Agricultural Water Management 201 (2018) 70–82

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Soil water and salinity dynamics under sprinkler irrigated almond exposed to a varied salinity stress at different growth stages

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ARTICLE INFO

Keywords:
Almond
HYDRUS-2D
Salinity
Leaching
Water balance
Water use efficiency

ABSTRACT

Water use and salinity dynamics in the soils are the crucial management factors influencing the productivity and long-term sustainability of almond and associated environment. In this study, HYDRUS-2D was calibrated and validated on measured spatial and temporal water contents and soil salinities (EC_e) distributions under almond irrigated with different water qualities (EC_{iw}) at different physiological stages. During two irrigation seasons (2014–15 and 2015–16), less saline irrigation water (average EC_{iw} 0.78 dS/m) was substituted for recycled irrigation water (average EC_{iw} 1.9 dS/m) in three phenologically different growth stages; pre-pit hardening, kernel growth, and post-harvest, along with no and full substitution during the entire season. Graphical and statistical comparisons (RMSE, MAE, ME, the Nash and Sutcliffe model efficiency, and the coefficient of determination) between measured and simulated values of water contents and EC_e in the soil showed a close agreement in all treatments. The water balance data revealed that the seasonal crop evapotranspiration of almond (ET_c) varied from 850 to 955 mm in different treatments over the two seasons which represented 68–79% of the water application. Trees irrigated with only less saline water through the two seasons (average EC_{iw} 0.78 dS/m) showed 10% higher plant water uptake as compared to those irrigated with recycled water only (average EC_{iw} 1.9 dS/m). Substituting less saline irrigation during the kernel growth phase, between pit-hardening and harvest, showed greater water uptake by almond and lower salinity buildup in the soil as compared to treatments that substituted less saline irrigation early or late in the season. For all treatments, the average daily root zone EC_e (2.4–3.7 dS/m) remained above the level of the almond salinity tolerance threshold (EC_e = 1.5 dS/m) throughout the period of investigation. Water use efficiency of almonds varied in a narrow range (0.21–0.25 kg m^{-3}) for different treatments. Deep drainage below the root zone (2 m) varied from 22.4–31.1% of the total water application (Rainfall + Irrigation), which was episodic and insufficient to contain the salinity below the almond threshold. This study provided a greater understanding of soil water and salinity dynamics under almond irrigated with waters of varying qualities.

1. Introduction

Water is becoming increasingly scarce worldwide, and sustainable use of the available water resources is the major water policy challenge for the future. In water-stressed regions, strong constraints due to natural climatic variability and increased use by other users make the allocation of water the core challenge for water resource management (Alcon et al., 2013). In addition to issues related to water quantity, the quality of water plays an important role in the sustainability of irrigated lands, especially in the context of salinity build up that could adversely impact the agricultural/horticultural crop productivity (Bresler et al., 1982; Maas, 1990; Pitman and Laüchli, 2002; Assouline et al., 2015). Impacts of soil salinity are varied and highly influenced by the soil type, inherent layering and hydraulic heterogeneity, quality and quantity of irrigation, the method of irrigation, rainfall amounts and distribution patterns, and salt tolerance of crops. At the same time, the installation of highly efficient, partial cover, irrigation systems in high-value crops including almond has a narrow wetted area that tends to concentrate salts in the rootzone. During periods of water scarcity, when irrigators are forced to limit their leaching fractions or forced to apply groundwater/recycled water, salts can rapidly accumulate to dangerous levels.

Almond production in the arid and semi-arid regions of the world

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https://doi.org/10.1016/j.agwat.2018.01.018
Received 24 October 2017; Received in revised form 9 January 2018; Accepted 19 January 2018

remains vulnerable to water availability and soil salinity. Although almond is a drought tolerant tree (Torrecillas et al., 1996), its production and profitability are highly dependent on the supply of irrigation water. The adoption of efficient irrigation techniques can increase the production by as much as ten-fold compared to non-irrigated lands (Egea et al., 2010). On the other hand, almond is sensitive to salinity, having a production threshold with respect to the electrical conductivity of the soil saturation extract (EC_e) of 1.5 dS/m and a reduction in the growth rate of 19% for a unit increase in salinity beyond the threshold (Maas, 1990). Thus, the salinity levels higher than the threshold anytime during the cropping season can have a serious impact on growth and nut production. Therefore, proper irrigation management in the orchard is very important to obtain sustainable yield, leach harmful chemicals from the root zone, save precious water, and increase the shelf life of the fruits. Precise information on the salinity impact at different growth stages can help develop more robust orchard salinity management guidelines.

