Application of Numerical Simulations for Optimization of Soilless Culture Systems

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Introduction

- With the global population projected to grow to more than 8 billion by 2024, irrigated agriculture faces momentous challenges to keep up with the increasing demand for adequate food supplies, especially in the arid and semi-arid regions of the world. As a result, soilless culture is regaining increased attention as it allows a more sustainable management of production resources along with higher achievable crop yields when compared to conventional agricultural production.

- Comprehensive physicochemical characterization of commonly employed soilless substrates such as perlite, volcanic tuff, coconut coir in conjunction with numerical modeling (HYDRUS-3D) of water and nutrient transport not only enables us to provide design guidelines for growth module geometry and irrigation management, but also to optimize substrates by mixing organic and inorganic constituents at different ratios.

Materials and Methods

- As a preliminary test of concept, water movement and transport of ammonium, nitrate, and phosphorus was numerically simulated with HYDRUS-3D (*Šimůnek et al., 2012*) for coconut coir and different irrigation management scenarios taking into account root water uptake in a typical greenhouse growth container (Fig. 1).

- Each container was populated with 5 tomato plants, each irrigated with a 1.6 l/hr pressure compensating drip emitter. The total amount of water supplied to the container per day was either 5 or 6 liters dependent on the growth stage in 1, 10 and 18 daily doses.

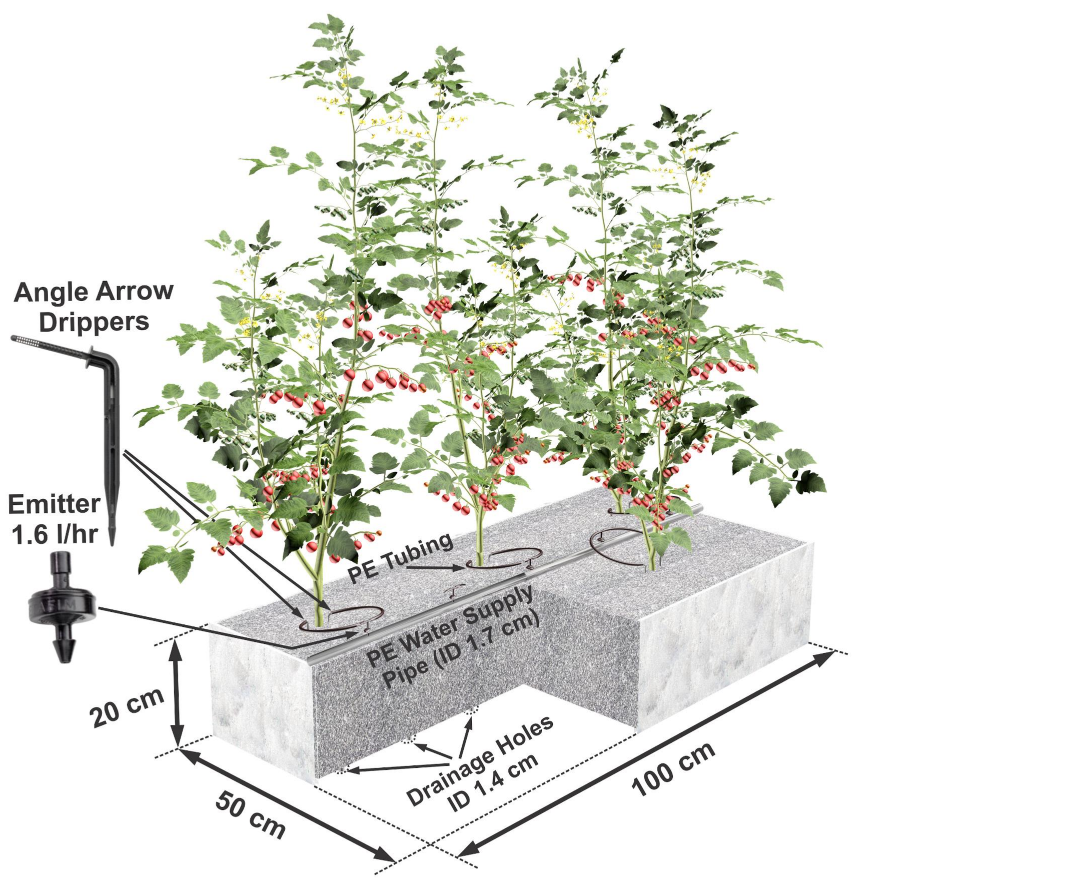

Figure 1: Sketch of the container used for the tomato growth experiments at the Ramat Negev Desert Agro Research Center.

