Water and Nutrient Uptake of Sweet Pepper and Tomato as (un) Affected by Watering Regime and Salinity

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Abstract

Scarcity or poor quality of irrigation water is increasingly becoming the "way of life" for growers in many mild climate regions. Water can be saved by two means: watering as little as possible (limit losses through drainage) or abundant watering with recollection and re-use of drainage (closed systems). Either way, an additional positive side effect is the reduction in pollution caused by percolation of fertilisers. However, both growing systems have risks: limited watering results in higher concentration of salts in the root zone, and all unused ions accumulate in closed systems. Since it is well known that increased salinity reduces yield (though it may increase product quality), growers are not keen to embrace such water-saving techniques. The objectives of this work were to investigate whether good-quality water can be saved by reducing drainage in open systems; and whether brackish water can be used in closed ones. We present the results of two concurrent experiments: one with drain-less watering in sweet pepper and one with (semi)closed water cycle in tomato. The sweet pepper experiment was designed to allow for limited watering (with good-quality water) without increase in salt concentration, and we show that the ability of plants to absorb water and to take up nutrients is independent of the watering regime (provided there is enough water in the root zone). The tomato experiment, on the contrary, allowed for salinity build-up by using brackish water in a closed system and we show that water and nutrients uptake is largely unaffected by salt accumulation (within boundaries), though there is a reduction in fresh yield, as expected.

INTRODUCTION

The response of yields to both water availability and to water salinity in the root zone, is the well-known law of diminishing returns. That is, there is a "saturation level", above which there is little advantage of increasing either watering or water quality. The exact shape of the yield response curve (to both water quantity and quality) of a particular crop depends on various factors, such as weather conditions and soil type as well as agricultural inputs such as labour, capital, fertilisers, pesticides. However, since overabundant water, short of water logging, usually does not cause harm, growers tend to "play safe" and irrigate abundantly, especially when associated costs are low.

However, good-quality irrigation water is becoming scarce, expensive or both, in many mild-winter climate regions. Reducing the amount of irrigation water results very often in an accumulation of salts in the root-zone, which causes yields to decrease. Another water-saving technique is closed-loop-growing systems. When available re-fill water is of poor quality (which is often the case) unused salts accumulate in the loop, which can result in yield loss.We investigated the management of greenhouse crops in these two cases: 1. traditional and drain-less irrigation in sweet pepper grown in rockwool

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and 2. closed-loop tomato with either good or brackish re-fill water.

MATERIALS AND METHODS

Both experiments were done in Wageningen, Holland, in 2001, in Venlo-type glasshouse compartments.

Sweet Pepper Experiment

Sweet pepper cv Spirit were transplanted (density 4.1 m^{-2}) at the beginning of January. Treatments began at the beginning of March and the experiment lasted until September 30, 2001. The control treatment was watered in a traditional fashion (resulting drainage fraction about 50%), whereas irrigation in the drain-less treatment aimed at maintaining volumetric water content in the rockwool at 50% (that we had determined as a level where virtually no drainage takes place). The control was based on an on-line sensor initially developed by IMAG (Hilhorst, 1998), and now commercially available. A built-in EC sensor was used to control salinity in the substrate. Whenever EC exceeded 3 dS/m, irrigation was drawn from a nutrient solution of 1 dS/m, as soon as EC dropped below 2.8 dS/m, then irrigation was with the “standard” solution of 3 dS/m. The same procedure applied also to the control treatment. We measured water gift, we knew the tank whence it came, and EC of both was measured daily. Amount and EC of drainage were determined both by tipping-buckets on 6-plant sections of a row (two per treatment) and by measuring flow pumped out an underground re-collection tank. Water uptake was determined as the difference between the two.

Daily compound nutrient uptake was determined as the difference between the sum of the products of the gift fluxes and the corresponding EC and the sum of the products of the drain events and the corresponding EC.

Plant growth and leaf area were determined by destructive measurements and yield was monitored. Table 1 gives the mean values over the treatment period of the controlled parameters, and the total water balance. Leaf Area Index (LAI) is reported for reference for the transpiration flux.

