

Effects of watertable depth, irrigation water salinity, and fertilizer application on root zone salt buildup

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Patel, R.M., Prasher, S.O. and Bonnell, R.B. 2000. **Effects of watertable depth, irrigation water salinity, and fertilizer application on root zone salt buildup.** *Can. Agric. Eng.* 42:111-115. Salt buildup due to irrigation water salinity and fertilizer application was studied in field lysimeters planted with green peppers (*Capsicum annuum*). Water was applied by subirrigation, and the fertilizers were incorporated at the soil surface. Three subirrigation water salinities, 1, 5, and 9 dS/m and two watertable depths, 0.4 and 0.8 m, were used. The soil salinity was determined by first measuring the bulk soil salinity by time domain reflectometry (TDR) and then converting it to soil solution salinity (EC_{sw}). It was found that the salinity of the subirrigation water affected EC_{sw} in the upper soil profile when the watertable was maintained at 0.4 m depth. The subirrigation water also affected the lower half of the soil profile when the watertable was maintained at 0.8 m depth; however, it did not affect any salt buildup in the upper half. Also, the addition of N, P, and K fertilizers did not contribute to the salt buildup in the soil. Although watertable depth and subirrigation water salinity affected EC_{sw} , they did not affect the green pepper yield. The experiment was conducted using field lysimeters filled with a sandy soil and covered with a plastic sheet to simulate arid conditions. Therefore, caution should be exercised in extrapolating the results of this study to field conditions and other soils.

L'accumulation de sel dans le sol due à l'irrigation avec de l'eau saline et à l'utilisation de fertilisants, a été étudiée au champs dans des lysimètres où ont été semés des plants de piment vert (*Capsicum annuum*). Un système d'irrigation souterraine a été utilisé, et les fertilisants ont été incorporés à la surface du sol. Nous avons testé trois concentrations de sel (1, 5 et 9 ds/m) à deux profondeurs de la nappe phréatique (0.4 et 0.8 m). La concentration de sel dans le sol a été déterminée en mesurant sa salinité globale par reflectométrie temporelle (TDR). Cette valeur a été ensuite convertie en sel soluble présent dans le sol: EC_{sw} (salinité de la solution du sol). Les résultats obtenus, ont montré que quand la nappe phréatique est maintenue à 0.4 m, la salinité de l'eau d'irrigation affecte la EC_{sw} , uniquement à la surface du sol. Cependant, quand la nappe phréatique est maintenue à 0.8 m, toute la moitié inférieure du profil du sol est affectée alors que la moitié supérieure est épargnée. L'addition de fertilisants (N, P et K) n'a pas eu d'effet sur la salinité du sol étudié. Même si la profondeur de la nappe phréatique et la salinité de l'eau d'irrigation ont affecté la salinité du sol, ils n'ont eu aucun effet sur le rendement des plantes de piment vert. L'expérience a été conduite en utilisant des lysimètres remplis de sol sableux et couverts de plastique pour simuler des conditions de climat aride. Il faudrait donc, être prudent quant à l'extrapolation de ces résultats à d'autres conditions et à d'autres types de sols.

INTRODUCTION

Fresh water resources are limited in many regions of the world that require irrigation for crop production. Although brackish

waters may be used to supply crop water needs (Rhoades et al. 1992), salt-sensitive crops do not perform well when salinity is above a certain limit (Maas and Hoffman 1977; Grattan et al. 1987). For green peppers, the threshold salinity (salinity of saturated soil paste extract, EC_e) has been reported to be 1.5 dS/m (Maas and Hoffman 1977). Under field conditions, the electrical conductivity of soil solutions (EC_{sw}) is 2 to 4 times the EC_e (Smedema and Rycroft 1983) and so the threshold salinity in terms of soil water can be as high as 3 to 6 dS/m. In general, surface methods of irrigation can lead to a rapid increase in salt content in the upper soil profile if evaporation rates are high and the water contains dissolved salts. This is extremely deleterious to salt-sensitive crops, particularly in early stages of growth. Although surface irrigated brackish water can be alternated with fresh water after the plants reach a less sensitive growth stage (Rhoades 1984), extensive salt buildup in the upper profile must often be dealt with before the next crop is sown. In regions with high evaporation and limited fresh water, even the application of nitrogen fertilizer can increase soil solution salinity and result in salt buildup (Lunin and Gallatin 1965a; Jurinak and Wagenet 1981).

