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# Regulated deficit irrigation, soil salinization and soil sodification in a table grape vineyard drip-irrigated with moderately saline waters

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ABSTRACT

Irrigation with moderately saline waters may provoke soil salinization and sodification. The objectives of this three-year study were (1) to quantify these processes in two seedless table grapevines (*Vitis vinifera* cvs. Autumn Royal and Crimson) subject to a full irrigation and two regulated deficit irrigations (RDI, irrigated at 80% and 60% of net irrigation requirements from post-veraison till harvest) with 1.7 dS m$^{-1}$ electrical conductivity irrigation waters, and (2) to assess the impact of soil salinization on grapevine's response. Soil samples were taken three times along each irrigation season and soil solution samples were extracted weekly by suction cups. Soil saturation extract electrical conductivity (ECe) and sodium adsorption ratio (SARe) were high in Autumn Royal (4.4 dS m$^{-1}$ and 6.1 (mmol l$^{-1}$)$^{0.5}$) and very high in Crimson (7.0 dS m$^{-1}$ and 8.6 (mmol l$^{-1}$)$^{0.5}$) due to relatively low leaching fractions (LF) (0.20 in Autumn Royal and 0.13 in Crimson). Soil solution salinity and sodicity were generally higher in the more severe RDI than in the full irrigation treatment. Soil salinity and sodicity generally increased along the irrigation seasons and decreased along the non-irrigation seasons. Salt accumulation or leaching and LF were significantly correlated, so that LF estimates could anticipate the required irrigation depths for soil salinity control. Grapevine yield declined with increases in soil salinity. Leaf Na concentrations were very low (<0.1%), but leaf Cl concentrations were higher and the maximum value of 0.61% measured in the more severe Crimson RDI treatment was within the interval reported as toxic in grapevine. Despite the water saving benefits of drip irrigation in combination with deficit irrigation strategies, its implementation in low-precipitation semiarid areas must be cautiously assessed and monitored because soil salinization and sodification may threaten the sustainability and profitability of these grapevine orchards irrigated with moderately saline waters.



## 1. Introduction

Regulated deficit irrigation (RDI), first proposed by Chalmers et al. (1981) as an irrigation strategy to save water without reducing crop yields, consists in the reduction of irrigation water to predetermined levels at certain developmental stages when the effects on crops are neutral or positive. RDI has expanded in the last decades in wine grapevines to improve water productivity (i.e., yield per unit water supply), berry composition, and wine quality (McCarthy et al., 2002; Ortega-Farias et al., 2012). However, RDI studies on table grapes are limited (Blanco et al., 2010), and the quality requirements are different than those of wine grapes since berry appearance and quality is mostly desired in table grapes.

Drip irrigation is generally used in RDI because of its capability to distribute water uniformly and to control the amount of water applied timely and precisely. Hoffman and Shannon (2007) and Hanson (2012) discussed the fundamentals and strategies to cope with saline waters when using drip irrigation. This system has the advantage of providing near the emitters high leaching and salt levels only slightly higher than those of the irrigation water. Since plant roots tend to proliferate near emitters, this allows water of relatively high salt content to be used successfully in many cases. Thus, Hanson et al. (2008) demonstrated that the wetting pattern around emitters results in higher leaching fractions (LF) and lower salinity levels than in other irrigation systems for a given amount of applied water. These authors defined the localized leaching fraction (LLF) as the actual LF representative of the local root domain near the drip line. Through HYDRUS-2D computer simulations, they concluded that LLF were positive for applied water amounts equal to or smaller than crop's ET, when the field-wide LF calculated through a water balance method would be zero or negative for these water applications.

Despite the benefits of drip irrigation for soil salinity control, the LLF in RDI could be insufficient to displace the salts from the active

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root zone of crops in the periods with interrupted irrigation. Therefore, a potential risk of RDI is reduced salt leaching by the applied irrigation water, increased evapo-concentration of salts present in the irrigation water, root zone soil salinization and concomitant yield decreases. However, quantification on the effects of deficit irrigation strategies on soil salinization and sodification is lacking, particularly in table grape vineyards subject to low-quality waters. In other crops such as cotton, Chen et al. (2010) concluded in a three-year study performed in an arid region of northwest China that deficit irrigation using saline waters was not sustainable due to the accumulation of salts in the soil to levels that exceeded the cotton salt tolerance. This soil salinization may also have a deleterious impact on the structural stability and hydraulic conductivity of sensitive soils due to sodification (i.e. increased sodium adsorption ratio and soil exchangeable sodium percentage) derived from the selective precipitation of calcium minerals as the soil water evapo-concentrates.

The total salt content in the soil as well as the concentration of specific ions such as Cl and Na, may have detrimental effects on vines such as reduced growth and yield, early leaf senescence and necrotic spots on leaves (Shani and Ben Gal, 2005). Grapevines have been classified on the basis of its shoot growth as moderately sensitive to soil salinity, with a threshold ECe (electrical conductivity of the soil saturation extract) of 1.5 dS $m^{-1}$, and a 9.6% growth decline per unit increase in ECe beyond this threshold (FAO, 1985). However, Zhang et al. (2002) concluded that these values were too conservative and that, depending on cultivars and rootstocks, they could range between 1.8–4.0 dS $m^{-1}$ (threshold ECe) and 2.3–15.0% (slope). Leaf Cl and Na toxic concentrations were also variable depending on rootstocks and cultivars (Downton, 1977), although Cl concentrations of 0.3–1.0% (dry-weight basis) and Na concentrations of 0.25–0.5% generally caused toxicity problems (Bernstein et al., 1969; Stevens et al., 2011; Walker et al., 2004). These problems may be mitigated by the use of rootstocks that reduce the accumulation of these ions as compared to own-rooted vines (Downton, 1977).

