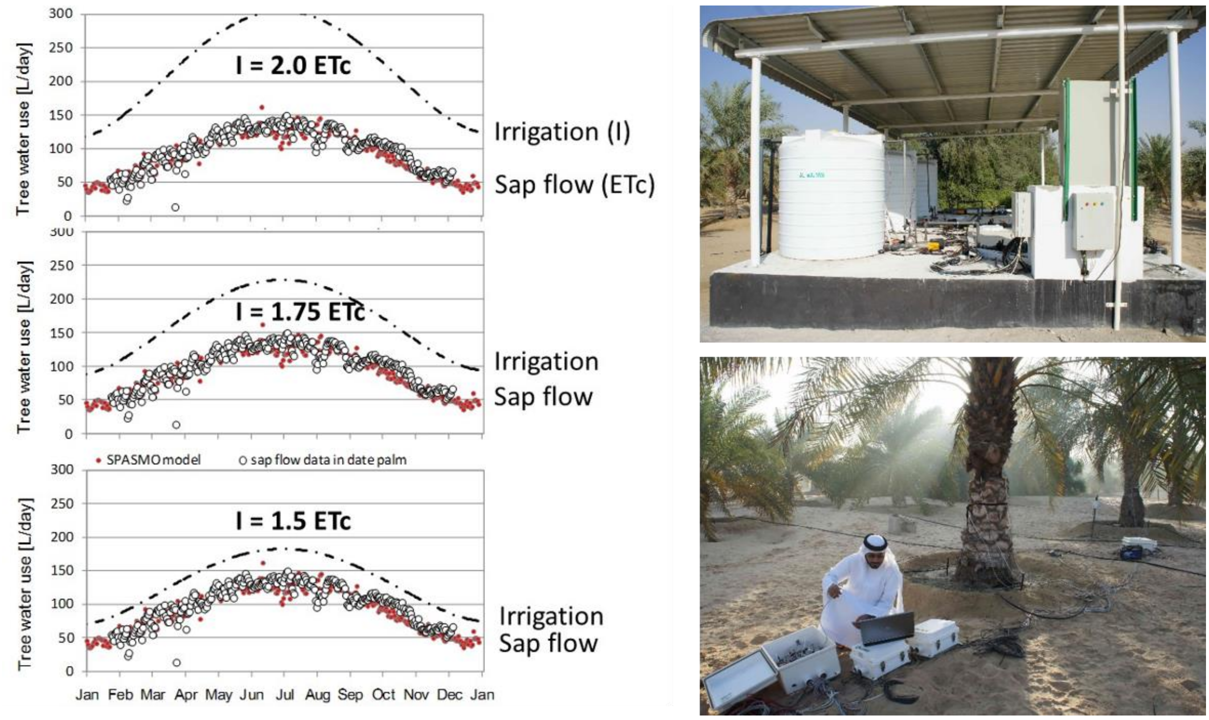

Figure 10. Components of experimental irrigation treatments (as multiples of ETc) of mature date palm trees at the International Biosaline Centre (ICBA) near Dubai, UAE, along with the measured ETc by the compensation heat-pulse method (open symbols) and that modelled by the FAO-56 model assuming a K_C of 0.38 (red dots).

Salinity

The impact on tree water-use of the two salinities of S1 (5 dS/m) and S3 (15 dS/m) is shown in Figure 11. The higher salinity irrigation water resulted in tree size and leaf area being reduced. The water use of the S1 tree is around 150-200 L/day as compared to 60-80 L/day for the S3 tree.

