

Irrigating Table Grapes in Arid Regions with Low Quality Water: Effects of Salinity and Excess Boron

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Abstract

Early ripening table grapes are an increasingly economically viable crop in arid and semi-arid regions. Table grape production is particularly attractive in arid regions where cultivation is dependant upon the availability of large amounts of irrigation water. Unfortunately, water resources in such areas are often limited and the salinity of available irrigation water tends to be high. The response of grapevines (*Vitis vinifera* L. cv. Sugraone) to salinity, excess boron (B) and combinations of the two were studied under controlled conditions in a number of lysimeter, pot and field experiments. In a lysimeter experiment, salinity reduced leaf scale transpiration and photosynthesis and both leaf and whole plant biomass production and (evapo)transpiration were found to be linearly related. Mortality of vines was dynamically associated with salinity level and time. Grapevine response to salinity was observed to involve two mechanisms: (i) a reduction in transpiration and growth which began as soon as salinity was experienced; and (ii) vine mortality which was correlated with salinity level, a sharp increase in Na and Cl content of leaves, and time. At lower salinities, the onset of mortality occurred later and death rates increased as the duration of exposure to salinity increased. For vines grown for four years in pots, B in solution at levels greater than 1.3 mg L^{-1} caused reduced growth (trunk size), reduced nodal lengths between leaves on branches, and increasing B caused severe visual toxicity symptoms including necrotic leaves. In spite of this, B in solution as high as 3.3 mg L^{-1} did not lead to reduced biomass production as measured by pruning weights or reduced fruit production as measured via harvest data. Increased salinity caused reduction in B accumulation in the vines.

INTRODUCTION

Early ripening table grapes are an increasingly economically viable crop in arid and semi-arid regions. Table grape production is particularly attractive in arid regions with hot dry climates and where cultivation is therefore dependant upon the availability of large amounts of irrigation water. Unfortunately, water resources in such areas including the Jordan and Arava Valleys of Jordan and Israel are limited and the salinity and boron (B) content of soils and available irrigation water tends to be high. Grapes have been defined as moderately sensitive to salinity (Downton, 1977; Maas, 1990). Maas (1990) combined data reports threshold values for grapevines of 1.5 dS m^{-1} in saturated paste electrical conductivity (ECe) and a salinity response of 9.6% yield decrease for every subsequent unit dS m^{-1} increase in ECe.

Elevated B is often found in association with agriculture in arid regions where natural soil B levels are high and where water sources used for irrigation can contain

additional B (Nable et al., 1997). Municipal and other wastewater effluents used for irrigation are also sources of excess B (Tsadilis, 1997). Boron toxicity is crop specific, manifested by damage to tissues where it accumulates, and generally leads to chlorosis and necrosis beginning at edges of mature leaves (Brown and Shelp, 1997). Grapes have been defined as sensitive to excess B by Maas (1990) who reported a threshold value of B in soil solution of 0.5-0.75 mg L⁻¹ above which vegetative growth is reduced. Specific information regarding B toxicity in grapevines is extremely limited. Nikolaou et al. (1995) found toxicity symptoms in Victoria grapes when irrigating with water containing 4 mg B L⁻¹. Peacock and Christensen (2005) reported that irrigation water containing greater than 1 mg B L⁻¹ may lead to toxicity in grapes and referred to saturated paste B of 1 mg L⁻¹ and leaf tissue content of 80 mg kg⁻¹ as indicative of toxicity. In many cases, especially in arid regions, high B in soil or water occurs concurrently with elevated salinity. We present a synopsis of research in Israel's arid Jordan and Arava valleys regarding table grapes (*Vitis vinifera* L. cv. Sagraone) cultivated in environments of high water consumption and low to no rainfall. The response of the grapevines to salinity, excess B and combinations of the two were studied under controlled conditions in a series of lysimeter, pot and field experiments.

MATERIALS AND METHODS

The Jordan and Arava Valleys

Situated on Israel's eastern border with Jordan, the Jordan and Arava Valleys are found north and south, respectively, to the Dead Sea in the Great Syrian-African Rift. Elevations in the valleys range from -400 m to +100 m. Rainfall is negligible (20 to 50 mm annually) and Class A pan evaporation reaches 3500 mm due to the predominantly hot and dry climate. Winter day time temperatures typically reach 20°C and rarely fall below 10°C, and summer temperatures often surpass 40°C.