- Nutrients were dissolved in the irrigation water at 20, 80 and 20 mg/l concentrations for NH_4^+-N, NO_3^--N and H2PO_4^--P, respectively. Non-equilibrium solute transport considering first-order decay reactions was simulated for transformation of ammonium (NH_4^+) to nitrate (NO_3^-) with the rate coefficient set to 0.2 d^{-1} (*Hanson et al. 2006*).

- Ammonium was assumed to adsorb to the solid phase considering a linear adsorption isotherm with a distribution coefficient k_d of 3.5 cm^3/g.

- A batch experiment was conducted to determine the P sorption isotherm with 0, 1, 5, 10, 50, 100 ppm concentrations of KH_2PO_4-P. Results were fitted with the Langmuir isotherm model (LIM):

$$\frac{C}{S} = \frac{C}{S_{max}} + \frac{1}{k\, S_{max}}$$

C = concentration of P (mg/l) in solution after 24 hours equilibration

S = amount of P adsorbed onto the solid phase (mg/kg)

Materials and Methods - Continued

- The LIM parameters for coconut coir were determined as 3.98 mg/kg and 2.47 mg/l P for S_{max} and k, respectively.

- Plant Root distribution in the container (Fig. 2) was modeled after *Vrugt (2001)* with parameters set to z_m=18 cm, z*=3.6 cm, r_m=13.5 cm, r*=0 cm and p_r=p_z=1 (*Hanson et al. 2006*).

- The Feddes water stress response function was employed for the simulations with parameters reported in *van Dam et al. (1997)* adjusting h_{3max} and h_{3min} based on reported soil water content stress threshold values for tomato plants. For coconut coir these values are h_{3max}=-710 cm and h_{3min}=-1420 cm.

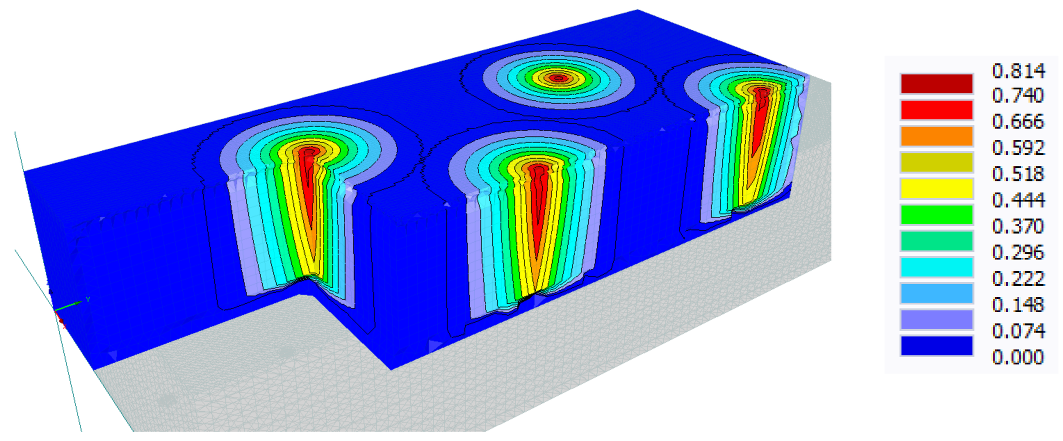

Figure 2: Normalized root distributions of tomato plants in the container.

Preliminary Results

- Figure 3 and 4 depict the concentration distribution of $NO_3^- - N$ and $H_2PO_4^-/HPO_4^{2-} - P$, respectively after 14 days of irrigation for the lowest and highest irrigation frequency when applying 5 and 6 liters per day.