There is little quantitative information about salt buildup with subirrigation using brackish water or from the surface application of fertilizers under subirrigation. Von Hoyningen Huene (1994) suggested that subirrigation can supply brackish water for crop growth without injury to plant shoots and, possibly, with little or no soil salt buildup problems. The objectives of this study were to: determine if application of fertilizer and subirrigation with brackish water would increase soil salinity; and evaluate the effect of fertilizer and subirrigation treatments on the yield of green pepper (*Capsicum annuum*). Because green peppers are one of the world's most popular vegetables, their growth responses to increasing salinity, water level, and fertilizer applications were also studied.

MATERIALS and METHODS

Field lysimeters

Seventy-two field lysimeters located at Macdonald Campus of McGill University, Quebec, were used in this experiment. The lysimeters were constructed from 12.5 mm thick, 1.0 m long polyvinyl chloride (PVC) pipe with an inside diameter of 0.45 m. A 10 mm thick, 0.6 m x 0.6 m PVC sheet was welded

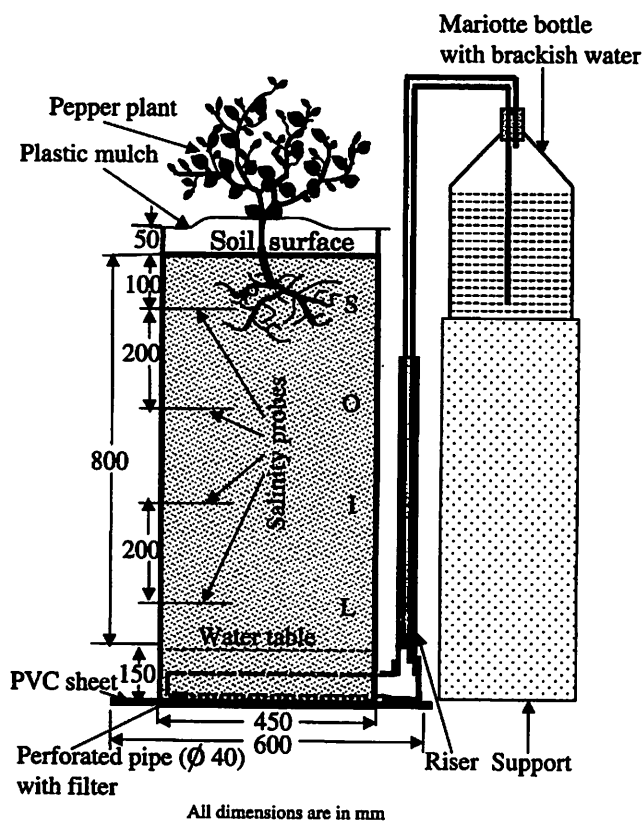


Fig. 1. Schematic of lysimeter and subirrigation system.

over one end of the pipe. A 40 mm diameter perforated PVC pipe was welded inside the lysimeter across the bottom to supply subirrigation water. A fabric filter was wrapped around the supply pipe to prevent soil particles from blocking the system. The supply pipe was connected to a riser pipe of equal diameter on the outside of the lysimeter, through which water was supplied. A Mariotte bottle was used to maintain the desired watertable depth. The lysimeters were kept above ground to facilitate measurement of salinity (Fig. 1).

The lysimeters were filled with sand-textured soil of the St. Amable complex found on Macdonald Campus of McGill University. The St. Amable complex has deep sandy deposits overlying a clay layer (Lajoie 1960). The upper 0.6 m sand layer was used and consisted of 91.2% sand, 4.2% silt, 1.1% clay, and 3.5% organic matter and had a bulk density of 1.4 Mg/m³.

The soil was uniformly mixed before filling the lysimeters. It was weighed and packed into the lysimeters in layers that were 0.1 m thick. Bulk density was maintained at 1.4 Mg/m³ by using the same mass of soil for each 0.1 m soil layer. The upper surface of each layer was scratched before packing another layer to ensure good contact between layers.

