COMBINED EFFECT OF REGULATED DEFICIT IRRIGATION AND LOW QUALITY WATER ON SALTS ACCUMULATION UNDER DRIP IRRIGATION.

Mounzer Oussama[1], Pérez S. Francisco[1], Pedrero S. Francisco[1], Alcobendas P. Rosalía[1], Bayona G. José María[1], Nicolás N. Emilio[1] and Alarcón C. Juan José[1].

Departamento de Riego: Centro de Edafología y Biología Aplicada del Segura, CEBAS-CSIC.
E-mail: omounzer@cebas.csic.es

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Abstract

This study aims to assess the combined effect of regulated deficit irrigation"RDI" and the use of low-quality irrigation water on salt accumulation. Six irrigation treatments have been differentiated in a commercial adult mandarin orchard, under drip irrigation. A control treatment (100% ETc) and an RDI treatment (50% ETc during stage II of fruit growth) were irrigated using three different water quality sources [good ($EC\approx1$,), low ($EC\approx3$) and time-variable ($1\leq EC\leq4$)]. Soil water content, soil matric potential and soil solution has been monitored on biweekly bases within the soil wetted volume under the emitter. Furthermore, gravimetric soil samples were taken before, at the beginning, at the end and after the application of RDI to evaluate the accumulation of salts at 10 and 30 cm away from the emitter and at 20, 40 and 60 cm depth. Field observations are compared with simulations of water and solute transport using HYDRUS-2D.

Resumen

El objetivo de este trabajo fue de evaluar el efecto combinado del riego deficitario controlado "RDC" y de la aplicación de aguas depuradas de baja calidad sobre la acumulación de sales en el suelo. Para ello, en una finca comercial con mandarinos adultos bajo riego localizado, se diferenciaron 6 tratamientos de riego. Se aplicó un Control (100% ETc) y un RDC (50% ETc durante la segunda fase de crecimiento del fruto) utilizando 3 fuentes de agua de distinta calidad [buena ($CE\approx1$,), baja ($CE\approx3$) y variable ($1\leq CE\leq4$)]. Cada 15 días, se registraron las variaciones del contenido de agua en el suelo, el potencial mátrico y la composición química de la solución del suelo. Además, se tomaron muestras gravimétricas antes, al inicio, al final y después de la aplicación del RDC. A posteriori se compararon los datos registrado en campo con simulaciones matemáticas utilizando el modelo HYDRUS-2D.

INTRODUCTION

Increasing water shortage and water competition between users are stressing forward adapting deficit irrigation strategies (Fereres and Soriana, 2007) and using non-conventional water resources (Mantell et al. 1985; Del Amor, 2000). Furthermore, the volume of treated wastewater is in continuous increase due to environmental concerns and the progressive implementation of the European WasteWater Directive (91/271/EEC). In Murcia-Spain there are at least 80 operating water treatment plants "WTPs" delivering more than 101.8 hm^3 per year: ESAMUR (2008), which restore up to 6% of the annual renewable water resources: PHCS (1997). The free availability of this considerable volume of water against the negative impact of water shortage and consequent political conflicts in the region has renewed and enhanced the use of urban wastewater in modern agriculture (mainly drip irrigation).

The use of treated wastewater for irrigation holds different risks for human health, environment and agricultural production system depending on the type of recycled water and the treatment employed. However, in developed countries, treated effluents are not allowed to be delivered to the environment before reducing possible health hazards to their minimum: Bixio et al., (2006). Nonetheless, almost all types of these effluents remain moderate to highly saline and consequently their long term use in irrigation may significantly affect the physical and chemical properties of the soil especially under modern and intensive agricultural system in arid and semi-arid areas (Ayars et al., 1993; Hillel, 2000; Pérez-Sirvent et al., 2003 and Angin et al., 2005). Oster (1994) reported that use of poor quality water requires some changes from standard irrigation practices, such as selection of appropriately salt tolerant crops, improvements in water management and, in some cases, the adoption of advanced irrigation technology. Inappropriate scheduling of water and fertilizers application has led to salinity buildup under long term use of drip irrigation: Darwish et al. (2005) and the prolonged use of wastewater for irrigation increased the compaction of the receiving soil and reduced its capacity of holding nutrients: Wang et al., (2003).