Nitrate (NO_3^-):

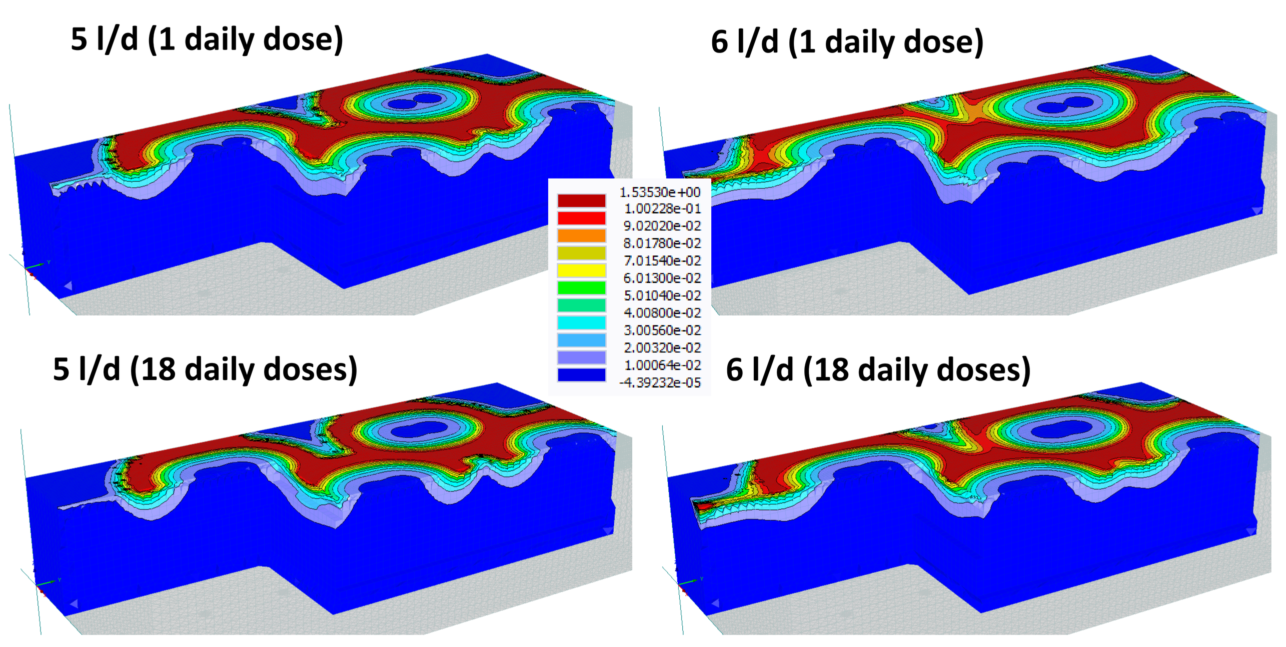

Figure 3: Nitrate concentrations after 14 days for 4 different irrigation scenarios.

Phosphorus (HPO_4^{2-}, $H_2PO_4^-$):

