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Water uptake by date palm on Haplic Luvisols in the Djibouti coastal plain

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ABSTRACT

Date palm tree (*Phoenix dactylifera* L.) has been cultivated since Anquity under arid and semi-arid climates. This symbolic oasis plant is an important resource for valuing water resources in harsh environments. The Djibouti Republic sustains the expansion of date palm cultivation as a way to settle nomad populations and fight hunger but lacks local references on date palm tree water requirements. This paper establishes the first set of reference data on date palm tree water uptake under the pedoclimatic conditions of Djibouti using an original setup. Date palm tree water uptake was estimated by modelling a succession of 3 infiltration-redistribution experiments, first in the presence of the palm tree, then under bare soil condition, and finally with a no-flow condition at the soil surface. The no surface flow (internal drainage) experiment allowed estimating soil hydraulic parameters, which were then used to simulate the other two experiments including soil evaporation or palm tree evapotranspiration, respectively. Actual evapotranspiration was estimated to 5.6 mm/d between February and April that is during the mild season in Djibouti (25–28 °C). The corresponding daily water uptake was 60 L/d/tree. Daily irrigation need was calculated as 125 L/d/tree assuming a leaching fraction of 40%, which is 4 times smaller than current recommendations. However, calculated daily irrigation need reached nearly 300 L/d/tree in the hot season. Additional studies are needed to confirm this estimation. Reducing the irrigation doses currently in use could lead to precious water savings, given the high pressure put on water resources in the Djibouti district.

1. Introduction

Date palm tree (*Phoenix dactylifera* L.) is an essential resource for the populations living in semi-arid and arid environments. This majestic plant has been cultivated for more than 4 millenia for its date fruits (Munier, 1973). Increasing population, shortage of fresh water resources related to climate change, volatility of food prices are major issues in Sub-Saharan Africa, and the Djibouti Republic is no exception (FAO, 2005). Recurring droughts in these last years have moved rural populations toward the capital city of Djibouti leading to an increased social pressure on an already-vulnerable suburban population (WAP, 2012). To face this situation, the government of the Djibouti Republic sustains the expansion of date palm cultivation with the double objective of encouraging the settlement of nomad populations and fighting hunger. A first step in this strategy was the setup of a successful research program on in vitro multiplication of date palm tree (Daher et al., 2015). The implementation of date palm tree groves implies also the mentoring of the agronomic characteristics of the date palm tree by farmers. Among them, knowledge of the water requirements is essential.

According to an Arabic adage, 'the palm tree lives with its feet in the water and its head in the fire of the sky'. In other words, the date palm tree is well adapted to a very dry atmosphere and strong sunshine as long as its water requirements are met. Date palm tree water requirements have been studied under various climate conditions using different methods. Saeed et al. (1986) and Mazahrih et al. (2012) have been using neutron probe measurements to study the water uptake of date palm trees in Saudi Arabia and the Jordan Valley, respectively. Mazahrih et al. (2012) estimated an annual water requirement of 53 m^3 per tree per year. Sellami and Sifaoui (2003) used sap flow measurements to estimate daily actual transpiration of date palm tree in an Oasis of Southern Tunisia (Tozeur), and found an average value of 1.9 mm/d for the Autumn period. Tripler et al. (2007, 2011, 2012) used weighing lysimeters to measure the water uptake of juvenile date palms in the Southern Arava region of Israël for various salinity concentration levels. Sperling et al. (2012) used the same set-up to validate estimations of date palm tree transpiration by sap flow measurement. Haj-Amor et al. (2016) used the HYDRUS-1D model (Šimůnek et al., 2016) to estimate the actual transpiration of date palm trees in Tunisia. The model was calibrated on soil water content measurements made using TDR probes. They found an average value of date palm tree actual evapotranspiration of 3.8 mm/d for the 2013 year. Askri et al. (2014) used also HYDRUS-1D to estimate date palm tree actual evapotranspiration in the same region, but relied on sap flow measurements for calibration.

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Actual daily transpiration rate of the date palm grove was found to vary between 0.3 and 6.8 mm/d during the 2006–2007 agricultural year for a water table at 1-m depth with an average of 2.2 mm/d. Sabri et al. (2017) evaluated undersupplying irrigation strategies for date palm in Morocco. They showed that the current irrigation strategy of farmers (69.6 m^3/y/tree) was largely above the water requirements of the date palm trees (50.4 m^3/y/tree).

No scientific data is available regarding the water requirement of date palm tree in the specific pedoclimatic context of Djibouti except for one evaluation based on reference evapotranspiration (Peyron, 2000). This study estimated that a 1-ha date palm grove located at Ambouli in Djibouti Town would need 13.000 m^3 of fresh water per year.

The objective of the study was to establish a first set of reference data on date palm tree water requirements under the specific climate conditions of Djibouti. As methods for measuring date palm tree evapotranspiration such as eddy covariance or sap flow methods could not be afforded, we used a more drastic one by measuring the soil water balance before and after palm tree removal. Three infiltration-redistribution experiments were performed successively, first in the presence of the palm tree, then under bare soil condition, and finally with a no-flow condition at the surface of the soil. The various terms of the soil water balance could then be quantified by modelling the three experiments.

2. Materials and methods

2.1. Study site

The study has been performed in a 3.5 ha date palm grove located in the Damerjog village (11°29′01.12″N, 43°11′50.39″E) on the coastal plain 15 km south of Djibouti town. The cultivated date palm trees are of the Barhi cultivar. The date palm grove was set up in 2004. The date palm tree used in this experimentation was chosen for its representativity of the date palm grove. It was 10 years old at the time of the experiment.

