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Long-term growth, water consumption and yield of date palm as a function of salinity

Effi Tripler[a,*], Uri Shani[a], Yechezkel Mualem[a], Alon Ben-Gal[b]

[a] *Department of Soil and Water Sciences, Faculty of Agricultural, Food and Environmental Sciences, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot 76100, Israel*
[b] *Environmental Physics and Irrigation, Agricultural Research Organization, Gilat Research Center, Mobile Post Negev 85280, Israel*

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ABSTRACT

Actual measurements of water uptake and use, and the effect of water quality considerations on evapotranspiration (ET), are indispensable for understanding root zone processes and for the development of predictive plant growth models. The driving hypothesis of this research was that root zone stress response mechanisms in perennial fruit tree crops is dynamic and dependent on tree maturity and reproductive capability. This was tested by investigating long-term ET, biomass production and fruit yield in date palms (*Phoenix dactylifera* L., cv. Medjool) under conditions of salinity. Elevated salinity levels in the soil solution were maintained for 6 years in large weighing-drainage lysimeters by irrigation with water having electrical conductivity (EC) of 1.8, 4, 8 and 12 dS m^{-1}. Salinity acted dynamically with a long-term consequence of increasing relative negative response to water consumption and plant growth that may be explained either as an accumulated effect or increasing sensitivity. Sensitivity to salinity stabilized at the highest measured levels after the trees matured and began producing fruit. Date palms were found to be much less tolerant to salinity than expected based on previous literature. Trees irrigated with low salinity (EC = 1.8 dS m^{-1}) water were almost twice the size (based on ET and growth rates) than trees irrigated with EC = 4 dS m^{-1} water after 5 years. Fruit production of the larger trees was 35–50% greater than for the smaller, salt affected, trees. Long term irrigation with very high EC of irrigation water (8 and 12 dS m^{-1}) was found to be commercially impractical as growth and yield were severely reduced. The results raise questions regarding the nature of mechanisms for salinity tolerance in date palms, indicate incentives to irrigate dates with higher rather than lower quality water, and present a particular challenge for modelers to correctly choose salinity response functions for dates as well as other perennial crops.

1. Introduction

Salinity causes osmotic imbalance, reduces water uptake and transpiration, and reduces yields of crops. Long-term effects of salinity on perennial crops include toxic consequences on physiological processes as ions are taken up and accumulated in plant tissues, as well as the cost of diverting energy from growth and production into mechanisms for stress tolerance or avoidance (Bernstein, 1975; Munns, 2002). Plant function and growth involves multifaceted, interconnected biological and physical factors and is determined not only by osmotic stress and specific-ion toxicity, but also by changes in soil-water availability via feedback mechanisms with soil water content and hydraulic conductivity. Due to these complexities and to difficulties integrating and up-scaling sub cellular mechanisms involving specific ions, current quantitative description of plant response to salinity relies on understanding and analysis of whole-plant and field-scale responses (Shani and Ben-Gal, 2005; Shani et al., 2007).

Management of saline water for irrigation is often based on application of excess water, designed to maintain minimum root zone salinity, thus avoiding or minimizing salinity-caused yield reduction (Ayers and Westcot, 1985). Maximization of crop yields when irrigation water is high in concentrated salts depends on providing plant water needs (transpiration, T) and evaporative losses as well as on maintaining minimum soil solution salinity through leaching. Evapotranspiration (ET) requirements are often estimated by measuring or calculating potential or reference ET (ET_0), which is a function of climate, and through the use of crop factors that consider plant size (cover) and physiological stage (Allen et al., 1998). Generally, salinity is not considered when calculating ET from ET_0, but it has been suggested that this omission could lead to overestimation of ET, due to the expected salinity-caused reductions

Abbreviations: ET, evapotranspiration; ET_0, reference evapotranspiration; EC, electrical conductivity.

* Corresponding author.
E-mail address: tripler@agri.huji.ac.il (E. Tripler).

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in *T* (Meiri et al., 1977; Ben-Gal et al., 2008; Dudley et al., 2008). While dependent as well on climate and soil type (Dudley et al., 2008), leaching requirements for maximized production are largely a function of the irrigation water salinity and the relative tolerance of the crop being irrigated (Rhoades, 1974). Information regarding the response of each specific crop to conditions of salinity is therefore fundamental for understanding plant–soil interactions and for proper management of saline irrigation water.

It is commonly acknowledged that biomass reductions brought about by conditions of salinity are associated with equivalent reductions in transpiration (De Wit, 1958; Childs and Hanks, 1975; Ben-Gal et al., 2003; Shani et al., 2007). Relative (biomass) yield (Y_r) can therefore be calculated from its proportional relationship with relative ET (ET_r) (Hanks, 1974):

$$Y_r = ET_r; \qquad \frac{Y}{Y_m} = \frac{ET}{ET_m} \tag{1}$$

where the subscript *m* denotes maximal. Water balance measurements allowing calculation of ET can therefore be used as indicators of biomass production and yield (Ben-Gal et al., 2003).

The Israeli southern Arava region is characterized by an annual ET_0 (class A pan) of ~3200 mm and only ~25 mm of precipitation. In other words, the total amount of rainfall in one year is not much more than the maximum ET_0 for a single summer day (14 mm). Typical of many other arid regions, the water resources of the southern Arava are limited and low quality. Thirty nine million m^3 of saline (EC of 2.8–6 dS m^{-1}) water extracted annually from local aquifers, and an additional 8 million m^3 of effluent water are used in the region for agriculture. High quality water (EC < 0.6 dS m^{-1}) is limited to approximately 5% of the water, produced from reverse osmosis desalination.