Lysimeter and Field Studies

Irrigation and soil water salinity and their influence on vine physiology, transpiration, mineral uptake, growth and yields were evaluated in lysimeter and field studies in the Arava Valley at Yotvata, Israel. Vines grown in sandy loam soil were irrigated with 6 salinity levels (0.5, 3, 5, 7, 9 and 12 dS m⁻¹) where salinity was increased by adding 1:1 molar concentrations of NaCl and CaCl₂ to the low salinity (0.5 dS m⁻¹) water in lysimeters and with 4 salinity levels (1.7, 3.5, 6 and 9 dS m⁻¹) in a five year vineyard experiment. Experimental detail is found in Shani and Ben-Gal (2005). In the lysimeter experiment whole-plant full-season measures of biomass production and water uptake (Shani and Ben-Gal., 2005) were accompanied by periodic leaf-scale measures of transpiration, net CO₂ flux and conductance by way of a portable CO₂/H₂O porometer system (HCM-1000, Walz GmbH, Effeltrich, Germany). Cuvette temperature were set to 25°C and light was held constant at 1500 μmol m⁻² s⁻¹. Measurements were made between 1000 and 1200 h (solar time) of 5-6 leaves per lysimeter at 4 days. Area (projected leaf area) based gas exchange parameters were calculated after von Caemmerer and Farquhar (1981). Pre-dawn plant water potential (Ψ_{pd}) was determined prior to sunrise by a Scholander-type pressure chamber (Plant Water Status Console 3000, Soilmoisture Inc., Santa Barbara, CA, USA) after Turner (1988).

Boron and B-Salinity Interaction

The response of table grapes to conditions of excess B and root zone salinity was investigated in experiments where vines were grown for four years in perlite media in 60 L pots at Gilgal in Israel's Jordan Valley. Vines were irrigated with either low salinity (EC = 1.3 dS m⁻¹) or high salinity (EC = 2.7 dS m⁻¹) solution containing B concentrations of 0.3, 1.3, 2.3, or 3.3 mg L⁻¹ B. Vines were monitored for growth, yield and B accumulation in vegetative tissues. Greater detail of the experiments can be found in Yermiyahu et al. (2006).

RESULTS

Salinity

Leaf-scale transpiration, leaf conductance and CO₂ uptake were all similarly reduced in grapevines as a function of increased salinity of the irrigation/soil solution (Fig. 1). Pre-dawn leaf water potential (Fig. 2) was reduced with increasing salinity. Vines submitted to the lowest salinity level (0.5 dS m⁻¹) had Ψ_{pd} of -0.22 while irrigation with 12 dS m⁻¹ water brought Ψ_{pd} to -0.7. No damage of the photosynthesis processes by salt stress could be detected with chlorophyll fluorescence. Stomata closure therefore limited the net photosynthesis with increasing salinity. The leaf level measurements correlated with whole-plant scale effects measured in the lysimeters (Shani and Ben-Gal, 2005). Linear relationships were found both between biomass production and evapotranspiration on the whole vine level and between photosynthesis and transpiration on the leaf level.

Fruit yield decreased in a sigmoidal fashion as a function of increasing irrigation water salinity with 50% yield decrease corresponding with EC of just over 4 dS m⁻¹ (Fig. 3). In both lysimeter and field trials, mortality of vines was dynamically associated with salinity level and time and corresponded with extreme accumulation of Na and Cl in shoots (Shani and Ben-Gal, 2005). Vines irrigated with 12 dS m⁻¹ water did not survive a single season. In the field experiment, vine mortality was a function of a combination of the salinity level and time (Fig. 4). No mortality was found for vines irrigated with the lowest salinity water (1.8 dS m⁻¹). Moderate salinity of irrigation water (3.5 dS m⁻¹) after 3 years caused >8% vine death which rose to >16% after 4 years. Higher salinity (EC 6) had >8% mortality after 3 years that increased to >33% after 4 years. Even higher salinity (9 dS m⁻¹) caused 83% mortality after 3 years and >90% after 4.

