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Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates

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ABSTRACT

The United Arab Emirates has a hyper-arid climate. Irrigation is essential for dates (*Phoenix dactylifera* L.), an important crop economically and culturally. Groundwater is relied on, yet it is a non-renewable resource at the rate it is being used. Furthermore, as the water-table drops, it is becoming more saline. Law no. 5 has been passed in Abu Dhabi to regulate the use of groundwater and set allocation limits for agriculture. For assessing the allocation of irrigation water to date farms under Law 5, we carried out measurements of tree water-use by the compensation heat-pulse method, complemented by measurements of the changing soil-water dynamics using time domain reflectometry and bulk soil electrical conductivity. Over four years we measured the hourly pattern of Lulu date-palm water use, ET_c, at two levels of irrigation-water salinity: Treatment S1 at 5 dS m^{-1}, and S3 at 15 dS m^{-1}. The mid-summer ET_c for the S1 Lulu trees is up to 190 L d^{-1}, on average, whereas for the S3 trees ET_c is lower at 130 L d^{-1} (68% of S1) because of the salt. Measurements of canopy radiation interception using a 'light stick' showed the S1 trees intercepted 26% of the incident radiation, whereas the S3 trees only intercepted 20% (ratio S3/S1 = 76%). The date yield of the S1 trees was 68 kg tree^{-1}, but was 46 kg tree^{-1} for the S3 trees (ratio 68%). Current practice is to irrigate trees with 275 L d^{-1}, irrespective of salinity. Our recommendation for Law 5 is to tailor irrigation to the seasonal demand in the reference evapotranspiration of ET_o, and allow for a 25% factor-of-safety and a 25% salt leaching fraction. For S1 date palms this would mean an annual average of 210 L d^{-1}, and for S3 just 137 L d^{-1}. This represents savings of 25–50% from current practice.

1. Introduction

The United Arab Emirates (UAE) has a hyper-arid climate with the reference evapotranspiration (ET_o) of Allen et al. (1998) exceeding 2000 mm, whilst having an average annual precipitation of around just 50 mm y^{-1}. There are very high summer temperatures, often exceeding 40 °C, and there are virtually no surface water resources. Groundwater is relied upon for irrigation, yet the water-tables are falling rapidly, primarily due to pumping for agriculture, which greatly exceeds the natural recharge rates from the scant rainfall. Wada et al. (2012) reported that in the UAE groundwater abstraction is some 1.55 (± 0.3) km^3 y^{-1}, and the groundwater resource is being depleted at a rate of 1.18 (± 0.4) km^3 y^{-1}. They calculate that 64% of the gross irrigation water demand in the UAE is supplied by non-renewable groundwater extraction. The UAE State of the Environment Report in 2015 (MOEW, 2015) reported that groundwater levels had dropped at 10 m per decade until the mid-nineties, and by a further 70 m since then. The agricultural, forestry, and landscape sectors account for nearly 60% of the annual water demand of 4.2 km^3 across all of the UAE. This global demand is met by desalinated water (42%), treated sewage effluent (11%), or groundwater (44%).

Dates (*Phoenix dactylifera* L.) are an important crop in the UAE, both economically and culturally. The UAE has the largest number of date palms for any single country in the world. It has over 40 million date palm trees, with a minimum of 200 cultivars, 68 of which have commercial importance (Jaradat and Zaid, 2004). The UAE is the world's 4th largest date producer, accounting for 12% of the world's production (Jaradat and Zaid, 2004). Irrigation of date palm currently accounts for

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about one third of all groundwater takes in the UAE (MOEW, 2015).

So there are serious challenges in terms of the quantity of groundwater left in the UAE. Furthermore, the MOEW (2015) report also pointed out emerging problems associated with the increasing salinity of the remaining groundwater stocks.

One of the key strategies for addressing Abu Dhabi's groundwater sustainability includes regulating for the responsible use of available groundwater. In 2017, Environment Agency – Abu Dhabi (EAD) announced the new Law No. 5 (2016), the Groundwater Organisation Law for the Abu Dhabi Emirate (https://www.ead.ae/Pages/Resources/environmental-laws.aspx). This law clearly states that groundwater resources in the Emirate of Abu Dhabi are owned by the Abu Dhabi Government. The main objective of this new law is to ensure proper management of groundwater resources in the Emirate. With the authorities and new responsibilities given to EAD, water users will no longer be able to use the groundwater on their property without an EAD licence. The licence will be granted under regulations contained in Law No. 5, and EAD will specify which wells should have flow meters, based on technical conditions that will be set. Furthermore groundwater extraction limits will be set according to the defined use for the water.

We have carried out 4 years of research on the water use of date palms that will enable the development of practical advice for improving the use of saline groundwater for irrigation on date farms. This can also help with the institutional and regulatory aspects of irrigation water management. We show here how our results are being used by EAD in the groundwater-take regulations that have been promulgated through Law 5 in Abu Dhabi.