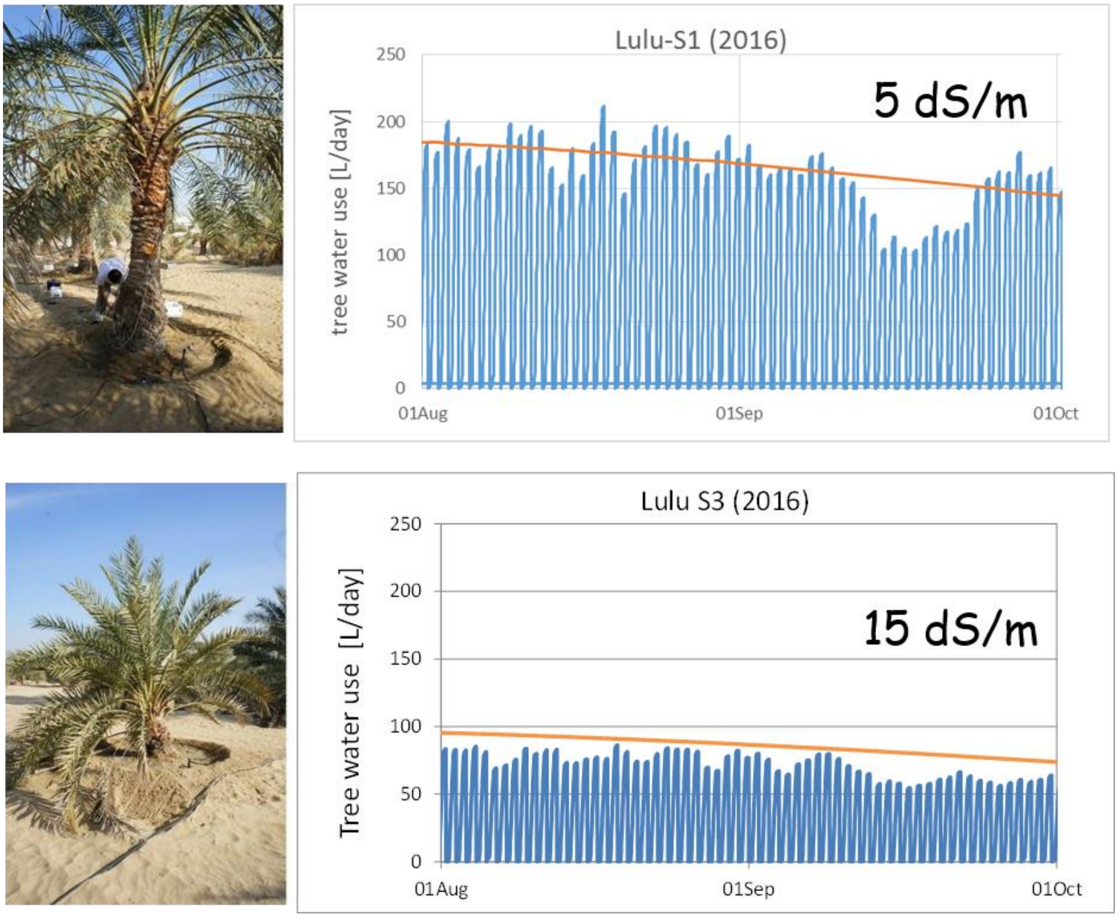

Figure 11. The daily water use of sap flow measured in three date palm trees (v. Lulu) at the International Biosaline Centre (ICBA) - Dubai, UAE. The upper plot is for a Lulu tree in the S1 (5 dS/m) treatment, and the lower plot is for the S3 (15 dS/m) treatment. The red line is the modelled tree water use (ETc).

Decision Support Tool

An output from this project will be a comprehensive Decision Support Tool (DST) that will enable EAD to provide irrigation allocations to date-palm farmers that will meet regulatory requirements, and the growers' needs for adequate water given their plantation conditions and the salinity of their groundwater. A prototype version of this DST has already been developed, and a screen shot of the output page is shown in Figure 12.

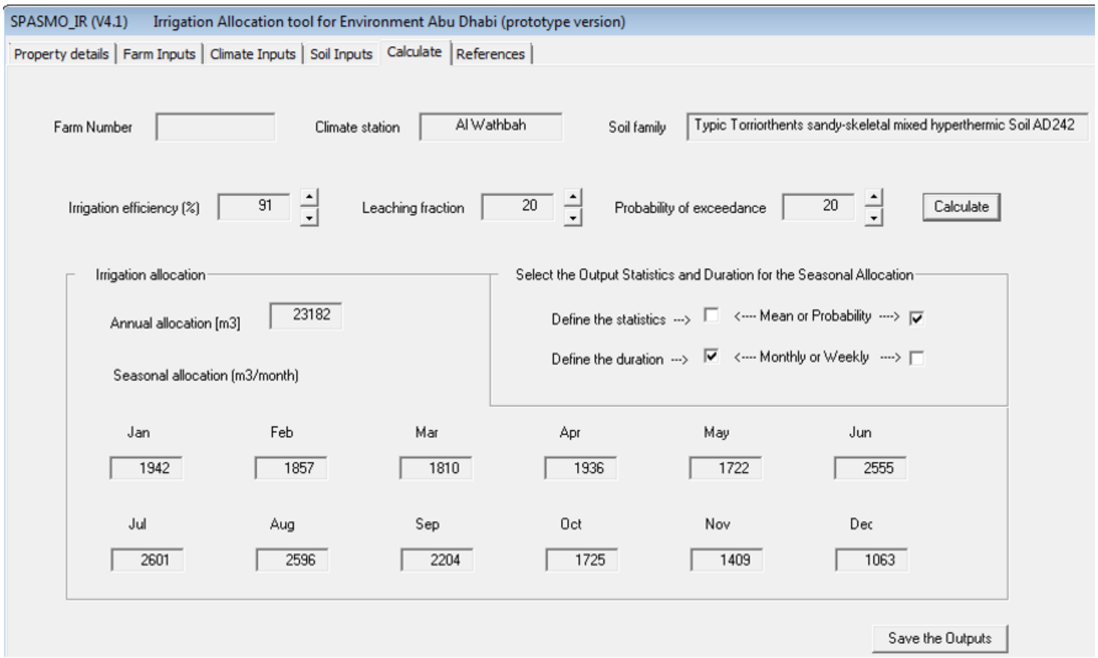

Figure 12. The output page from the prototype of the irrigation-allocation decision support tool (DST) that has been developed for Environment –Abu Dhabi.

Conclusions

Mature date palms growing near Dubai are using 150 L of water per day during the middle of summer and about 50 L per day during the middle of winter. Furthermore, the salinity of the groundwater used for irrigation is shown to have a strong effect on the water use by date palm trees. Our data shows the water use of the palm trees to be about two and a half times less than the amount suggested by the FAO-56 guidelines, as the *K*c is found to be 0.38, not 0.95 (FAO-56) . Information from our field experiments are being used to parameterize a decision support tool for irrigation allocation that is being developed for Environment Agency - Abu Dhabi (EAD). This DST will take into account the planting density of the growers' trees, the variety, and the salinity of the water used for irrigation. More sustainable use of groundwater can be achieved by better matching irrigation to crop water demands and salinity. However, our preliminary results show that care must be taken when reducing the irrigation volumes since the date palms growing on light sandy soils, with almost no rainfall, are very responsive to soil moisture stress. As well, with higher salinity groundwaters, irrigation must supply enough excess water to leach salts from the rootzone.

Acknowledgements

The knowledge from the results is being used to guide policy development for the use of groundwater to irrigated date palms. This research forms the basis of Ahmed's PhD programme through Massey University. This research is being conducted under a Government-to-Government agreement. The Government of New Zealand and the Government of the United Arab Emirates entered into a Memorandum of Understanding relating to Cooperation on Environmental Management Development ("the MOU") on 21 January 2013. The objective of the MOU is to encourage the mutual cooperation between Governments in the areas of environmental management development.

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