The date palm is a highly profitable tree crop in arid regions; over 520 ha (65,000 trees) have been planted to date in the southern Arava, representing more than 25% of the country's total date fruit production. Date palm plantations in the Arava are irrigated with effluent or brackish (EC = 2.5–5.5 dS m^{-1}) groundwater. Annual commercial water application for mature plantations reaches 2500 mm and average daily irrigation quantity for a single mature tree (typical spacing of trees is 9 m × 9 m) from June to September is 950 L.

Current understanding of date palm behavior under conditions of salinity stress can be credited mainly to work published in the 1960s by Furr and collaborators (Furr and Armstrong, 1962; Furr et al., 1966; Furr and Ream, 1968). Based on these works, the crop has been classified (Maas, 1990, 1993) as "tolerant" with a threshold of 4.0 dS m^{-1} in soil saturated paste EC (EC_e) under which there is no response to salinity, and a subsequent reduction of 3.6% in yield (biomass production) for every increase of 1 dS m^{-1} EC_e. Date palms have an apparent mechanism for ion exclusion at the root level, as was measured for sodium and chloride by Furr et al. (1966) and by Tripler et al. (2007). Work by Djibril et al. (2005) suggested that such a mechanism and subsequent tolerance levels in dates are cultivar specific. It has been suggested that the effect of salinity on date palms is largely due to osmotic potential gradients between the soil and plant (Tripler et al., 2007).

In preliminary work, Tripler et al. (2007) found that salinity decreased both water uptake and growth of young, non-bearing, date palms and that the tree's vegetative response to salinity was substantially greater than that commonly referred to in the literature. Relative vegetative cover and relative accumulated ET at the end of 12 months of treatments decreased linearly in association with increased soil solution salinity. The reduction rate was 10% for every increase of 1 dS m^{-1} in EC_e. This response of dates to salinity was not only substantially greater than that previously reported by Bresler et al. (1982) and by Maas (1990), but also showed no indication of a threshold value as increased salinity corresponded with decreased production even at the lowest tested levels, when EC_e increased from 3 to 5 dS m^{-1}. Date palms with higher vegetative growth rates are expected to reach higher economic potential faster and to allow for orchard management of greater fruit loads (Zaid and Arias-Jimenez, 1999). The nature of the effect of salinity on fruit production or quality of dates is unknown.

Table 1
Physical and chemical properties of Arava loamy sand soil (*Typic Torrifluvent*).

Soil parameter		Value	Units
Particle size distribution[a]	Sand	83	%
	Silt	8	%
	Clay	9	%
[b]Bulk density		1.3	Mg m^{-3}
Organic matter content		1.3	%
[a]Sat. water content, θ_s		0.36	m^3 m^{-3}
[a]Residual water content, θ_r		0.03	m^3 m^{-3}
[c]Sat. hyd. conductivity, K_s		0.15	m h^{-1}
[c]Air entry pressure head, ψ_w		−0.2	m
[c]Pore size distribution index, β		0.55	–

[a] Shani et al. (1987)
[b] Ben-Gal and Shani (2002)
[c] Shani et al. (2007)

There is little data available concerning the long-term response of date palms, or other fruit trees, to stress-causing environmental factors including salinity. Included in the inherent challenges of multi-year studies is the fact that physiological processes and response mechanisms are expected to be either accumulative and/or dynamic and to differ as trees grow from non-bearing juvenile to mature, fruit bearing stages. Actual measurements of water uptake and use, and the effect of water quality considerations on ET, are particularly important in efforts to quantify mechanisms involved in soil–water–plant interactions and to understand and model crop growth and soil processes. We hypothesized that root zone salinity stress response mechanisms in perennial fruit tree crops would vary as a function of tree age and phenological growth stage. The objective of this research was to investigate ET, growth, and fruit yield in date palms (*Phoenix dactylifera* L., cv. Medjool) as a function of root zone salinity as the trees deveoped from seedlings to maturity.

2. Materials and methods

2.1. Weighing lysimeters

Twenty date palm seedlings from tissue culture (Zvieli Nursery, Kinneret, Israel) were planted in Arava loamy sand soil (*Typic Torrifluvent*), in 20, one cubic meter volume weighing-drainage lysimeters, at the Southern Arava R&D station Israel (lat. 29°53′N; long. 53°3′E), in December, 1999. Soil hydraulic properties are given in Table 1. Seedlings were grown under uniform high-quality conditions (sufficient water of EC = 0.5 dS m^{-1} plus nutrients) for 12 months at which time salinity treatments began (January 2001).

Each lysimeter consisted of a PVC container filled with soil, a bottom layer of highly conductive porous media (rockwool) in contact with the soil, and drainage piping filled with the same material extending downward from the lysimeter bottom (Ben-Gal and Shani, 2002). The rockwool drainage extension disallowed saturation at the lower soil boundary while permitting water to move out of the soil and be collected. Individual lysimeters were positioned on square weighing platforms with load cells situated in each corner. Over the course of the seven-year study, as the palm trees developed from seedlings to mature trees, their size, including their root systems, increased greatly. To sustain natural growth and avoid deterioration in root development or large oscillations in the daily change of water storage (ΔW) as the trees developed, the volume of all the containers was enlarged from 1 to 2.5 m^3 (1.4 m diameter, 1.7 m tall) during the winter of 2003. The 10 lysime-