AGRICULTURAL WATER MANAGEMENT 95 (2008) 587–597

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

Agricultural Water Management

Effect of irrigation water salinity on transpiration and on leaching requirements: A case study for bell peppers

Alon Ben-Gal[a,*], *Eviatar Ityel*[b], *Lynn Dudley*[c], *Shabtai Cohen*[d], *Uri Yermiyahu*[e], *Eugene Presnov*[a], *Leah Zigmond*[f], *Uri Shani*[g]

[a] *Environmental Physics and Irrigation, Agricultural Research Organization, Gilat Research Center, Mobile Post Negev 85280, Israel*
[b] *Shaham-Extension Service, Ministry of Agriculture, Israel*
[c] *Department of Geological Science, Florida State University, Tallahassee, FL, United States*
[d] *Central and Northern Arava Research and Development, Hazeva, Israel*
[e] *Soil Chemistry and Plant Nutrition, Agricultural Research Organization, Gilat Research Center, Israel*
[f] *Southern Arava Research and Development, Yotvata, Israel*
[g] *Department of Soil and Water Sciences, Faculty of Agricultural, Food and Environmental Sciences, The Hebrew University of Jerusalem, Israel*

ARTICLE INFO

Article history:
Received 24 July 2007
Accepted 27 December 2007
Published on line 13 February 2008

Keywords:
Leaching fraction
Irrigation management
Evapotranspiration
Drainage
Lysimeters
Yield
Capsicum annum

ABSTRACT

Maximization of crop yields when the salinity of irrigation water is high depends on providing plant transpiration needs and evaporative losses, as well as on maintaining minimum soil solution salinity through leaching. The effect of the amount of applied irrigation water was studied regarding transpiration, yields, and leaching fractions as a function of irrigation water salinity. Bell pepper (*Capsicum annum* L. vars. Celica and 7187) in protected growing environments in the Arava Valley of Israel was used as a case study crop to analyze water quantity–salinity interactions in a series of lysimeter, field and model simulation experiments. Leaching fraction was found to be highly influenced by plant feedback, as transpiration depended on root zone salinity. Increased application of saline irrigation water led to increased transpiration and yields. The higher the salinity level, the greater the relative benefit from increased leaching. The extent of leaching needed to maximize yields when irrigating with saline water may make such practice highly unsustainable.

1. Introduction

Maximization of crop yields when salinity of irrigation water is high depends on providing plant water needs (transpiration, T) and evaporative losses, as well as on maintaining minimum soil solution salinity through leaching. Evapotranspiration (ET) requirements are often estimated by measuring or calculating potential ET (ET_p), which is a function of climate, and through the use of species dependant crop factors that consider plant size (cover) and crop physiological stage (Allen et al., 1998). Generally, salinity is not considered when calculating ET from ET_p, but it has been suggested that this could lead to overestimation of ET due to the expected salinity-caused reductions in T (Meiri et al., 1977; Letey and Dinar, 1986; Dudley et al., 2008).

Salinity causes osmotic imbalance, reduced water uptake and transpiration, and reduced yields (Bernstein, 1975). Management of saline water for irrigation is often based on application of excess water, designed to maintain minimum root zone salinity and thus minimize salinity-caused yield

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[*] *Corresponding author*. Tel.: +972 8 9928644; fax: +972 8 9926485.
E-mail address: bengal@volcani.agri.gov.il (A. Ben-Gal).

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doi:10.1016/j.agwat.2007.12.008

reduction (Ayers and Westcot, 1985). The leaching fraction (LF) is the relative volume of applied water that carries salts out of the root zone. The minimum LF that will keep the soil salinity below a required level is the leaching requirement (LR). A variety of formulations have been proposed for estimating the LR, but all are based on a functional relationship between irrigation water salinity and crop yield. The Food and Agriculture Organization of the United Nations (FAO) recommends computing LR as (Ayers and Westcot, 1985):

$$\mathrm{LR} = \frac{\mathrm{EC_{iw}}}{5\mathrm{EC_e^*} - \mathrm{EC_{iw}}} \tag{1}$$

where EC is the electrical conductivity, iw denotes irrigation water, $\mathrm{EC_e^*}$ is the EC of the soil saturated paste extract corresponding to the soil salinity tolerated by the crop. Values of $\mathrm{EC_e^*}$ used to determine LR are usually either $\mathrm{EC_e}$ of the threshold value ($\mathrm{EC_e}$-0%) – meaning 0% yield decrease due to salinity – or $\mathrm{EC_e}$-10%, reflecting a 10% yield loss. Examples of LR for bell pepper irrigation at $\mathrm{EC_e}$-0% and $\mathrm{EC_e}$-10%, calculated according to Eq. (1) and the corresponding relative water application rates ($\mathrm{I/ET_p}$) are shown for irrigation water salinities of 0.5–5.5 dS/m in Table 1. It has been suggested (Meiri and Plaut, 1985; Corwin et al., 2007; Letey and Feng, 2007; Dudley et al., 2008) that calculating LR with formulas like Eq. (1) is imprecise due to failure to consider soil type, climate, or salinity-induced reduction in plant transpiration. Such omissions could possibly result in underestimation of actual leaching and overestimation of LR.