Tomato Experiment

Round tomato cv Aromata were transplanted (density 2.5 m^{-2}) at the end of March, on closed-cycle rockwool slabs. Treatments began at mid-May and the experiment lasted until August 28, 2001. The control treatment was refilled with water containing 0.8 $mmol \cdot l^{-1}$ Na. Irrigation water was automatically brought up (when necessary) to an EC of 3.5 dS/m by injection of concentrated nutrient solutions (A & B system). The other treatment simulated a water source containing 12 $mmol \cdot l^{-1}$ Na, used to refill a basic solution of 1.6 dS/m. No EC control took place at water gift and whenever (manually-measured) EC in the slabs exceeded 9 dS/m, the mixing tank was emptied and the slabs were drained. The evolution of EC in the substrate is shown in Fig. 1 for both treatments.

Water gift was over-abundant in order to prevent salt accumulation in the substrate and was measured. Amount and EC of drain was determined both by tipping-buckets on 8-plant sections of a row (two per treatment) and by measuring flow pumped out the two underground re-collection tanks. Water uptake was determined as the difference between the two. The amount of water flushed each time out of the system was recorded as well.

Plant growth and leaf area were determined by destructive measurements and yield was monitored. Table 2 gives the mean values over the treatment period of the controlled parameters, and the total water balance.

The uptake concentration of each macro-nutrient for the good-water tomato treatment was determined from the fertilisers supply and water uptake over the whole period. For the other treatment it has been determined for each nutrient and each period between two flushing events through the following equation:

$$C_{uptake} = C_{irrigation} - \left(C_{substrate,\,final} - C_{substrate,initial}\right)V / W_{uptake}$$

where C indicates concentration (mmol/l); V is the specific volume of water in the system (l/plant) and W_{uptake} is the volume of water (l/plant) taken up in the time interval.

RESULTS AND DISCUSSION

Compound nutrient uptake (cumulated over 5-day periods) in the two sweet-pepper treatments is shown in Fig. 2. There is obviously much spreading among the points, which is difficult to avoid in such “commercial scale” experiments. The main result is that the two best-fit lines are overlapping, what implies that statistically the two data sets are equal. This means that plants have taken up nutrients at the same rate, and the larger nutrient supply in the control treatment (refer to Table 1) has been wasted. This is confirmed by the fact that there is no relevant difference in water uptake, nor fresh weight. This may be explained by the hydraulic properties of rockwool (Da Silva et al., 1995) that display a virtually flat trend in pressure head for volumetric water contents in the range from 50 to 80%. It may be relevant to observe that also dry matter production content was found to be unaffected by watering (in this range) in a similar experiment the year before (Bonasia et al., 2001).

Ignoring the large spreading of the points in Fig. 2, it may be interesting to observe that the best-fit lines imply the following trend for the compound nutrient uptake concentration (dS/m):

$$C_{uptake} = 1.8 - 0.4W_{uptake}$$

with W_{uptake} in·l/(plant·day. It is indeed well-known in practice that at high transpiration rates, relatively more water is taken up than nutrients.

The uptake concentration of each macro-nutrient for both tomato treatments is shown in Fig. 3. It is important to observe that, despite the inherent inaccuracy of experiments at this scale, the values we have determined are very similar for the two treatments and to the values found in Sonneveld (2000) for Dutch greenhouse conditions.

With respect to the uptake rate of sodium, Malorgio et al. (2001) found that:

a. uptake of sodium by tomato is nearly proportional to the sodium concentration in the nutrient solution and
b. uptake concentration is higher in substrate than in NFT technique, at a given concentration in the irrigation water.

We think this could explain why we determined a $C_{\mathrm{uptake},\ Na}$ about 8, whereas Malorgio et al. (2001) determined it to be 10 in substrate and 7 in NFT (at a concentration of 12 mmol/l, such as we had). They do not give the drainage fraction they have applied to their substrate experiment, but it is unlikely to have been as high as ours (66%, see table 2). Kempkes and Stanghellini (2002) have shown that EC in the substrate is significantly reduced by increasing the drainage fraction, so that we can confidently state that our results are consistent with those of Malorgio et al. (2001), considering that our substrate management was quite similar to an NFT system.

