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Evaluation and analysis of deep percolation losses of drip irrigated citrus crops under non-saline and saline conditions in a semi-arid area

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In arid and semi-arid regions, irrigation management is important to avoid water loss by soil evaporation and deep percolation (DP). In this context, estimating the irrigation water demand has been investigated by many studies in the Haouz plain. However, DP losses beneath irrigated areas in the plain have not been quantified. To fill the gap, this study evaluated DP over two drip-irrigated citrus orchards (Agafay and Saada) using both water balance and direct fluxmeter measurement methods, and explored the simple FAO-56 approach to optimise irrigation in order to both avoid crop water stress and reduce DP losses in case of non-saline and saline soils. The experimental measurements determined different terms of the water balance by using an Eddy-Covariance system, fluxmeter, soil moisture sensors and a meteorological station. Using the water balance equation and fluxmeter measurements, results showed that about 37% and 45% of supplied water was lost by DP in Saada and Agafay sites, respectively. The main cause of DP losses was the mismatch between irrigation and the real crop water requirement. For Agafay site, it was found that increased over-irrigation had the effect of reducing soil salinity by leaching salts.

The applied FAO-56 model suggested an optimal irrigation scheduling by taking into account both rainfall and soil salinity. The recommended irrigations could save about 39% of supplied water in non-saline soil at Saada and from 30% to 47% in saline soil at Agafay.

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1. Introduction

In the southern Mediterranean region, as in many arid and semi-arid regions of the world, water scarcity is one of the main factors limiting crop development, growth and yield (Kharrou et al., 2013). In this region, irrigation is a major component of water demand. It is estimated that about 83% of available resources is dedicated to agriculture with an efficiency lower than 50% (Chehbouni et al., 2008). In Morocco, this waste of water has several origins including leakage during water routing, but also a lack of irrigation efficiency in the field (Belaqziz et al., 2013; Khabba et al., 2013). Indeed, scheduling in timing and amount of irrigation is mostly determined according to the water availability so that the actual plant water needs are generally not taken into account. In addition, the traditional flooding systems are predominantly leading to significant water loss by soil evaporation and deep percolation (DP) (Kharrou et al., 2011). Currently, the Moroccan government has set up an ambitious program for irrigation conversion from flood to drip (PMV, 2013). However, the obtained results for DP are surprising as an inadequate use of the drip technique may lead to substantial water losses (Khabba et al., 2013). It has been shown that the DP losses for the drip irrigation sites are in the range 29–41% of water input while they are relatively lower for flood irrigation, ranging from 26 to 31% (Khabba et al., 2013). Moreover, as the soil salinity may limits plant growth (Ayars, Corwin, & Hoffman, 2012), the farmers usually apply excessive irrigation to leach soil salinity out of root layer or root zone and hence avoid salinity stress (Visconti, de Paz, Rubio, & Sánchez, 2012). In general, over-irrigation amounts are arbitrary and largely estimated. In our study basin, this situation leads to an overexploitation of groundwater, with a level decreasing from 1 to 3 m year^{-1} (Boukhari, Fakir, Stigter, Hajhouji, & Boulet, 2015; Le Page et al., 2012).

In order to preserve water resources, the rationalisation of irrigation water use is necessary.

An accurate estimation of the water consumed by evapotranspiration (ET) and lost by DP would provide a basis for improving irrigation efficiency (Kharrou et al., 2013; Belaqziz et al., 2013).

Regarding ET, crop coefficients and associated measurements have been reported in the literature and used to test, develop and calibrate a range of ET models (Allen, Pereira, Howell, & Jensen, 2011; Er-Raki et al., 2013). DP is commonly assessed by the soil water balance equation when both ET and water supply irrigation and rainfall are available (Sammis, Evans, & Warrick, 1983). The method has been used under different irrigation techniques and for various crops (Vázquez, Pardo, Suso, & Quemada, 2006; Wang, Song, Han, Zhang, & Zhang, 2012). DP can also be measured by direct methods such as lysimeters (Allen, Howell, Pruitt, Walter, & Jensen, 1991, p. 456; Duncan, Srinivasan, & Mc Millan, 2016; Kim, Jabro, & Evans, 2011), or fluxmeters (Deurer, Clothier, Green, & Gee, 2008; Gee et al., 2009). However, these methods are expensive (Upreti, Ojha, & Hari, 2015) and may disrupt flow, causing errors in the measured drainage (Gee et al., 2009).

Other indirect methods have also been used such as the hydraulic method (Allman, Jankovský, Allmanová, & Messingerová, 2015; Qinbo, Chen, Xunhong, Zhicai, & Minhua, 2011), temperature measurements in the unsaturated zone (Constantz, Tyler, & Kwicklis, 2003; Landon, Hamid, Gabriel, & Martin, 2016), and geochemical tracers (Stephens, Moore, Cartron, & Blandford, 2006; Stonestrom et al., 2003).

In Morocco, citrus is one of the main components of agricultural systems (Boubker, 2004). Currently, it covers a total area of about 120,000 ha (MAPM, 2013), but it is in rapidly expanding. However, in Morocco, the key physiological stages of this crop (from flowering to maturation) coincide with the dry period (March–October). Thus, intensive irrigation is necessary for citrus development (El Hari, Chaik, Lekouch, & Sedki, 2010). As far as we know such a study on the estimation of DP for citrus in Morocco conditions has never been performed before.

In this context, the objective of this study is twofold: 1) the evaluation and analysis of DP for citrus orchards irrigated by drip system and grown under semi-arid conditions, and 2) the exploration of FAO-56 simple approach to optimise irrigation in order to both control crop water stress and to reduce DP in the case of saline and non-saline soils. The analysis of DP losses can potentially provide useful information for optimising citrus irrigation schedules under non-saline and saline soil conditions. To our best knowledge it is the first time that the FAO-56 method has been tested for citrus under saline soil conditions.

2. Materials and methods

2.1. *Sites description*

The study was conducted on two citrus orchards: Agafay and Saada (Fig. 1). The Agafay site covers an area of 38 ha approximately 44 km southwest of Marrakech city (31°29′ 50.19″N, 008°25′ 02″W). The field experiment was carried out from 2006 to 2013 in a mandarin orchard planted in July 2000. The trees were planted at a spacing of 4 m in rows and 6 m between rows, which is about 35% ground cover. The height of trees was about 3 m and the depth of the root zone around 0.6 m. This depth was determined by making five pits near to the tree's root zone. The crop was maintained in over-irrigated conditions by drip irrigation: the irrigation frequency was almost every day without taking into account rainfall events. Moreover, the amount of water applied by the farmers during each irrigation event varied between 2 and 9 mm day^{-1} depending on climatic conditions. The Agafay site is divided into three sectors and irrigated within 24 h at a rate varying from 28 to 60 m^3 ha^{-1}. Note that irrigation is applied during rainfall events in order to leach the soil salinity from the root zone.

The soil type is homogeneous, with high sand and low clay contents (18% clay, 32% silt and 50% sand). According to the pedo-transfer function of Wosten et al. (1995) the soil moisture at field capacity (θ_{fc}) and wilting point (θ_{wp}) are 0.26 and 0.12 mm^3 mm^{-3}, which corresponds to 156 and 72 mm at the root zone at the experimental plot, respectively.

The Saada site is located approximately 15 km west of Marrakech city (31°37′36″N, 08°09′35″W). It covers an area of 128 ha and is planted with 13-year old mandarin trees; the

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