A number of approaches based on our understanding of the response of crops to water, salt tolerance and soil processes including leaching exist that can be used to evaluate plant response to both amount of applied water and salinity. These approaches have lead to semi-empirical production functions for specific crops (Letey et al., 1985; Letey and Dinar, 1986) and to physically based conceptual models of water uptake as reviewed by Hopmans and Bristow (2002) and Feddes and Raats (2004). Such models allow consideration of environmental factors and dynamic interactions within the soil–water–plant system and enable prediction of crop response to various irrigation regimes, calculation of LFs and evaluation of LRs. Typically, the models calculate water uptake or transpiration and their reduction due to insufficient amount of soil–water and excess soil–water salinity. Examples of this approach have been recently presented in models utilizing both numerical (Dudley and Shani, 2003) and analytical (Shani et al., 2007) solutions.

Table 1 – Leaching requirement (LR) for peppers according to Food and Agriculture Organization (Ayers and Westcot, 1985)

$\mathrm{EC_{iw}}$	90% potential yield		100% potential yield	
	LR	I/Ep	LR	I/Ep
0.5	0.05	1.05	0.07	1.08
1	0.10	1.11	0.15	1.18
2	0.22	1.29	0.36	1.57
3	0.38	1.60	0.67	3.00
5.5	1	~12	2.75	~1260

Based on saturated paste solution electrical conductivity ($\mathrm{EC_e}$) threshold of 1.5 dS/m and $\mathrm{EC_e}$ causing 10% yield decrease of 2.2 dS/m. *I/Ep* is equivalent irrigation rate (irrigation relative to potential evaporation) for each LR. $\mathrm{EC_{iw}}$ is irrigation water electrical conductivity.

The analytical solution of Shani et al. (2007) predicts plant performance under varied environmental, biological (crop) and management parameters. The model assumes steady-state conditions and representative root zone values for salinity and moisture. Essentially, the model predicts the crop response to conditions of soil–water and salinity, while considering the influence of the plant itself on soil–water content and salt concentration. Water uptake by plants, water and salt leakage below the roots and yield are calculated by solving for transpiration in a single mathematical expression according to limitations imposed by root zone salinity and water status. Input variables include the quantity and salinity of applied water, plant sensitivity to salinity and water stress, $\mathrm{ET_p}$, and soil hydraulic parameters. The model has been shown to accurately predict measured results for cases where irrigation is frequent and regular. The model facilitates evaluation of the effect of irrigation water quantity on transpiration and drainage and therefore allows prediction of LFs for any irrigation water quantity–salinity combination.

We have chosen bell pepper (*Capsicum annuum* L.) growing in the Arava Valley of Israel as a model crop for studying the relationship between transpiration and water- and salt-stress. In this arid region, bell pepper is economically important as a winter crop, produced for export to European and North American markets. Due to local water scarcity, only saline groundwater with $\mathrm{EC_{iw}}$ of 2.2–3.7 dS/m is available for irrigation in the region. Protected (net house, greenhouse) peppers, grown from August to May, will typically be irrigated with 12,000–14,000 $\mathrm{m^3}$/ha of this saline water—an amount believed by growers to maximize yields.

The pepper plant has a shallow root system, which extracts 70–80% of its water from the top 0.3 m soil layer (Dimitrov and Ovtcharrova, 1995). This, together with high stomatal density, explains why pepper is regarded as relatively vulnerable to water stress. Bell pepper is considered moderately sensitive to salinity. Maas (1990) reported an $\mathrm{EC_e}$ threshold value of 1.5 dS/m, below which no effect on growth is expected, and a 14% decrease in biomass production for every additional 1 dS/m. Recent studies have reported varied responses of pepper to salinity. For greenhouse peppers thresholds ranging from 0 to 2 dS/m and slopes defining linear decrease in yield due to subsequent increase in salinity ranging from 8 to 15% have been reported (Sonneveld, 1988; Chartzoulakis and Klapaki, 2000; Navarro et al., 2002). Navarro et al. (2002) suggested that newer commercial varieties may be more sensitive to salinity than older ones. Yermiyahu et al. (2008), working with the "Celica" variety used in this study, reported 12% shoot biomass reduction for every 1 dS/m increase in $\mathrm{EC_e}$, a value similar to that reported by Maas, starting with their lowest salinity of $\mathrm{EC_e}$ = 0.8 dS/m.

The objective of the current study was to evaluate the effect of irrigation water application rates on transpiration, yields, and LFs as a function of irrigation-water salinity. The specific case study of water quantity–salinity interactions for bell