Experimental procedure and salinity measurement

The 72 lysimeters were laid out on the north-south axis in 6 rows of 12 lysimeters each. There were 24 treatments, comprised of two watertable depths (0.4 and 0.8 m from the soil surface), three irrigation water salinities (EC_{iw} of 1, 5, and 9 dS/m) and four types of fertilizer applications. Naturally saline well water was used for subirrigation. The chemistry of the water was: total dissolved solids 12,713 mg/L, sodium 4100

mg/L, calcium 375 mg/L, magnesium 307 mg/L, chlorides 6548 mg/L, and carbonates 457 mg/L (the major ions were Na⁺ and Cl⁻). The saline water was diluted using tap water to obtain the desired salinity levels for subirrigation. The fertilizer applications were: KP, N1K, N1PK and N2PK, where K=230 kg K/ha at planting, P=200 kg P/ha at planting, N1=35 kg N/ha at planting and 35 kg N/ha at flowering, N2=70 kg N/ha at planting and 70 kg N/ha at flowering stage. The fertilizers were applied as solids in the form of ammonium nitrate (N), triple super phosphate (P), and muriate of potash (K). The fertilizer per plant (one plant/lysimeter) was calculated on the basis of 24,691 plants/ha (0.9 m x 0.45 m plant spacing). Each treatment was randomly assigned to the 72 lysimeters, giving three replicates per treatment.

Green pepper (*Capsicum annum* cv. BellBoy) seedlings were planted in plastic pots (0.1 m diameter and 0.1 m deep) on June 18. Water was sprinkled every third day until one plant was transferred to each lysimeter on July 15, at which time one liter of water was applied to each lysimeter. Thereafter, 1.5 liters of water, divided in five equal volumes, was applied every third day to each plant. The basal fertilizer was applied in the lysimeters on July 14. Subirrigation with brackish water began on August 3. The fertilizer for the flowering stage was applied on August 12.

There were 74.8, 94.6, 57.2, and 119.2 mm of rainfall in June, July, August, and September, respectively. However, each lysimeter was covered with plastic to keep out rain and simulate arid conditions, and no surface irrigation water was applied in the lysimeters. The green pepper plant in each lysimeter grew through a small cut in the plastic cover. Some evaporation from the soil surface could have occurred through this slit and around the edge of the cover, because its circumference was fixed to the lysimeter only at five places using small pieces of duct tape. The monthly means of daily average temperatures were 17.2, 21.0, 20.1, and 13.9°C in June, July, August, and September, respectively.

The bulk soil salinity (EC_a) and water content (θ) were measured at weekly intervals at different depths with the time domain reflectometry (TDR) method, using a Tektronix 1502B cable tester. The salinity probes were inserted horizontally at 0.1 and 0.3 m depths from the soil surface in those lysimeters within which the watertable (WT) was held at a 0.4 m-depth. In the lysimeters wherein the watertables were maintained at a 0.8 m-depth, the salinity probes were at 0.1, 0.3, 0.5, and 0.7 m below the soil surfaces. For converting EC_a to EC_{sw} , the TDR was calibrated. First, the surface conductance (EC_s) of the soil was determined in the laboratory, and it was found to be negligible. Next, ceramic cups were inserted at the same depths at which the TDR probes were inserted (0.1, 0.3, 0.5, and 0.7 m). The lysimeters were then flushed with water having salinity levels of 1, 3, 5, 7, and 9 dS/m. Soil water was extracted by applying vacuum to the ceramic cups, and EC_{sw} was determined for each depth. At the same time, EC_a and θ were determined with TDR. The transmission coefficient (τ) values were determined by dividing EC_a by $EC_{sw} * \theta$ from which the relationship between τ and θ was derived:

$$\tau = 0.0575 + 0.9519\theta \quad (1)$$

The soil solution salinity (EC_{sw}) was calculated from bulk soil salinity by using (Rhoades et al. 1976):