Boron Toxicity

Boron accumulation in leaves was found to be correlated with B toxicity symptoms which included reduced leaf size and internodal distance between leaves, and chlorosis and necrosis beginning with leaf margins. Boron accumulated in grapevine leaves linearly as a function of increased B in irrigation solution, with time and with age of leaves. Highest B levels were found at the end of each season and in the oldest leaves. Boron accumulation patterns and levels were repeated for each year of the experiment. Boron influenced vine growth; at low levels of B (0.3 mg L⁻¹) canopy development was restricted but trunk size was not. Contrary to this, at high levels of B, substantial visual symptoms of B toxicity were observed, pruning biomass was not affected, and total accumulated biomass measured by trunk size was reduced over time (Fig. 5). In spite of severe visual toxicity damage and reduced overall growth rates, commercial fruit yield of the vines remained unaffected by high environmental B levels.

Boron Salinity Interactions

Significantly greater B was found to accumulate in leaves of vines receiving the lower salinity irrigation water as compared to those receiving higher salinity solution when B concentration was high. Boron increased with time within the 2003 season at each B treatment level (Fig. 6). Boron increase in leaves as a function of increased solution B was evident in all of the sampling dates. The extent of B accumulation with increased B in solution increased as time went on as seen in the slopes of the linear regression analysis (Fig. 6). While low level B treatments had similar B leaf content, higher levels of B in solution led to less leaf B accumulation when salinity was higher.

Salinity was found to reduce pruning biomass but not to affect trunk circumference. Neither increased B in irrigation solution (to as high as 3.3 mg L⁻¹) or increased salinity (2.7 dS m⁻¹) were found to decrease fruit yield in the grapevines. No interaction between salinity and B effects on growth or yields of the vines was found.

DISCUSSION

Leaf Sampling for Salinity and B Status

Mineral content of vine leaves was seen in all of the experiments to be a function of time and placement of the leaf on the vine in addition to reflecting environmental exposure. Due to high transpiration rates, high levels of ions of mineral salts (Na, Ca, Cl) (Shani and Ben-Gal, 2005) as well as B (Fig. 7 and Yermiyahu et al., 2006) were found in what are considered “diagnostic leaves” (leaf opposite to basal bunch) even when the vines were exposed to relatively low environmental levels of salts and B. Clearly, attempts at relating salt or B damage to ion content measurements in leaves are unpractical as no clear relationships exist and levels correlating with toxicity damage in one situation are not likely to hold true under other conditions. Even comparative observations of trends in ion content in leaves must carefully consider leaf placement, age and sampling date in order to provide useful information.

Horticultural Risks of Salinity and Boron on Table Grapes

Grapevine response to salinity is seen to involve two mechanisms: First, a reduction in transpiration and growth beginning immediately with exposure to root zone salinity; and second, vine mortality correlated with salinity level, a sharp increase in Na and Cl content of leaves, and time. At lower salinities, the onset of mortality occurs later and death rates increase as the duration of exposure to salinity increases. Previous investigations on salt-stressed grapes showed initial inhibition of CO₂-uptake (Walker et al., 1981). However, any apparent non-stomatal inhibition of photosynthesis was an artifact arising from patchy stomatal closure with increasing salinity (Downton et al., 1990; Buckley et al., 1997). The reduction in photosynthesis is mainly controlled by stomatal limitation of CO₂-uptake rather than a decrease of the photosynthetic capacity through direct toxic effects of Na⁺ and Cl⁻ on the photosynthetic process (Downton et al., 1990; Gibberd et al., 2001, 2003).

Quantification of the first salinity response mechanism supports management and decision making regarding utilization of saline soils and water for irrigation and encourages implementation of irrigation regimes designed to minimize root zone salinity. Lower root zone salinity leads to increased vine vigor and long-term production. The second mechanism is problematic as it suggests that conditions of salinity will have eventual catastrophic results and that cultivation of grapes under such conditions at best is destined to a shorter than expected vineyard lifetime. The phenomena of gradual vine death related to salinity has been observed in wine grapes in Texas (McEarchern, 1995) and in the Negev highlands (Ben-Asher et al., 2006). Ion uptake patterns largely influence transpiration efficiency and are rootstock specific (Downton, 1985; Gibberd et al., 2003). Possibly rootstock choice for specific ion exclusion could influence both long and short term tolerance.