Water uptake by plant roots tends to increase salt concentration of the soil solution especially under saline conditions. During RDI application and high evapotranspiration demands additional osmotic potentials could be induced. This can lead to roots being exposed to higher toxicity hazards and to very different soil osmotic and matric water potentials from the bulk of the soil during the water depletion period.

The study described here below aimed at assessing the distribution and buildup of salinity in the soil irrigated by surface drip irrigation while applying regulated deficit irrigation "RDI" strategies and using saline treated wastewater.

MATERIAL AND METHODS

The experiment was conducted during the citrus production cycle (2007/2008), at a commercial orchard located in Campotejar-Murcia Spain (38º07´18´´N; 1º13´15´´W). The experimental plot of 0.5 ha was cultivated with 8-year old mature mandarin trees (*Citrus clementina* cv. 'Orogrande') grafted on Carrizo citrange [*Citrus sinensis* (L.) Osb. x *Poncirus trifoliata* L.]. The trees were spaced by 3.5 m between plants and 5 m between rows. The irrigation system consisted of a single lateral per plant row and 3 self compensating emitters per tree, spaced 0.9 m apart and providing 4 $l.h^{-1}$ each. The soil had a clay-loam texture (48% clay, 41% loam and 11% sand) with an average bulk density of 1.65 $g.cm^{-3}$. The irrigation doses was scheduled on the basis of weekly evapotranspiration of the crop "ETc" estimated as reference evapotranspiration (ETo), calculated with the Penman-Monteith methodology: Allen et al., (1998), and a monthly crop factor.

The irrigation control unit was equipped and supplied with three water sources; the first (AT) was pumped from the Tajo-Segura water conveyance channel ($EC \approx 1\ dS.m^{-1}$), the second (AC) was delivered by the irrigators association of Campotejar ($1 \leq EC \leq 4$) and the third (AD) was pumped from the wastewater treatment plant of the North of "Molina de Segura" and automatically mixed at the irrigation control head with water from "AT" to guarantee an irrigation water of $EC \approx 3 dS.m^{-1}$.

Two irrigation treatments were differentiated for each water source. A control treatment irrigated to recover 100% ETc throughout the growing season and a regulated deficit irrigation treatment (RDI) irrigated to recover only 50% ETc during the second stage of fruit growth, being unsusceptible to moderate water stress: González-Altozano and Castel (1999) and which extended from Jun 22nd to August 13th. A total of 6 treatments with 4 replicates each were distributed using a completely randomized design. Each replicate consisted of 3 x 4 trees with the 2 central trees being used for periodic sampling.

The soil water content (θ_v), the soil matric potential (Ψ_m) and the soil solution were sampled on biweekly basis. The θ_v was measured at 0.2 m away from the first emitter perpendicular to the irrigation lateral, using the TDR for the top 0.1 m and the neutron probe from 0.2 down to 1 m depth following a 0.1 m step. On the opposite symmetry side, the Ψ_m was measured at 0.2, 0.4 and 0.6 m depth using WaterMark® tensiometers. The soil solution was sampled at 0.3 m depth using suction lysimeters (Diameter = 63 mm) installed at 0.1 and 0.3 m away from the same emitter.

Gravimetric soil samples were collected 4 times a year from 0.2, 0.4 and 0.6 m depths at 0.1 and 0.3 m away from the emitter. The first sample was taken in January, the second at the beginning of RDI application, the third at the end of RDI application and the last one was gathered in the end of the irrigation season (end of November).