Another relevant result is that there seems to be no difference (with respect to yield) between fluctuating and steady EC. The yield loss that we have had (see Table 2) is what could be expected on the basis of the results by Cariglia and Stanghellini (2001) in view of the average EC in Table 2. Similarly, the reduction in transpiration is proportional in both experiments to the reduction in leaf area (Table 1 & 2), which indicates that there is no stomatal effect of either treatment, as pointed out by Eheret and Ho (1986) and observed by Li and Stanghellini (2001) for tomato under saline treatments. What seems to be confirmed is that accumulation of salts brings about a reduction in water uptake and fixation in biomass that is proportional to the average increase in osmotic potential in the root environment. The fact that nutrient uptake is not very different at the two salinity levels (Fig. 3) is consistent with the findings of Li et al. (2001), who have shown that there is no effect on dry matter fixation and yield, at least in the range of osmotic potentials considered here.

CONCLUSIONS

Good quality water can be saved in open systems, and bad quality water can be used in closed loops. However, in both cases a very good management is required to limit salt accumulation. There will be (fresh) yield loss proportional to the average level of salts in the system.

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Tables

Table 1. Mean EC, both of irrigation water and in the slabs and drain. Soil volumetric water content (mean values over the treatment period). Total water fluxes and fresh weight.

Sweet pepper	Drain	Drain-less	% of control
Mean EC irrigation dS/m	2.37	1.51	64
Mean EC slab & drain dS/m	2.9	2.9	100
Volumetric water content %	63	49	78
Water gift l/plant	344.6	157.1	46
Water uptake l/plant	143.1	138.6	97
Transpiration l/plant	136.6	132.2	97
Mean LAI	4.9	4.7	96
Biomass (no roots) kg/plant	6.5	6.4	98
Yield kg/plant	4.2	4.2	100

Table 2. EC of irrigation water and in the slabs and drain (mean values over the treatment period); total water fluxes and fresh weight. LAI is shown for reference.

Round tomato	Re-fill good	Re-fill brackish	% of control
Mean EC irrigation dS/m	3.8	6.9	182
Mean EC slab & drain dS/m	4.4	7.6	173
Water gift l/plant	463	463	100
Water use l/plant	152	153	101
Flushed l/plant	6.2	27.1	437
Water uptake l/plant	145.8	125.9	86
Transpiration l/plant	136.4	118.1	87
Mean LAI	2.1	1.8	86
Biomass (no roots) kg/plant	9.4	7.8	83
Yield kg/plant	7.8	6.5	83