Boron, in spite of causing even severe visual symptoms of toxicity, does not seem to be a genuine problem in vineyards in the arid areas studied. The reason for this lies in the specific growing conditions of the Jordan and Arava Valleys where early ripening and excess total annual vegetation are combined with conditions of salinity. Patterns of B accumulation in leaves are repeated in annual cycles. Fruit is harvested during May and June before the high B concentrations seen by the vines affected fruit growth. Additionally, biomass production occurring in the late summer and fall does not seem to have a role in the next season's harvest as vines with relatively decreased and damaged vegetation do not show long-term negative effects on annual vegetative growth or on fruit yield. The salinity of soils and irrigation water that accompany the high B concentrations is itself another reason that B toxicity does not come into play. Increased salinity reduces B accumulation in leaves. If salinity was lower, there would likely be greater risk of B toxicity.

ACKNOWLEDGEMENTS

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Figures

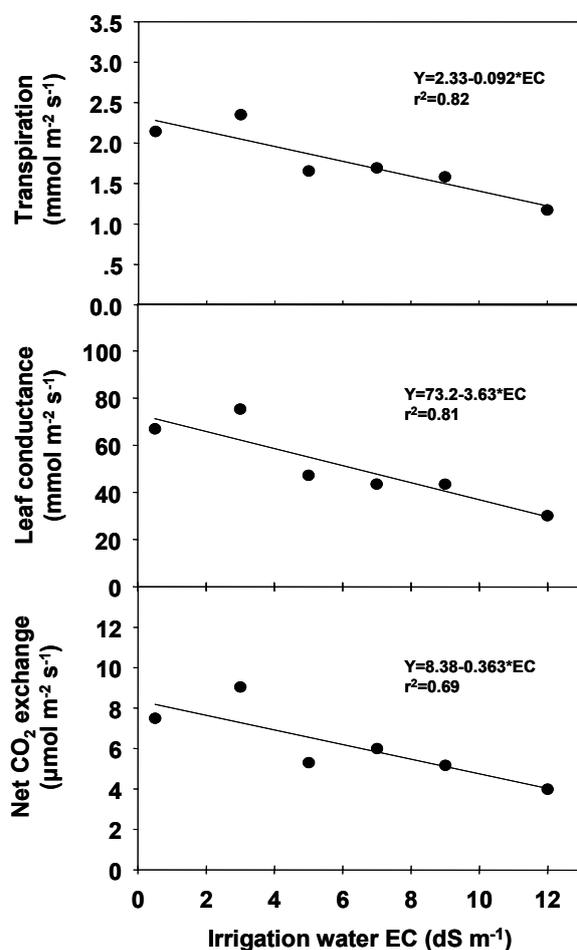


Fig. 1. Leaf scale gas exchange. Transpiration, conductance and CO₂ flux measured on April 4 on leaves of vines growing in lysimeters receiving treatments of salinity of irrigation water at Yotvata Israel. Symbols are average measured data (n=20), lines are best fit linear regression.

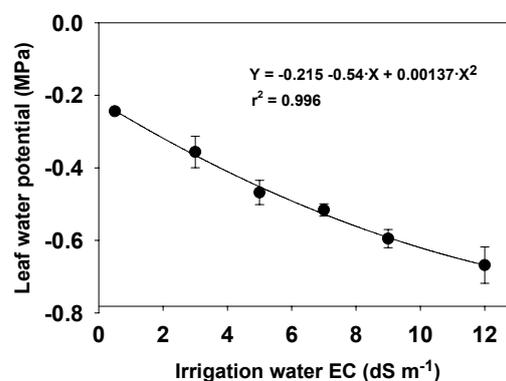


Fig. 2. Pre dawn leaf water potential measured in April, approximately 75 days after budburst, in lysimeter grown vines at Yotvata, Israel. Symbols are average measured data, error bars are standard deviations and the line is best fit quadratic regression.

