Modelling Salt Accumulation in a Closed System: a Tool for Management with Irrigation Water of Poor Quality

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Abstract

The most obvious way to save water under scarcity is to re-collect and re-use drain water, in what are called "closed growing systems". In practice, accumulation of salts in the cycle requires such systems to be flushed from time to time, with consequent waste of water and fertilisers, often ending up in polluting percolation. The rate of salt accumulation depends on many factors, the most obvious being the quality of the water used to re-fill the system. Other relevant factors are the uptake of minerals by the crop and the relative size of water fluxes (transpiration, irrigation) and buffers (substrate, tanks) in the system We have built a model of salt evolution in a closed system depending on these factors. The model has been validated in an experiment with tomato. We show that the model can predict rather well the evolution of most important minerals in the system, when some critical processes are well described. Thereafter we use a couple of examples to show how such a model can be used for determining the best management strategies under various external conditions. We conclude that while it is true that management under scarcity requires more skills than are now common among growers in arid regions, tools can be developed that could warrant economic viability of protected cultivation also in the regions where sustainability is presently in doubt.

INTRODUCTION

Water resources in the Mediterranean basin are being depleted at a rate that is not sustainable. In many horticultural areas the only water that is plentiful is the brackish water drawn from ground wells affected by seawater intrusion. Water of good quality is either scarce or expensive (or both).

The most obvious way to save water under scarcity is to re-collect and re-use drain water, in what are called "closed growing systems". In practice, accumulation of salts in the cycle requires such systems to be flushed from time to time, with consequent waste of water and fertilisers, often ending up in polluting percolation. The rate of salt accumulation depends on many factors. We describe A model of salt evolution in a closed system depending on these factors. The model can be used for determining the best management strategies under various external conditions as use of various water (quality) sources and the consequences of yield on changing the maximum level of EC in the system.

MATERIALS AND METHODS

The Model

A growing system can be represented by several storage volumes, each with associated properties. The properties of a volume depend on its kind, its capacity and the flow in and out of it. Fresh water is added at one point, whereas outflow can be both uptake by the crop and possibly discharge out of the system. In figure 1 the main volumes and flows of the model are presented. There can be several water sources, such as a basin, well, tap and ditch water. Each source has a capacity, a maximum flow and a quality. The quality of the resources is represented by the ion-concentration from which the EC is determined. The flow from the resources and the drain are combined in the mixing tank.

At an irrigation event, a flow is withdrawn from the mixing tank. The EC of this supply water is controlled and if the EC is below the set point, fertilizers are added (from concentrated solutions in tanks A and B). Usually the pH is controlled and regulated afterwards.

For a good prediction of the salt accumulation in the system, the uptake of ions by the crop must be known. Literature tells that uptake is in some cases driven by transpiration, and in other by assimilation. There is evidence (Malorgio et al., 2001) that uptake of “non useful” ions (such as Na and Cl) may be proportional to their concentration in the root environment.

The model calculates transpiration and assimilation through two subroutines developed respectively by Stanghellini (1987) and Gijzen (1992), the latter based on the photosynthesis model of Farquhar and von Caemmerer (1982). Both subroutines require indoor climate to be known. Further, the user is required to give in the “crop sheet” the proportionality factor for uptake of the main nutrients and the process to which uptake is proportional. Such factors can be found for some crops in the literature (Sonneveld 2000).

The main farm-specific internal model data are:
- Area of protected cultivation [m^2]
- Capacity drain water tank [m^3]
- Capacity basin (rain water) [m^3]
- Maximum capacity well [$m^3.h^{-1}$]
- Maximum capacity ditch [$m^3.h^{-1}$]
- Maximum capacity tap [$m^3.h^{-1}$]
- Capacity disinfection and desalinization equipment [$m^3.h^{-1}$].