The local climate is arid with a mean annual temperature of 31.3 °C and daily temperatures reaching 39 °C during the hot season. Mean annual solar radiation and relative humidity are 162.8 $W.m^{-2}$ and 52.4%, respectively. Mean monthly potential evapotranspiration is 161.3 mm. Low annual rainfall is recorded at the study site (e.g., 71 mm in 2013).

The terrain of the coastal plain is made of recent (≤ 1My) fine sedimentary deposits of marine origin, mainly sandy or clayey alluvium and madrepores (Jalludin and Razack, 2004; Bouh, 2006). These sedimentary deposits are very suitable for agriculture. The soil is a Haplic Fluvisol according to the WRB. Its profile is heterogeneous with a sand texture in the top 90 cm and a loamy texture below 100 cm (Table 1). The soil bulk density profile is quite homogeneous except the 20–30 cm depths that have lower values.

A large pit (240 cm wide and 200 cm deep) was dug at the foot of the palm tree stem after the end of the experiments. A 20 cm-mesh grid was applied to the vertical face of the pit located below the tree and the number of root impacts counted in each cell of the grid (Böhm, 1979). All roots were counted whatever their size. The Surfer® 10 software was used to build a root density map using kriging interpolation.

2.2. Experimental set-up

For the calculation of reference evapotranspiration ET_0 by the Penman-Monteith-FAO method (Allen et al., 1998), it is necessary to know several climatic parameters: air temperature, solar radiation, air humidity, and wind speed. To measure all these parameters, a WatchDog model 2900ET 2000 series weather station (Technologies Spectrum, Inc., Illinois, USA) was installed in the palm grove. The measurements were acquired every 30 min, transferred to a computer via an AUX port and processed through the Specware 9 Pro version 9.03 software (Spectrum Technologies, Illinois, USA). Climate was monitored from January 2013 to June 2014 (Table 2).

Six neutron probe access tubes down to a depth of 160 cm and 25 tensiometers from 10 to 150 cm depth have been put in place in the soil in a radial pattern around the date palm tree (Fig. 1). The closest access tube and tensiometers to the palm tree were located just at the foot of the palm stem, i.e. 40 cm from the center of the irrigation pond. The diameter of the palm tree was around 80 cm at its junction to the soil surface. The farthest access tube and tensiometers were located 2 m from the center of the irrigation pond, i.e. 1.6 m from the palm stem, in the ridge delimitating the pond. The deepest access tube was chosen to monitor soil water content given that only one access tube could be monitored during infiltration. Measurements were performed every 10 cm from 10 to 160 cm depth with a CPN® 503 neutron Hydroprobe (CPN, California, USA) with an Americium-241/Berylium radioactive source of 50 mCi (1.85 GBq) activity. For matric potential, the tensiometer whose behavior was closest to the mean behavior of all the tensiometers installed at the same depth was selected. Tensiometers (SDEC, France) were installed vertically from the soil surface at 10, 20, 30, 40, 60, 100, and 150 cm depths, filled with de-aerated water, and sealed with a neoprene stopper, allowing for the insertion of a movable pressure transducer system (SMS

Table 1
Particle size distribution and bulk density of the soil profile.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm^3)
10	62.15	28	9.85	1.36
20	71.5	19	9.5	1.18
30	59.55	29.75	10.7	1.2
40	56.4	28.5	15.1	1.32
50	57.85	30.2	11.95	1.27
60	57.8	28.8	13.3	1.35
70	61.2	28.25	10.55	1.35
80	52.25	33.05	14.7	1.35
90	50.35	35.5	14.15	1.38
100	35.6	46	18.5	1.37
110	26.5	49	24.5	1.38
120	36.5	44.2	19.3	1.27
130	48.2	34.9	16.92	1.28
140	21.85	56.65	21.5	1.28
150	30.4	50.75	18.85	1.37
160	29.45	48.55	22	1.28

Table 2
Climate data measured at the date palm grove from January 2013 to June 2014.

Month	Mean temperature (°C)	Mean solar radiation (W/m^2)	Mean relative humidity (%)	Mean wind speed (m/s)	Rainfall (mm)	Calculated ET_0 (mm)
Jan-13	25.90	175.37	61.85	0.61	2.5	163.11
Feb-13	25.87	210.23	60.75	0.63	0.0	173.26
Mar-13	27.55	195.53	67.27	0.66	54.2	178.45
Apr-13	30.33	235.03	62.77	0.67	1.1	214.23
May-13	32.31	221.93	59.67	0.47	6.7	203.07
Jun-13	35.63	197.40	36.10	0.51	0.0	218.53
Jul-13	38.31	195.74	26.92	1.28	0.2	290.49
Aug-13	41.00	336.81	24.57	1.09	0.0	300.00
Sep-13	33.81	213.57	52.01	0.50	0.7	163.76
Oct-13	30.93	205.21	57.24	0.42	0.0	199.23
Nov-13	28.26	187.98	61.41	0.44	5.9	170.74
Dec-13	25.97	182.36	58.54	0.44	0.0	169.20
Jan-14	25.22	180.00	61.79	0.48	0.2	163.24
Feb-14	25.87	173.09	63.29	0.49	0.0	142.19
Mar-14	27.50	210.36	63.70	0.56	0.2	191.91
Avr-14	29.86	229.31	61.67	0.47	0.0	206.78
May-14	32.24	216.60	60.11	0.49	0.0	211.85
Jun-14	33.86	195.35	42.62	0.47	0.0	149.28