NUMERICAL SIMULATION

Hourly evolution of the soil water content and chloride transport was simulated during one year using the HYDRUS-2D model: Šimûnek et al., (2008) for the control and RDI treatments irrigated with good and reduced water quality respectively. Chloride is the most prevalent ion in irrigation waters. Its threshold concentration for causing damage varies with crops. However, its side effects are usually more pronounced in woody perennial fruit trees: Feigen et al., (1990).

The modeled flow domain was a vertical symmetry transect, at the first emitter position (at 0.9 cm from the trunk) and perpendicular to the drip line, with 2.5 m in width and 1m in depth. A soil extension of 0.2 m depth and 0.5 m width with a waved top boundary was added on the top left corner to represent the soil bed (Figure 1). The boundaries at distance "$d = 0 cm$" and "$d = 250 cm$" from the emitter were assumed to be no-flow boundaries, and the bottom was assumed to be a free-drainage boundary. The upper boundary was assumed to be atmospheric where the potential evapotranspirative flux was estimated from the reference Evapotranspiration (ETo Penman Monteith) and the crop coefficient (Kc) considering that surface evaporation was no more than 5% of ETc. Variable input water flux was computed from the applied irrigation schedule (doses and frequency) of the simulated irrigation system. The radius of the saturated zone below the emitter was considered variable in time and was computed through the modified HYDRUS-2D code (provided by the author of the model "J. Šimûnek"). This modified code switch from a Neumann (flux) to a Dirichlet (head) boundary condition whenever the surface pressure head required to accommodate the specified emitter flux for a surface node, is larger than 0: Gärdenäs et al., (2005). The root distribution function described by Vrugt et al., (2001) was implemented using the values (150, 130, 1) in the vertical direction and (150, 50, 1) in the horizontal direction for the corresponding parameters. The root water uptake was subjected to the soil water stress response function of Feddes et al. (1978).

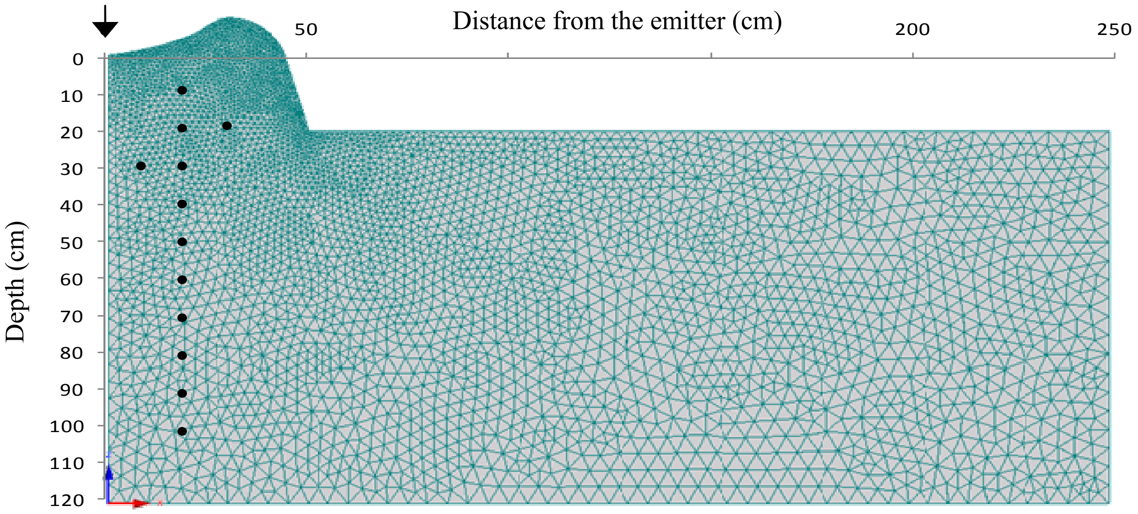

Figure 1: Geometry of the simulated soil domain. The black points represent the observation nodes equivalents to the measurement sites in the field.