As an example of the working of the model, we work out the substrate here in more detail. The substrate is modelled as an object with a fixed maximum water retention capacity and an actual capacity ($l.m^{-2}$). The maximum capacity is calculated by multiplying the substrate volume with the retention capacity of this type of substrate. For rockwool slabs for instance, this is about 80 %. The actual water capacity of the substrate varies because there is an unbalanced supply and drainage. Each hour the water and ion balance of the substrate is updated. The supply of water and ions consists of supply water out of the mixing tank (via the dose unit). The depletion is the sum of the water and nutrient uptake by the crop and the drain flow out of the substrate. This drain flow happens only when the maximum capacity of the substrate is exceeded. The drain volume is then equal to the excedence volume. The water balance of the substrate can be calculated by:

$$Cap_{new} = Cap_{old} + \Phi_{supply} - \Phi_{uptake} \quad (1)$$

If the new actual capacity exceeds the maximum capacity, a drain flow is calculated by:

$$\Phi_{drain} = Cap_{new} - Cap_{max} \quad (2)$$

The concentration of n ions in the substrate (IC) is given by a vector of n elements. The ion balance of the substrate can be calculated by:

$$Ion_{in} = \Phi_{supply} \times IC_{supply} \quad (3)$$

$$Ion_{out} = Ion_{uptake} + \Phi_{drain} \times IC_{drain} \quad (4)$$

Out 3 and 4 follows

$$IC_{new} = (IC_{old} + Ion_{in} - Ion_{out}) / Cap_{new} \quad (5)$$

Water and Nutrient Uptake By the Crop

The model calculates a desired water and nutrient uptake and a resulting water and nutrient uptake. It is possible that the resulting uptake is smaller than the desired uptake when the actual substrate capacity (water and or ion concentration) is smaller than the calculated uptake. The desired water uptake is related to the transpiration. The transpiration is calculated as function of the climate inside. The desired ion uptake can per ion be related to the transpiration or to the photosynthesis.

Corrections on the Default Nutrient Solution

In practice each 2 weeks a sample of the nutrient solution in the substrate (root extract) is taken. This sample is analysed on EC and IC. When the concentration of certain ions reaches a minimum or maximum value the recipe of the nutrient solution is adapted while the EC of the nutrient solution is maintained. Kreij (1999) gives limit values of concentrations of the main and spore elements and adjustments for the recipes. The model can optional (automatic or by hand) make corrections to the recipe. The automatic calculation is made by the formulas of Sonneveld and Spaans (1989).

RESULTS AND DISCUSSION

Model Validation

The model has been validated in an experiment with tomato, where the degree of “closeness” of such a system was determined in two cases: one with good water quality of re-fill water (NaCl < 1 mmol/l) and another with water containing 12 mmol/l NaCl. We show that the model can predict rather well the evolution of most important minerals in the system (Figure 2) for the main ions: S, Ca, Mg, N, K and P, by comparing calculations with two-weekly analyses of root extract. Although the recipe of the nutrient solution each two weeks changed (depended on the analysis results), for the most elements the trend and level of the ion concentration is predicted rather well. The Ion uptake in this case is transpiration related for all ions. The used uptake concentrations are the same as presented by Sonneveld (2000), with only minor changes (<10%).

Remarkable is the trend in concentration in the experiment of potassium and phosphorus. Both show great fluctuations during the experiment in concentration level, while the model can’t predict well the trend in those concentrations. It is well possible that the uptake for those elements should be related to the assimilation instead of transpiration.

Case Studies

The drain fraction has influence on the distribution of salts and possible accumulation in the substrate. In this case, the drain fraction is changed between 33% (advised as minimum in closed systems) and 66% overall drain fraction in the experiment. In figure 3, the EC in the substrate and in the mixing-tank for four drain fractions, are presented. In general, if the drain fraction increase, the EC in the drain tank is closer to the set point (3.5 in this case). As a consequence of this, less nutrients are added in the system. An increase of drain fraction results in a higher EC level in the substrate, which means more fertiliser input into the system. When the drain fraction increases, the system is mixed up better.

There can be several water sources. In the previous case, the refill water was rainwater with Na levels of about zero. In this case we assume the refill water has 20 $mMol.l^{-1}$ Na, and we analyse three different strategies.