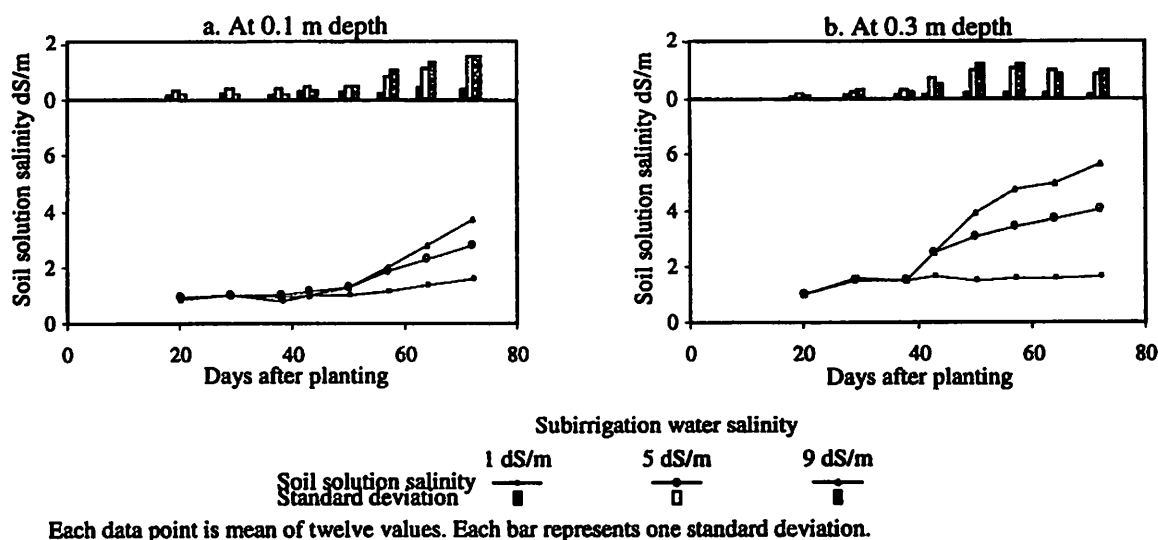


Fig. 2. Soil solution salinity at different depths in the lysimeters under 0.4 m watertable.

$$EC_{sw} = \frac{EC_a - EC_s}{\theta \tau} \quad (2)$$

where:

- EC_{sw} = soil solution salinity (dS/m),
- EC_a = bulk soil salinity (dS/m),
- EC_s = surface conductance (dS/m),
- θ = volumetric moisture content, and
- τ = transmission coefficient.

By substituting Eq. 1 for τ , Eq. 2 was rewritten as:

$$EC_{sw} = \frac{EC_a}{0.0575\theta + 0.9519\theta^2} \quad (3)$$

The EC_{sw} at 0.1 and 0.3 m depths (D), which were common to both watertable treatments, were analyzed with repeated measures using SAS Version 6.12 for Windows (SAS Institute 1996) to determine salt buildup over time in the soil profile.

Table I. Repeated measures ANOVA of watertable depth, subirrigation, water salinity, measurement depth, time, and interaction effects on soil solution salinity.

Source		Source	
WT	**	T	**
IR	**	TxWT	**
WTxIR	**	TxIR	**
D	**	TxWTxIR	**
DxWT	**	DxT	**
DxIR	**	DxTxWT	**
DxWTxIR	**	DxTxIR	**
		DxTxWTxIR	**

WT: watertable depth; IR: salinity levels of subirrigation water;
D: salinity measurement depths; T: time of salinity measurement
** significant at $P < 0.01$

Whenever the green peppers were ready to harvest, the fruits were handpicked and weighed. At the end of the season, the total mass of green pepper harvested per plant was calculated. Also, at the end of the season, the plants were cut and their fresh masses were recorded. The total of green pepper mass harvested per plant and the shoot masses were analyzed with the General Linear Model (GLM) using SAS.

RESULTS and DISCUSSION

Analysis of EC_{sw} data

The electrical conductivity of the soil water (EC_{sw}), derived from time domain reflectometry measurements (EC_a), was determined eight times (T), after the initiation of subirrigation. In the first step of a repeated measures ANOVA analysis of these data, it was found that the fertilizers did not influence the EC_{sw} . This may have been due to the low doses of applied N, most of which was likely taken up by the plants. Since fertilizer and its interactions with the other factors (WT, EC_{iw} , D, T) were not significant, an ANOVA analysis was run that did not consider fertilizer in the statistical model (Table I). It is evident from the Table I that EC_{sw} values in space and time are dependent on watertable depth and subirrigation water salinity.

The EC_{sw} data from the lysimeters with the watertable held at 0.4 m are plotted in Fig. 2a-b, while those from lysimeters with a 0.8 m watertable are shown in Fig. 3a-d. The effect of irrigation water salinity at a given depth is understood to be indicated by the separation of the EC_{sw} curves (Figs. 2a-b and 3c-d). When the curves are concurrent, there is no measurable difference due to the irrigation water salinity. Separation of the curves tends to increase with time and depth. This indicates that the saline front is mixing with the initial fresh water, first at lower depths and, subsequently, at higher depths in the profile. Thus, at the initial stage of mixing of the saline irrigation water with the original soil water, the increase in EC_{sw} caused by the 9 dS/m irrigation water is not distinguishable from that caused by the waters of lower salinity.