The hourly precipitation, crop Evapotranspiration (Evaporation = 0.05*ETc and Transpiration = 0.95*ETc), irrigation input flux and chloride concentration were introduced into the HYDRUS-2D model. Field measurements of the soil water content at different depths were introduced into the objective function of the HYDRUS-2D model to predict the soil hydraulic parameters (θ_r, θ_s, α, n, k_s and I) and consequently estimate the soil water and chlorides distribution within the root zone of mandarin trees under different drip irrigation regimes.

RESULTS

Applied water

The irrigation water coming from AT, AC and AD sources was monthly sampled and analyzed to assess the annual evolution of its quality in terms of electrical conductivity (Figure 2A) and sodium adsorption ratio "SAR" (Figure 2B). The EC of "AT" was almost constant with an annual average of 1.19 dS.m^{-1} and that of "AD" was roughly maintained around 3.18 dS.m^{-1} through the on-site mixing with water coming from "AT". The irrigation water pumped from "AC" showed a variable EC due the water delivering policy followed by the irrigators association. This policy depended on the available water resources throughout the irrigation season (Tajo-Segura conveyance channel, groundwater and/or treated wastewater).

The SAR values of the three water sources were between 0 and 10 indicating the presence of a reduced sodification power especially when the SAR and EC are compared together. However, the SAR values of AC and AD are closer to the upper limit and the application of leaching fraction is highly recommended. The quantity of irrigation water applied amounted 5377 m^3.ha^{-1} for the control treatment and 4423 m^3.ha^{-1} for the RDI treatment. Consequently 18% of the seasonal irrigation water requirements were saved without significant reductions in the final crop production (Data not shown).

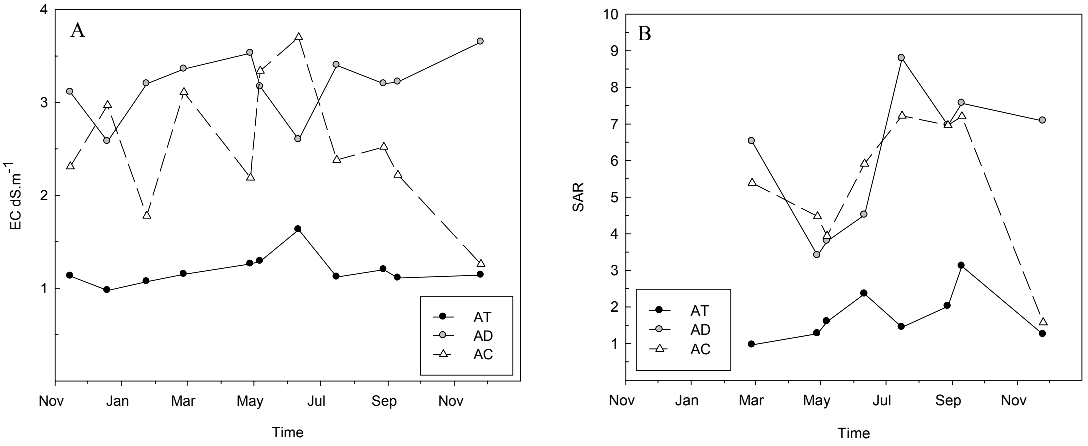

Figure 2: (A) Evolution of the electrical conductivity EC and (B) the sodium adsorption ratio SAR of the three irrigation water sources AT: water conveyance channel, AD: treated Wastewater and AC: irrigators association.

Soil matric potential

The values of the soil matric potential of the three control treatments (C-AT, C-AD and C-AC) were maintained above -20 kpa revealing optimum soil water conditions within the top 0.6 m throughout the growing season. For the RDI treatments (RDI-AT, RDI-AD and RDI-AC), only the Ψ_m at 0.2 m depth was maintained above -20 kpa whereas the water tension at 0.4 and 0.6 m depths decreased progressively as affected by the deficit irrigation. Under RDI and good quality water "AT" the registered Ψ_m values were significantly below those recorded within the soil under RDI treatment and reduced quality water. This could be the result of a reduced root water uptake in the "AC" and "AD" treatments as affected by increased soil osmotic water potential especially that Watermark tensiometers measure only the matric component of the soil water potential.