The set-point EC of irrigation is fixed beforehand on a level of 3.5 $dS.m^{-1}$.

The set-point irrigation is steadily above the EC in the mixing tank with a offset of 0.5 $dS.m^{-1}$.

The set-point irrigation is fixed and 50 % of the system volume is refreshed by 50% whenever the Na level in the substrate reach a pre-fixed level of 40 $mMol.l^{-1}$.

In figure 4 the EC level in the substrate as a result of those three strategies and a standard with good refill water (≈ 0 Na) are shown.

Figure 5 shows the Na concentration in the substrate as a result of the three strategies and the standard. The strategy with the variable EC set point and the fixed set point gives the same Na concentration in the substrate. This agrees with the expectations because in both treatments the system is refilled with the same amount of water (transpiration is the same). The standard (rain water as refill) shows even a small decrease of Na. Figure 5 shows that the Na level can be somehow regulated at a certain level in the fixed EC and dump strategy. In Figure 6 we show the NO_3 concentration in the substrate. It is clear that the strategy with the fixed set point leads to a fast depletion of the NO_3 concentration in the substrate. The strategy with the variable EC set point gives a concentration level near to the standard, but as in figure 5 shown a (too) high Na concentration in the slab. The strategy with the dump (flush) of water out of the system at a certain threshold gives NO_3 concentrations that stay nearly between the borders of too high and too low concentration levels. (see the dotted horizontal lines in figure 6). The high concentration at the beginning could possibly be prevented by a partly variable EC initially and a fixed EC set point later on.

CONCLUSIONS

The model is able to calculate well the concentration of salts in the system and its evolution.

An increase of drain fraction reduces the input of fertilisers (and thus the accumulation of salts) in the system.

The model provides insights into good management under poor quality of irrigation water

ACKNOWLEDGEMENTS

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Literature Cited

Farquhar, G.D. & S. von Caemmerer, 1982. Modelling of photosynthetic response to environmental conditions. In: Water Relations and Photosynthetic productivity. Springer Verlag, Berlin: 549-587.

Gijzen, H. 1992. Simulation of photosynthesis and dry matter production of greenhouse crops. CABO simulation report 28: 69 pp & 10 Annexes.

Stanghellini, C., 1987. Transpiration of greenhouse crops: an aid to climate management. PhD dissertation, Agricultural University, Wageningen, 150 pp.

Sonneveld, C. 2000. Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture. PhD dissertation, Agricultural University, Wageningen, 151 pp.

Sonneveld, C; Spaans, L.; Een universeel computermodel voor het berekenen van voedingsoplossingen. PBG Naaldwijk. Intern verslag nr. 13. Maart 1989. (in Dutch)

Kreij, de, C.; Voogt, W.; Bos, van den, A.L.; Baas, R. Bemestings Adviesbasis Substraten. PBG Naaldwijk. ISSN 1387-2427. Mei 1999. (in Dutch)

Malorgio, F., Incrocci, L., Carmassi, G., Pardossi, A. & Tognoni, F., 2001. Accumulo di sali (NaCl) e consumo minerale in pomodoro coltivato in systemi idroponici a ciclo chiuso. Italus Hortus, 8(6): 43-48.