1.1. Background

Our research on water use by the Lulu variety of date palm began with a pilot project in 2014 (EAD Contract 30409). In that 9-month long pilot-project we installed sapflow equipment in three Lulu date palms in the low-salinity irrigation treatment S1 with 5 dS m^{-1} water (Treatment S1). Also, time domain reflectometry (TDR) rods of varying length were inserted into the soil within the irrigation basins, and around it, to measure the changing soil water content. Preliminary results from this work, up until August 2014 at the end of the pilot project, were presented at the 2015 International Horticultural Congress (Al Yamani et al., 2017). Here we just present a brief update of this antecedent research as it provides the context for the results from the current project. The main results in this current paper are from the extension project (EAD Contract 31983) which formally began in 2015, although the data from the pilot project continued to be logged over the remaining months of 2014. For completeness, we present here the results for the full calendar year of 2014 for Lulu S1. In 2015, the extension project then expanded this work to extend the measurements on Lulu S1 over 3 more years, as well as to measure the palm water-use and soil-water and salt dynamics of Lulu under a high-salinity irrigation treatment S3 with 15 dS m^{-1} water.

1.2. Objectives

The outcome sought by this research carried out under Contracts 30409 and 31983 was to provide quantitative values for the allocation of irrigation water to date farms under Law 5, as a function of date variety and irrigation water salinity. To achieve this we carried out direct measurements of date palm water-use by the compensation heat-pulse method, complemented by measurements of the changing soil-water dynamics using TDR. Our objectives were:

- To measure, over several years, the daily pattern of Lulu date-palm water use, $ET_{c,}$ under two levels of irrigation water salinity: 5 and 15 dS m^{-1}. These Lulu trees were on an 8 × 8 m spacing.
- To determine the crop factor, K_c, for these date palms so that palm-tree water use could be predicted from weather data using the reference evapotranspiration ET_o.
- To predict the daily irrigation requirements for Lulu date palms at these two levels of irrigation salinity for use in guiding the application of Law 5.
- To develop a 'light stick' device to enable proximal sensing of the percent light interception, as a surrogate measure of the canopy leaf-area of date palms, so as to predict the K_c for other date-palm varieties, different tree ages, other groundwater salinities, and other planting densities.

2. Materials and methods

2.1. Study site

Our field experiments were carried out at the International Centre for Biosaline Agriculture (ICBA) (25.09 °N; 55.39 °E; 48 m a.s.l.) near Dubai. The date variety Lulu was selected from a long-term date experiment at ICBA involving 18 varieties that was started in 2001 and 2002. Lulu is one of the more salt-tolerant varieties of dates. Three levels of water salinity were applied: S1 = 5, S2 = 10 and S3 = 15 dS m^{-1}. Over several years, the hourly pattern of *ET*c was measured in treatments S1 and S2. There were five Lulu trees in the S1 treatment, and five in the S3 treatment. The centre three trees of each treatment were instrumented, with the outer two acting as guard trees. Yield data were collected and we report here the results for 2017. The date palms flowered in March and the number of fruit bunches were thinned to between 4 and 9 per tree. The harvest of the dates took place during the first two weeks of August 2017.

The soil of the field site is a Typic Torriorthent sandy-skeletal hyperthermic soil (AD151; Abdelfattah, 2013) with a sand content of over 90% and a bulk density in the range of 1500 – 1600 kg m^{-3}.

A weather station located at ICBA measured solar radiation (LiCor 1200, LiCor Inc., Lincoln, Nebraska 68504-5000, USA), air temperature and relative humidity at 2 m (Vaisala HMP 45C, F1-00421 Helsinki, Finland), wind speed at 2 m (RM Young) and rainfall (TE525 MM-L, Texas Electronics, Dallas, Texas 75237) using a Campbell data logger (CR1000, Campbell Scientific, Logan, Utah 84321-1784, USA). The weather data are used to estimate hourly and daily values of the reference evapotranspiration (*ET*o) using the standard crop-factor approach (FAO-56; Allen et al., 1998). The transpiration of the date palms is related to ET_O (mm day^{-1}) through the dimensionless crop factor, K_C (Eq. (1)):

$$ET_C = K_C.\, ET_O, \tag{1}$$

where ET_C is the crop water use (mm day^{-1}) and K_C is determined from the ratio of the measured daily sapflow to the corresponding daily evaporative demand.

Changes in volumetric soil water content (θ, m^3 m^{-3}) were measured using TDR. The three waveguide rods were of 5 mm diameter and set 50 mm apart. The central rod from each set of waveguides was insulated using glue-lined heat-shrink tubing to minimise the effects of signal attenuation down the core rod by the saline water. There were nine waveguides around each of the three instrumented trees of both treatments. Inside the irrigation basin were installed four sets of waveguides of 1 m length and two of length 2 m. Two 1-m long waveguides were installed on the distal side of the berm of the irrigation basin. As well, one 1-m long set of waveguides was installed midway between two of the irrigation basins to act as reference for the un-irrigated soil. 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). Because of the shielded central rod, we carried out a laboratory calibration to determine the impact of the insulation on the measured dielectric permittivity (Ferré et al., 1996), so that we could infer θ using the TDR algorithm of Baker and Allmaras