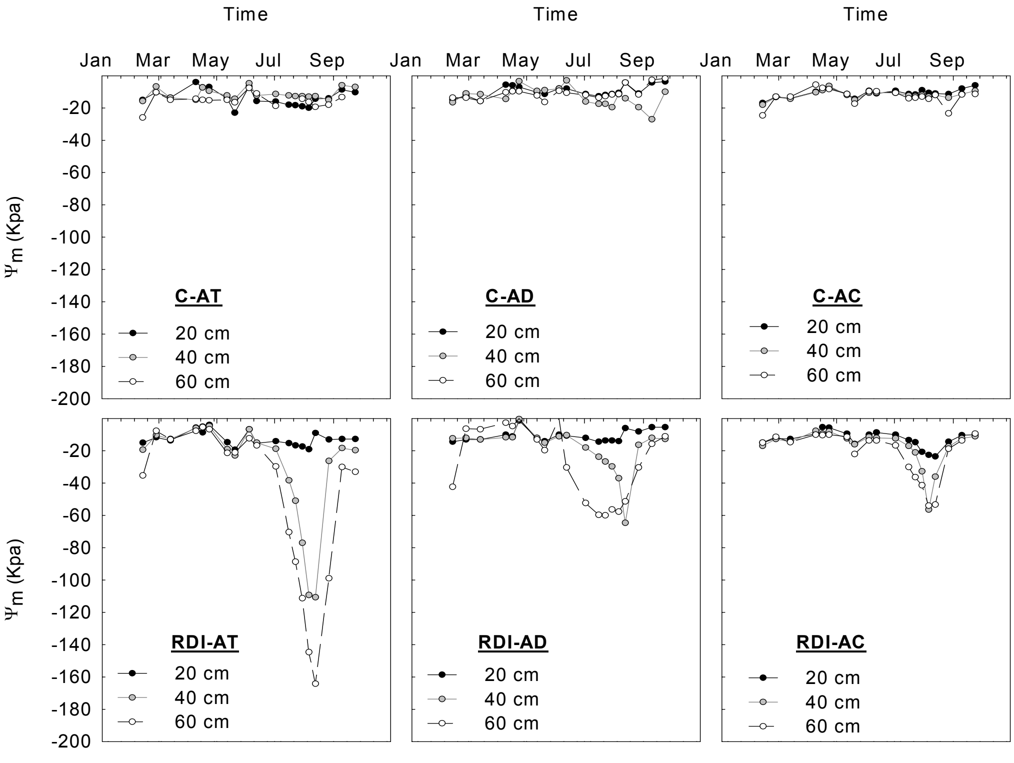

Figure 3: Seasonal evolution of the soil matric potential recorded at 0.2 m away from the emitter and at three depths (0.2, 0.4 and 0.6 m) for the 6 irrigation treatments. The letters C and RDI stands for control and regulated deficit irrigation treatment respectively whereas the letters AT, AD and AC refer to the water source withdrawn from the Tajo-Segura conveyance channel, the Wastewater treatment plant and the irrigators association.

Soil solution

The used suction lysimeters did not perform constantly to extract enough water from the soil especially during the deficit irrigation period. The electrical conductivity of the soil-water extracted at 0.3 m depth was highly variable and unexpected in some occasion when compared to the applied irrigation treatments (Figure 4). Therefore, we could not identify any tendency or significant differences between treatments in terms of salts accumulation in the soil. It was neither clear at both distances from the emitter of the same treatment. Even so, higher EC values were observed at 0.3 m than at 0.1 m from the emitter.