Figures

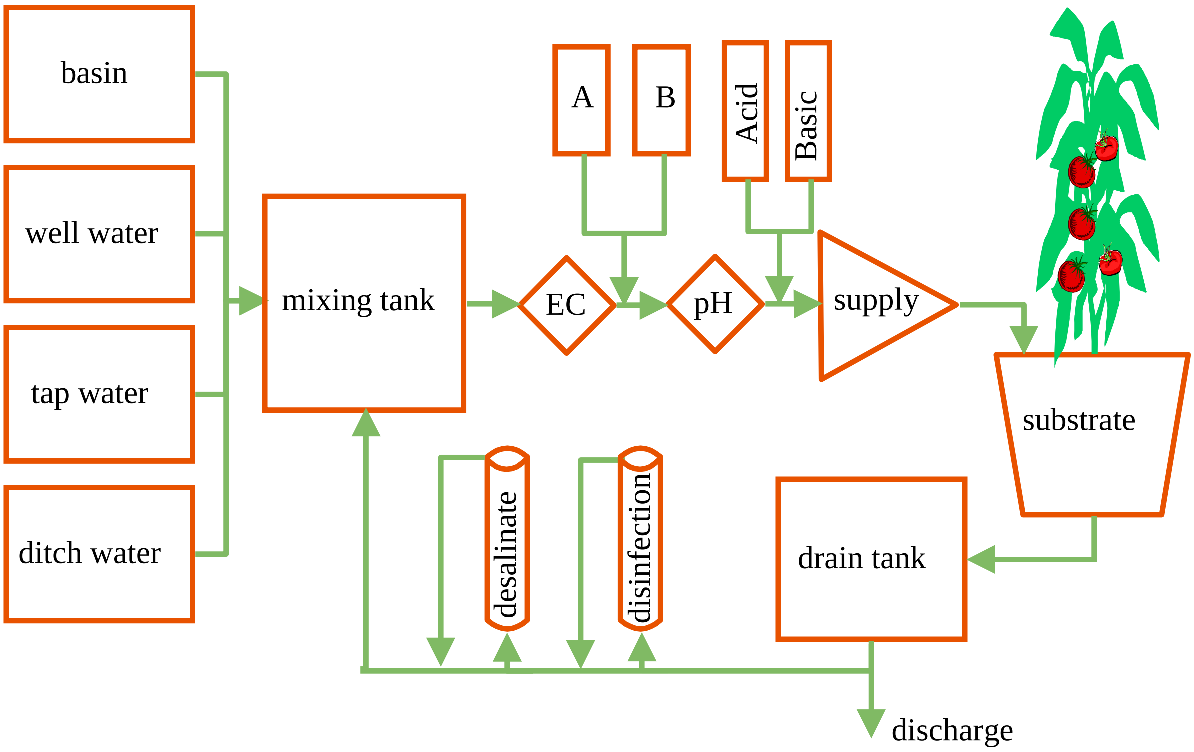

Fig. 1. Main volumes and flows of the model.