Different deficit irrigation options (regulated deficit irrigation, RDI; sustained deficit irrigation, SDI; and partial root zone drying, PRD), including their impact at different growth stages of almond (Girona et al., 2005; Goldhamer and Viveros, 2000; Romero et al., 2004; Goldhamer et al., 2006; Egea et al., 2010; Puerto et al., 2013) have been extensively studied over the almond growing season (Nortes et al., 2009; Egea et al., 2013; Monks et al., 2017). These investigations highlighted the impact of reduced water applications on various physiological parameters, kernel size, and kernel yield. Other studies focussed on the almond water requirement and crop coefficients (Stevens et al., 2012; Espadafor et al., 2015; García-Tejero et al., 2015), an irrigation system design (Phogat et al., 2012), and water productivity of almonds under reduced water applications (García-Tejero et al., 2011; Phogat et al., 2013). On the other hand, the studies on the implications of the application of saline/recycled water irrigation on the water availability to almonds and salinity dynamics in the soil are sparse. Notably, the salinity related studies are specifically focused on the identification of tolerant root stocks (Gradziel and Kester, 1998; Camposeo et al., 2011) and genotypes (Rouhi et al., 2007; Sorkheh et al., 2012; Rajabpoor et al., 2014; Bahrami et al., 2015). Franco et al. (2000) reported a 46% reduction in the almond kernels when seasonally irrigated with high salinity water (4.6 dS/m) compared to when less saline water (0.8 dS/m) was used. Nightingale et al. (1991) observed the greatest accumulation of salinity (5.7 dS/m) beneath the trickle line source for 50% ET_C irrigation and laterally away from the trickle line for 100 and 150% ET_C irrigation. Therefore, the information on the impact of saline/recycled water irrigation at different growth stages of almond on the water balance and salinity dynamics in the soil could improve the understanding of the use of such water for the almond production and ensure the long-term sustainability of high-value horticulture crops.

Predictive science and numerical models such as HYDRUS-2D (Šimůnek et al., 2016) present an excellent opportunity to gauge the impacts of irrigation practices (Kandelous and Šimůnek, 2010; Ramos et al., 2012; Phogat et al., 2012; González et al., 2015), water quality (Hassan et al., 2005; Ramos et al., 2011; Hassanli et al., 2016) and climate change (Austin et al., 2010) on potential water and salinity hazards and to control offsite movement of costly inputs into the surface and subsurface water bodies (Phogat et al., 2014). Moreover, the partial wetting pattern and irregular root water uptake in a drip-irrigated orchard make it difficult to apply and interpret standard water balance techniques and require a large number of measurements (Ben-Asher, 1979). Thus, a numerical model (HYDRUS-2D) was employed to evaluate the impact of different qualities of water applications to almonds at different growth stages on the water balance and salinity dynamics in the soil.

The objectives of this study are (1) to calibrate and validate HYDRUS-2D to describe water content distributions and spatiotemporal salinity dynamics in the soils under sprinkler-irrigated almond with recycled water, (2) to simulate water movement and salinity dynamics for other experimental irrigation treatments including substituting less saline irrigation water for the resident recycled water irrigation at three phenologically different growth stages, and (3) to evaluate the water use efficiency of almonds under the different irrigation treatments.

2. Materials and methods

2.1. Experimental details

The experimental site was established at a mature almond plantation located in the Northern Adelaide Plains irrigation district, approximately 35 km north of Adelaide, South Australia (34.628°S and 138.683°E). The orchard was planted in 1998 and designed to have two adjacent rows of a commercial variety, Nonpareil, bordered on either side by pollinators, Price and Keane. All trees were grafted to Bright peach hybrid rootstock with rows planted in a north-south direction. Trees were spaced at a distance of 5.5 m within the rows and 7.5 m between rows.

The trial was designed as a randomized unblocked design, with four treatments replicated four times, plus an additional demonstration plot. Each treatment plot consisted of micro-sprinklers (five trees) along a tree line and was three rows wide. It covered a double row of Nonpareil trees plus a single row of a pollinator variety. All soil and plant measurements were collected from the three central trees in the middle row. The treatment infrastructure was installed before the 2013–14 irrigation season and was designed to substitute recycled (more saline) water irrigation (2 seasons average EC_{iw} = 1.9 dS/m) with less saline water (2 seasons average EC_{iw} = 0.78 dS/m) at one of the three phenological growth stages. The treatment when recycled water irrigation was used for the entire irrigation season represents the control treatment (A). In treatment B, less saline water was applied between the buds burst and pit hardening (BB-PH) stages. In treatment C, less saline irrigation was applied between the pit hardening and harvest (PH-H) stages, whereas in treatment D, less saline irrigation was applied between the harvest and leaf fall (H-LF) stages. The number of days during the three physiological stages when less saline water was applied in treatments B, C, and D was 84, 108, and 73 during 2014–15 and 88, 101, and 88 during and 2015–16, respectively. In addition, a non-replicated plot (treatment E) of trees was irrigated with less saline water during the entire season for demonstration purposes. Table 1 gives details about the four replicated irrigation treatments and the non-replicated demonstration treatment. Further details about the trial design are described in Pitt et al. (2015).

Irrigations were scheduled to replace estimated tree evapotranspiration, which was evaluated based upon a modified version of the protocol developed by the Almond Board of Australia (2011). The Almond Board of Australia (ABA) provides a spreadsheet based on a

Table 1
The timing of exposure to non-saline irrigation water in treatments A–D (replicated) and treatment E (a non-replicated demonstration plot).

Treatments	Irrigation	Growth Stages		
		1	2	3
		BB[*] to PH#P[#]	H to H[λ]	H to LD[η]
A - Control	Saline all year	Saline		
B	Non-saline at BB-PH	Non-saline	Saline	
C	Non-saline at PH-H	Saline	Non-saline	Saline
D	Non-saline at H-LD	Saline		Non-saline
E	Non-saline all year	Non-saline		

[*] Bud burst.
[#] Pit hardening.
[λ] Harvest.
[η] Leaf drop.