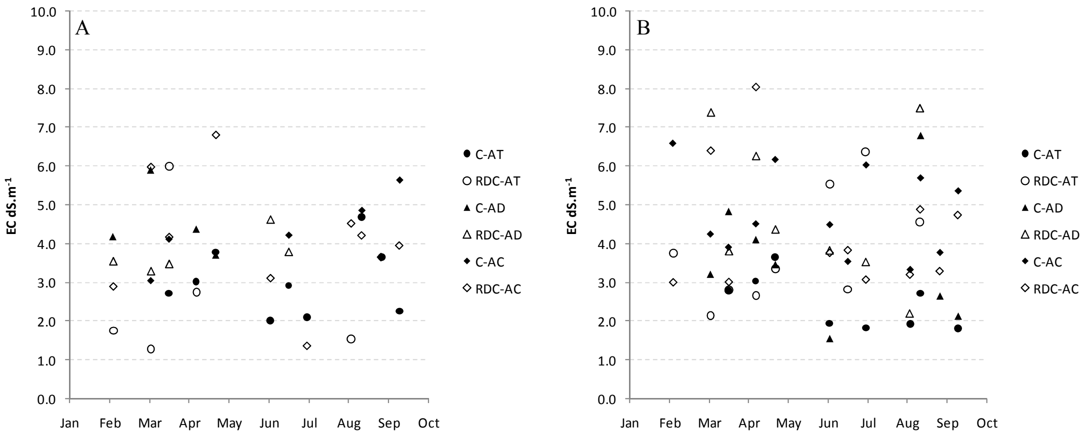

Figure 4: Electrical conductivity of the soil solution extracted with suction lysimeters at 0.3 m depth and 0.1 (A) and 0.3 m (B) away from the emitter.

Soil water content

The hourly simulated and biweekly field records of the soil water store “SWS” down to 1 m depth under full irrigation and RDI treatment are depicted on Figure 5. From the beginning of the irrigation season till the 22nd of June, the SWS was maintained at field capacity for both treatments. Since that date till August 13th the SWS of the RDI treatment was depleted progressively by root water uptake while only 50% of the water lost by ETc were restored to the soil. Later on, the full irrigation practice (100% ETc) was resumed and the SWS recovered progressively its initial state about 1 month later. The simulated values of SWS fitted satisfactorily with the observed measurements except during the SWS recovery period for the RDI treatment. This could be the result of a hysteresis process.

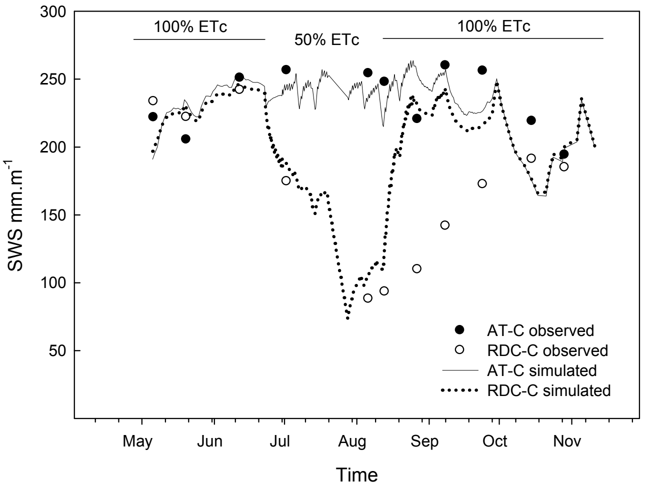

Figure 5: Seasonal evolution of the soil water store “SWS” simulated by HYDRUS-2D (continuous and dashed lines) and measured by neutron probe (filled and empty circles) under full irrigation and RDI treatment respectively.