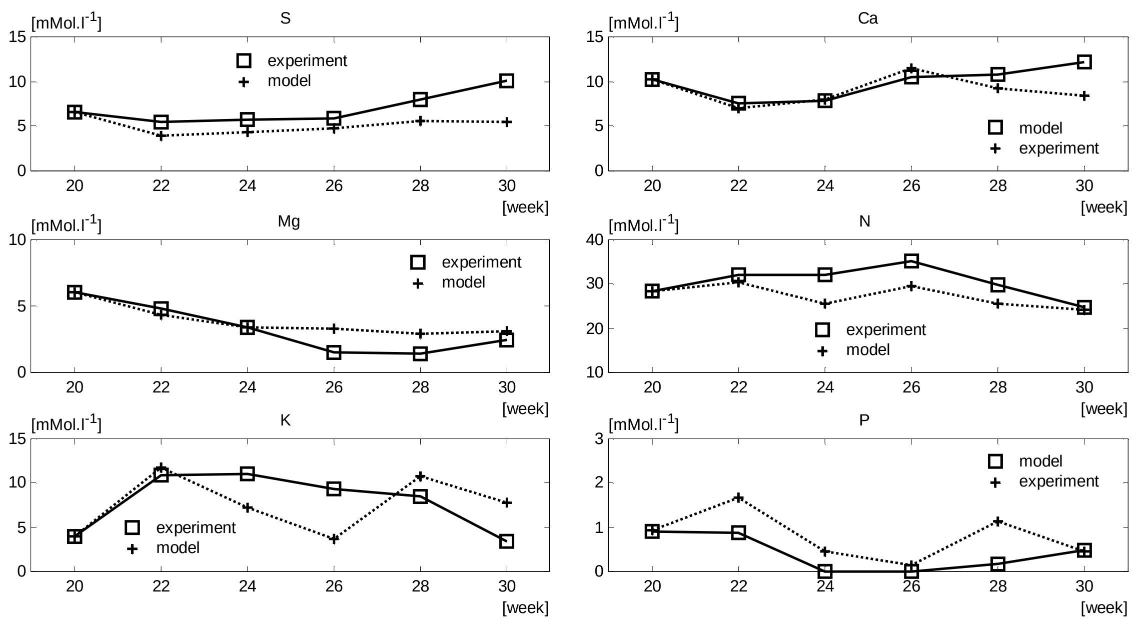

Fig. 2. Two weekly measured ion concentration for the 6 main ions: S, Ca, Mg, N, K and P, in the experiment and calculated by the model.

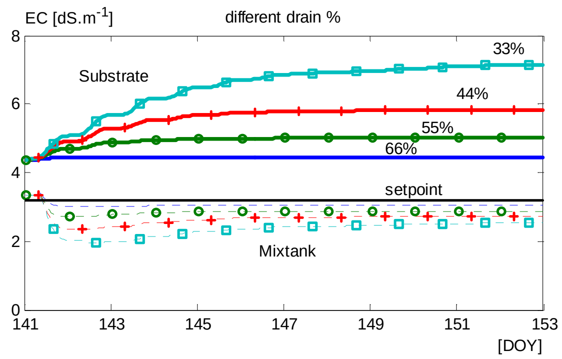

Fig. 3. The EC in the substrate and in the mixing-tank with four different drain fractions.

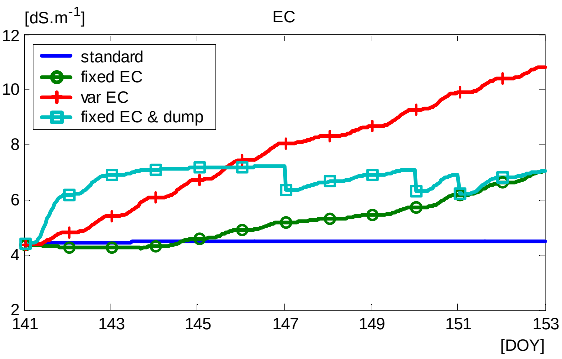

Fig. 4. EC level in the substrate as a result of 3 strategies when the refill water contains 20 mMol Na and a standard with good refill water.

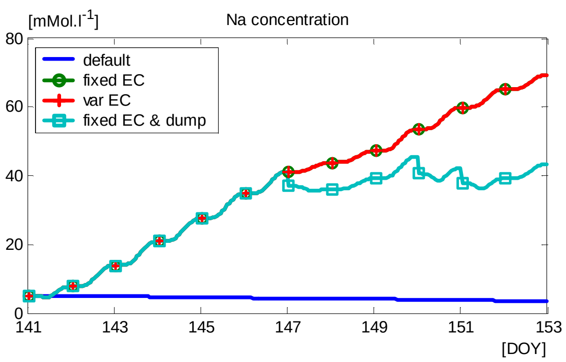

Fig. 5. The Na concentration in the substrate as a result of three strategies and the standard.

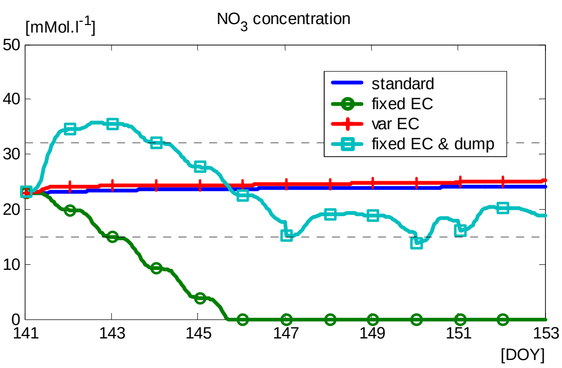

Fig. 6. The NO_3 concentration in the substrate as a result of three strategies and the standard.