With time, the original fresh water continues to be removed by evapotranspiration from the top of the lysimeter, the dilution effect diminishes, and the soil solution salinity (EC_{sw}) tends to

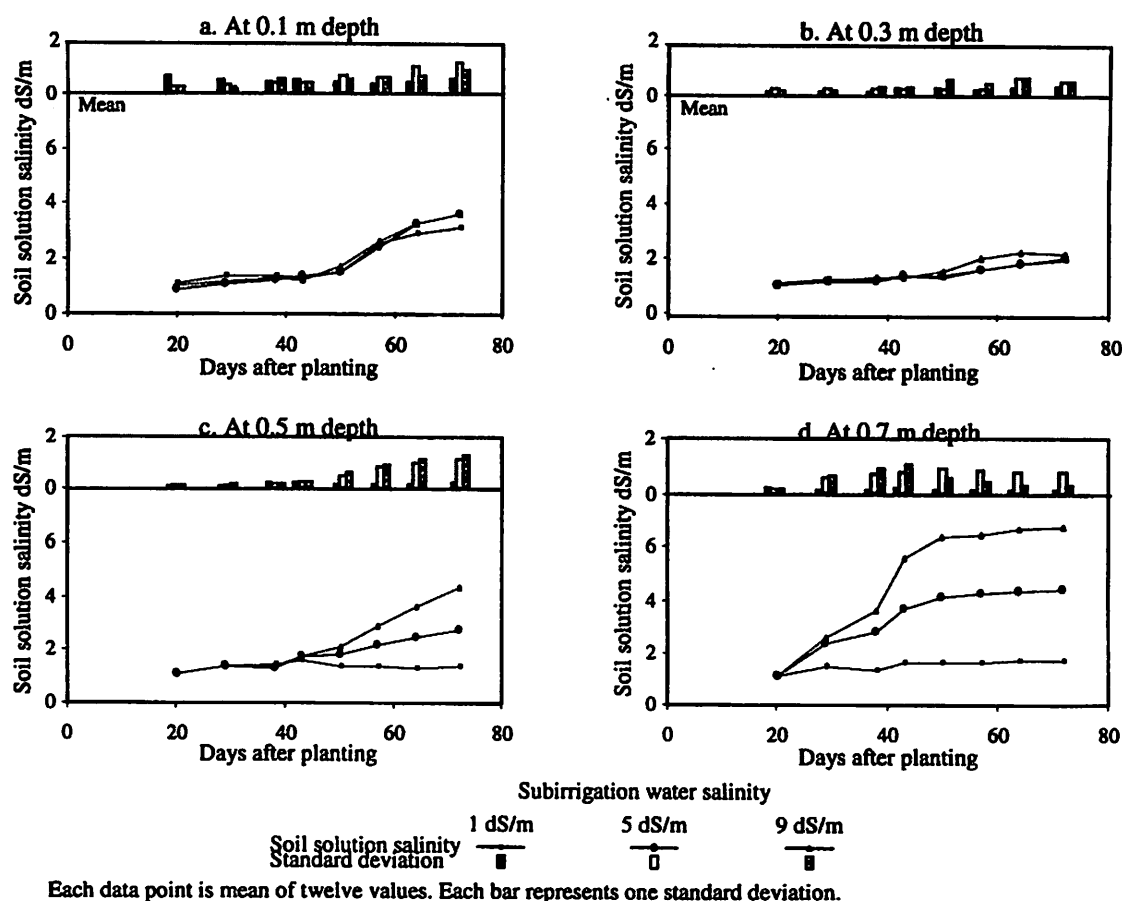


Fig. 3. Soil solution salinity at different depths in the lysimeters under 0.8 m watertable.

increase. In such a process, one would expect the separation of curves to occur first at the measurement depths closest to the watertable depth. This is corroborated by the series of figures presented (Figs. 2a-b, 3a-d).

It is interesting to note the time at which the salinity increased at different depths in the profile; this can have a direct impact on plant growth. Figures 2a and 3a show that the upper root system was not affected by the salinity of the irrigation water until about 19 days or longer after the start of subirrigation. In practice, this would give salt-sensitive crops an excellent head start, particularly if they are transplanted rather than direct-seeded. One might also expect that crops with shallow root systems will perform better when subirrigated with brackish water than when surface irrigated with water of the same salinity.