Chloride distribution

The spatial distribution of chloride concentration within the soil profile subject to 2 irrigation regimes at the start and conclusion of RDI application, using good and low quality irrigation water, is presented on figure 6 and 7 respectively. The initial chloride concentration in the soil was set equal to 0.5 $mg.cm^{-3}$ (500 ppm). From January first till Jun 22nd, both treatments were irrigated to fully recover the water lost by Evapotranspiration. During this period the soil water content between plant rows decreased progressively as affected mainly by evaporation whereas the wetted bulb below the emitter was maintained at field capacity by frequent irrigation. These conditions have generated a decreasing gradient of humidity outward the emitter and produced the accumulation of salts in the upper soil layer and at the outer limits of the wetted soil volume even when applying good quality water. At 100 cm away from the emitter, the chloride concentration under the "C-AT" treatment increased from 0.5 $g.cm^{-3}$ in January up to 6 $g.cm^{-3}$ on Jun 22nd (Figure 6A) and to 10 $g.cm^{-3}$ on August 12th (Figure 6B). During the period of RDI regime the irrigation doses was reduced by half, consequently the wetted bulb shrank and the chloride concentration of 6 $g.cm^{-3}$ on Jun 22nd (Figure 6C) started increasing closer and within the active root zone and reached a doubled value of 20 $g.cm^{-3}$ at 0.3 m depth (Figure 6D). For the AD treatments the effect of drip irrigation in terms of solute concentration was intensified by the reduced quality of irrigation water. The homogeneous distribution of chloride concentration set at 0.5 $g.cm^{-3}$ in January was altered by the heterogeneous irrigation water input and root water uptake and was increased within the upper soil layers up to 16 $g.cm^{-3}$ before the application of RDI (Figure 7A and 7C) and up to 50 $g.cm^{-3}$ after it (Figure 7D).

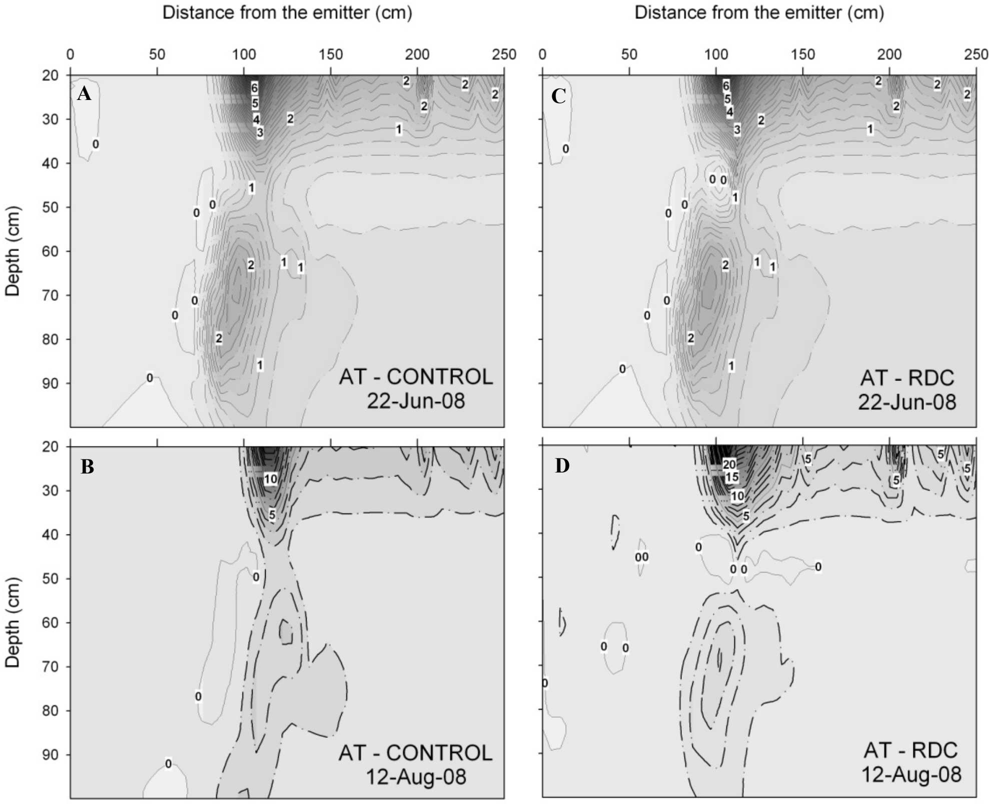

Figure 6: Simulated 2D-Spatial distribution of chloride concentration ($mg.cm^{-3}$) at the start (Jun 22nd) and conclusion (August 13th) of RDI application using good quality water (AT source).