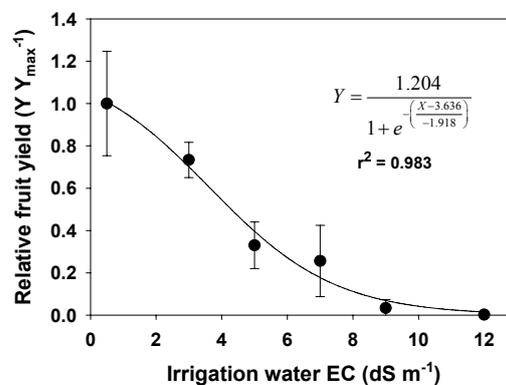


Fig. 3. Grapevine response to irrigation water salinity. Harvested fruit as a function of irrigation water salinity for vines grown in lysimeters in Yotvata Israel. Symbols are average measured data, error bars are standard deviations and line is 3 parameter sigmoidal best fit regression.

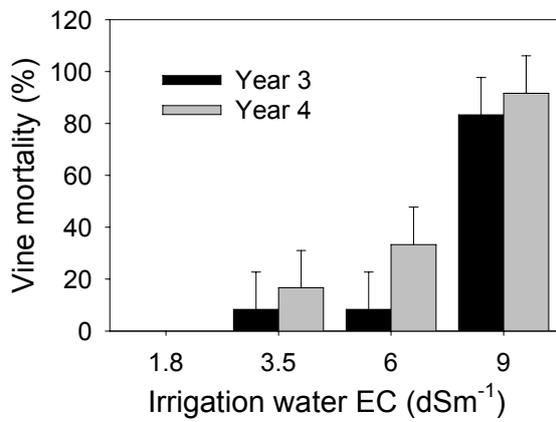


Fig. 4. Extent of vine death as a function of irrigation water salinity and time in field vineyard experiment at Yotvata Israel. Columns represent averages and error bars standard deviations. From Shani and Ben-Gal, 2005.

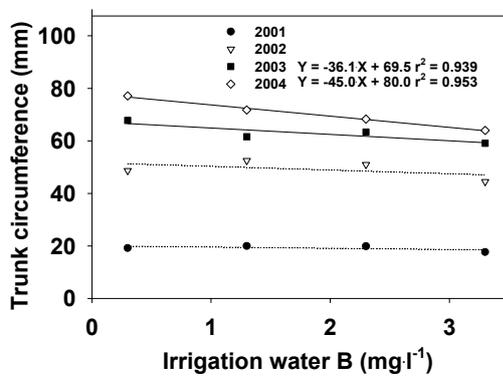


Fig. 5. Vine growth measured in January each year as trunk diameter as a function of B in irrigation solution and time for vines grown in pots in Gilgal, Israel. Symbols are averages of experimental results and lines are best fit linear regression. Solid lines are given for significant ($P \leq 0.05$) relationships.

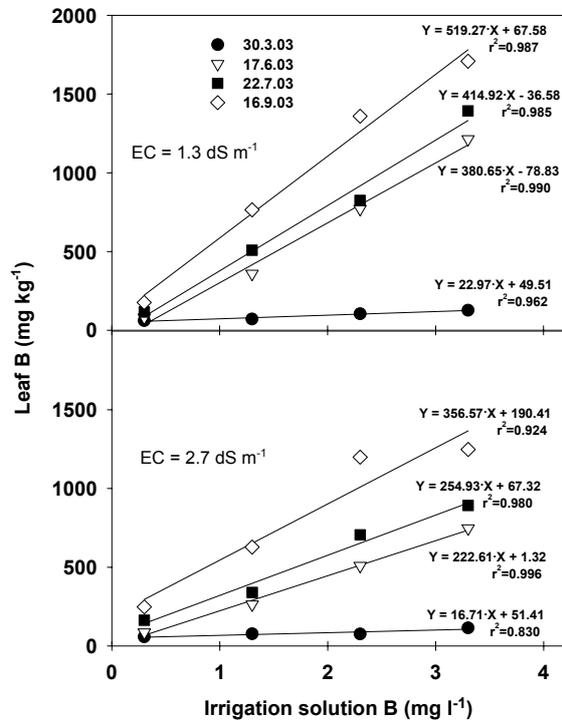


Fig. 6. Boron in grapevine diagnostic leaves as a function of B in irrigation solution for cases where irrigation water was less saline ($EC = 1.3 \text{ dS m}^{-1}$) and more saline ($EC = 2.7 \text{ dS m}^{-1}$). Lines are best fit linear regression ($P \leq 0.05$).