Figures

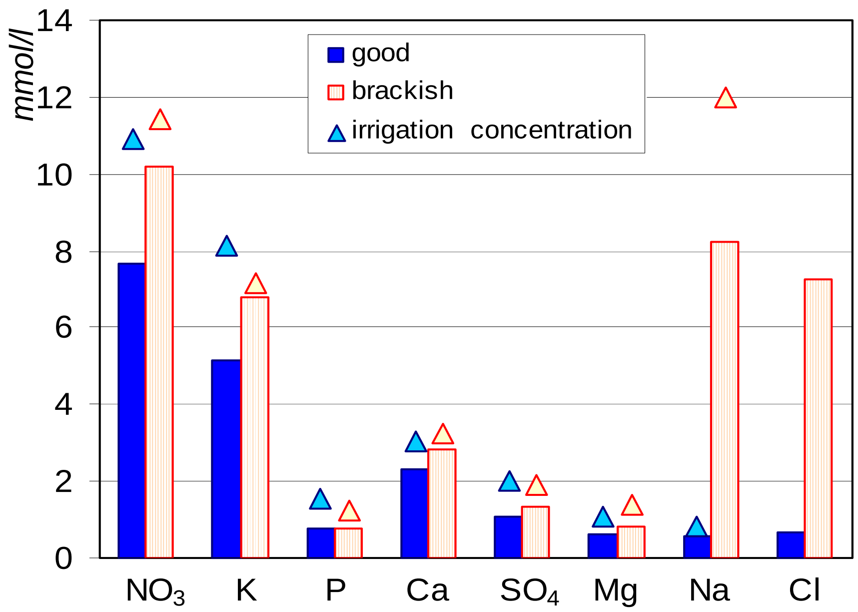

Fig. 1. Evolution of EC in the slabs for the two treatments.The one re-filled with brackish water was flushed anytime EC exceeded 9 dS/m.

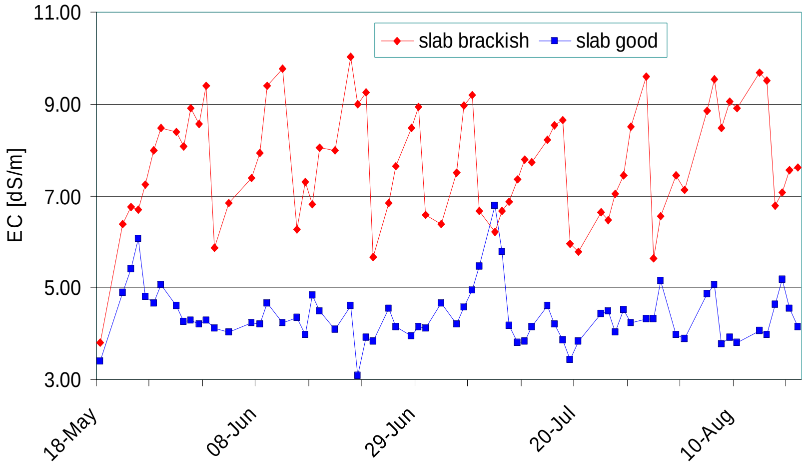

Fig. 2. Total nutrient uptake (sweet pepper)for each 5-day period vs the water taken up in the same period.The best–fit lines (nearly overlapping) show that there is no significant difference between uptake in the two treatments

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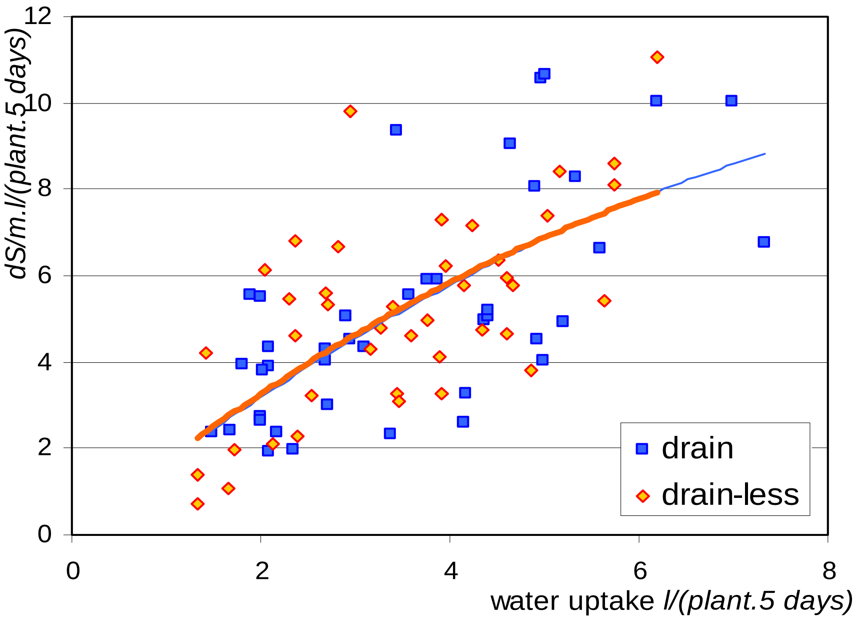

Fig. 3. Mean uptake concentration of each macro-nutrient for the two tomato treatments (bars). The triangles show the corresponding average concentration of the irrigation water.