The objectives of this research were (1) to quantify soil salinization and sodification in two table grapevines subject to different irrigation strategies, including RDI, and (2) to assess the impact of soil salinization on the yield, productivity and Na and Cl leaf ion concentrations in these table grapevines.

## 2. Material and methods

### 2.1. Field conditions, plant material and irrigation management

A three-year study (2007–2009) was conducted in a 12-ha, four-year-old table grape vineyard located in the Santa Barbara commercial orchard of the ALM Group, in the county of Caspe in Northeastern Spain (Ebro River Basin, 41.16° N, 0.01° W). Two seedless table grape cultivars (*Vitis vinifera* cvs. Autumn Royal and Crimson) grafted onto Richter 110 rootstock (moderately tolerant to salinity according to South Australian Research and Development Institute-SARDI) were planted at a density of 1142 plants $ha^{-1}$ in two sectors of the vineyard at a distance of 2.5 m between vines and 3.5 m between rows. The vineyard, managed according to the usual cultural practices in the farm, was cultivated using a Spanish horizontal trellis system with a protective plastic mesh 2.5 m above ground. The vines were irrigated at night by a single trickle line located close to the vines with 2.2 l $h^{-1}$ self-compensating emitters spaced 0.5 m. The weekly irrigation depths (I), measured with volumetric water meters installed in each lateral, were calculated as: I = NIR/Ea, where NIR is Net Irrigation Requirements calculated as ETc–Pef (where ETc is crop evapotranspiration and Pef is effective precipitation (P) taken as 75% of total P, according to Blanco et al., 2010) and Ea is the irrigation application efficiency taken as 0.95. These weekly I values were split in daily applications. Irrigations were applied daily from April to September, the typical irrigation season for the area. Eventual irrigation applications were also applied in February, March and October depending on the actual meteorology.

Samples of irrigation water were taken on a weekly basis. The irrigation water was moderately saline, with 2007–2009 mean values of 1.7 dS $m^{-1}$ (ECw), 2.4 (mmol $l^{-1})^{0.5}$ (SARw), 5.5 (Na), 6.5 (Ca), 3.2 (Mg), 6.1 (Cl), 6.2 ($SO_4$) and 3.4 ($HCO_3$) (ions in meq $l^{-1}$). Table 1 gives the irrigation-season mean ECw and SARw and the coefficients of variation for each studied year.

The mean annual values in the area for the period 2007–2009 were 291 mm for precipitation (P) and 1430 mm for reference evapotranspiration (ETo) calculated with the FAO Penman–Monteith (Allen et al., 1998) according to the SIAR weather station network (MARM, 2011). The P/ETo ratio was 0.20, classifying the Mediterranean climate as arid (P/ETo ≤ 0.2). A meteorological station was installed in the vineyard recording air temperature, relative humidity, global solar radiation, precipitation, and wind speed. The sensors were placed just below the protective mesh, except the rain gage that was placed above. The daily values of vineyard crop evapotranspiration (ETc) were estimated multiplying the ETo computed using the FAO Penman–Monteith method (Allen et al., 1998) and the daily averages of the meteorological data by the crop coefficients (Kc) adjusted for this particular vineyard. The seasonal curves of daily Kc were developed using the procedure described by Allen et al. (1998). The tabulated vineyard Kc values (Allen and Pereira, 2009) were adjusted to take into account (a) the P and average ETo during the initial stage, and the averages of wind speed and minimum relative humidity during the mid and end-season stages, and (b) the effect of the plastic mesh in reducing ETc by using a net coefficient of 0.65 (Moratiel and Martínez-Cob, 2012). The duration and dates of the different periods for calculation of Kc were determined from the soil ground cover data measured by digital photography (Blanco et al., 2010; Suvočarev et al., 2013).

Three irrigation treatments were given based upon a percentage of NIR: control (T1 or full), irrigated at 100% NIR throughout the irrigation season, and two RDI treatments irrigated at 100% NIR throughout the irrigation season except from post-veraison till harvest, when they were irrigated at 80% (T2 or RDI-80%) and 60% (T3 or RDI-60%) NIR. In the studied years, veraison in these grapevines started from mid July to early August, and harvest from mid to late September in Autumn Royal and early to mid October in Crimson. The 80% (T2) and 60% (T3) irrigation depths were obtained by substituting the 2.2 l $h^{-1}$ emitters by 1.6 l $h^{-1}$ emitters spaced 0.45 and 0.60 m, respectively.

### 2.2. Soil sampling and analysis

The soil in this vineyard is deep, well drained, medium to coarse textured, and high in calcite and gypsum (Blanco et al., 2010). Field capacity (mean = 23.7%) and permanent wilting point (mean = 7.8%) were determined with the Richards pressure plate apparatus. The soil is classified as Xeric calcigypsid, coarse loamy, mixed (gypsic), thermic (Soil Survey Staff, 1999).

The soil samples were taken by auger in consecutive years at the right and left sides of the selected vines (one vine per cultivar and irrigation treatment). Each sample was a composite of two subsamples taken at both sides in the front of the closest emitter to the vines at two distances (10 and 30 cm) from each emitter and at three soil depths (0–20, 20–40 and 40–60 cm). This procedure was performed at three times: (1) beginning of each irrigation season (mid February), (2) beginning of the RDI treatments (mid July to early August), and (3) end of each irrigation season (early November).