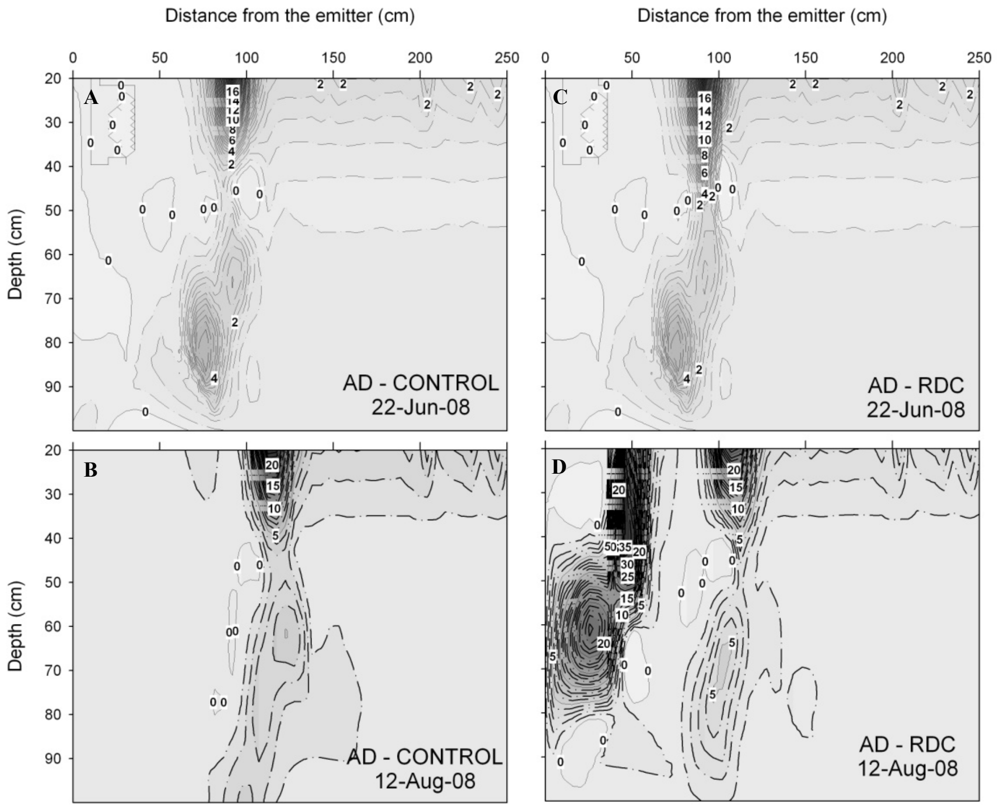

Figure 7: Simulated 2D-Spatial distribution of chloride concentration (mg.cm^{-3}) at the start (Jun 22nd) and conclusion (August 13th) of RDI application using reduced quality water (AD source).

The ambiguous values of point measured salt concentration could be explained through the simulated solute dynamic and distribution. The preselected sites of sampling of the soil solution (at 0.1 and 0.3 m from the emitter and 0.3 m depth) seem to be located within a soil volume that is continuously leached by irrigation water. Consequently the sampled soil solution did not represent the real effect of drip irrigation, low quality irrigation water and the use of regulated deficit irrigation strategies on the accumulation of salts. This hypothesis would be confirmed through the laboratory analysis of the gravimetric soil samples collected during 2008 (samples under processing) and by further studies during the coming years.

CONCLUSIONS

A fair agreement was found between the field measured and HYDRUS simulated values of the soil water content. Simulated water movement and solute transport under good quality drip irrigation system emphasizes the possible accumulation of salts at the fringe of the wetted soil volume under the emitter. This phenomenon is accelerated when using low quality irrigation water and during the application of regulated deficit irrigation. Further studies are required to confirm the simulated results and to establish practical guidelines for a sound application of water saving strategies while using low quality irrigation water.

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