There are several arid and semiarid regions in the world where there are shortages of fresh water and where ground water is shallow and saline. In such areas, fresh water may be available in very limited quantities or be obtainable only during a certain time of the year, e.g., during the monsoons. Not only can this fresh water be used to flush out accumulated salts in the root zone, but it can effectively be stored as soil moisture for crops in dry periods; as the stored fresh water becomes depleted, subirrigation with brackish water can bring the crops to maturity.

The experiment was conducted in sandy soil, and the effect of subirrigation with brackish water may differ in other soils,

given different physio-chemical properties. Arid conditions were simulated by covering the soil surface with plastic. The plastic cover was not an airtight lid and the atmospheric air circulation over the lysimeter soil surface took place. Therefore, some evaporation from the soil surface would have occurred. Under field conditions, values of the ambient variables can vary considerably, but we believe that the general trend of salt buildup observed in the experiment would be similar to what might be expected to occur under field conditions. Moreover, standard deviation also increased with time, as shown in Figs. 2 and 3, which may also indicate some intrusion of saline water into the crop root zone with subirrigation.

Green pepper yield

There was a significant difference in the yield of green peppers between the PK fertilizer treatment, and the N1PK and N2PK treatments; but, the yields for the N1K, N1PK, and N2PK treatments were not significantly different (Table II). The yield was highest for the lysimeters supplied with all three nutrients (Table II). Lunin and Gallatin (1965b) found that yield decreased due to an increase in salinity from the fertilizer, but Gerg et al. (1993) reported that such was not always true. Data from our experiment suggest that salinity from the fertilizer did not reduce the yield of green peppers. It is to note that threshold EC_{sw} for green pepper is about 4.5 dS/m, a figure obtained by multiplying the threshold EC_e of 1.5 dS/m (Maas and Hoffman 1977) by 3, as suggested by Smedema and Rycroft (1983). It is evident that EC_{sw} in the upper portion of the root zone is below

Table II. Wet masses for green peppers and plant shoots, mean and standard deviation.

Variable	Peppers (g/plant)	Shoots (g/plant)
Watertable depth (m)		
0.4	494±35a	468±23a
0.8	450±30a	452±19a
Salinity level of subirrigation water (dS/m)		
1	515±41a	475±30a
5	429±42a	462±28a
9	473±43a	443±25a
Fertilizers		
PK	367±32b	380±23b
N1K	441±43a,b	416±29b
N1PK	570±41a	504±25a
N2PK	510±63a	539±34a
Average mass	472	460

K: 230 kg K/ha; P: 200 kg P/ha; N1: 35 kg N/ha when planting and 35 kg N/ha when flowering; N2: 70 kg N/ha when planting and 70 kg N/ha when flowering

Mean masses with same letters under watertable depth, salinity level of subirrigation water, and fertilizers are not significantly different ($P < 0.05$).

this limit (Figs. 2a-b, 3a-b). This might explain why there was no detectable effect on yield due to salinity of irrigation water, while the yield was fertilizer dependent (Table II).

CONCLUSIONS

This study indicated that the salt buildup in the soil profile occurred from the bottom upwards when brackish water was used to subirrigate green peppers plants that were initially raised in pots with non-saline water. The resulting dynamics of salt buildup in a sandy soil permitted early plant development without hindrance to the activity of the upper root system. The results indicated that, under the conditions of this experiment, water with a salinity as high as 9 dS/m had been used for subirrigation for up to three weeks before the upper root zone (0-0.3 m) was influenced, even when the watertable depth was as shallow as 0.4 m. However, the higher the salinity of the irrigation water, the higher would be the residual salinity at the end of the growing season. Soil flushing with suitable water would be needed in such cases to prevent salt accumulation. If fresh water is available during other periods in the year, one could use it for flushing the salts. It could also be noted that if the soil salinity is very high at the end of the cropping season, one could use slightly brackish water (as an alternative to fresh water) to flush out the excessive salts present in the soil.

The significance of this work is that supplemental subirrigation of sandy soils in arid regions may be possible using brackish waters to produce green peppers and perhaps other salt-sensitive crops. Field experiments in arid conditions could establish the wider applicability of this method. Further, work can be oriented towards developing a model of salt buildup in subirrigated soil which, when appropriately

combined with crop growth and climatic models, could be used to plan crop production in arid and semi-arid regions where fresh water supplies are limited.

ACKNOWLEDGMENTS

The authors thank NSERC for providing financial support for this project.

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