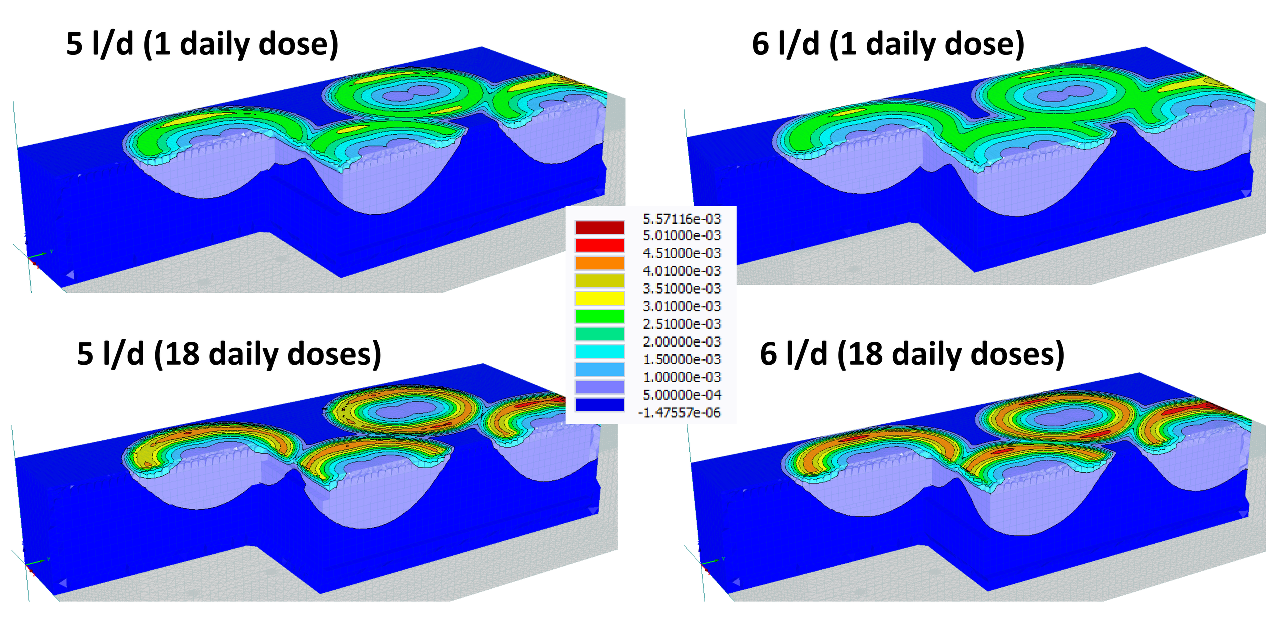

Figure 4: Phosphorus concentrations after 14 days for 4 different irrigation scenarios.

Preliminary Results - Continued

- Figure 5 indicates that despite a higher root water uptake for the 6 l/d water application, the nitrogen uptake in either form (i.e., NH_4^+-N and NO_3^--N) is higher for 5 l/d irrigation.

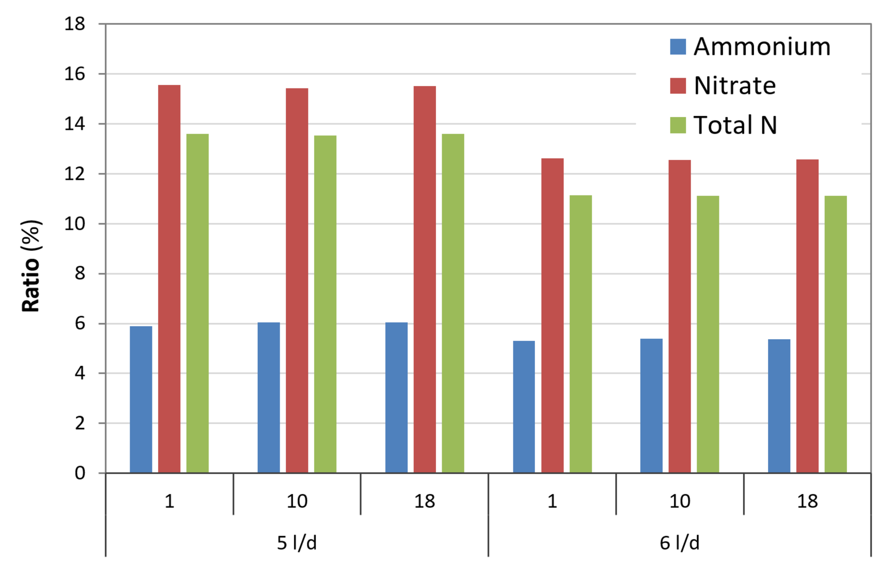

Figure 5: The ratio of Nitrogen root uptake to the total applied amount.

- For phosphorus (Fig. 6) the overall amount of root uptake is higher when irrigation is applied at a rate of 6 l/d. However, the efficiency of applied phosphorus decreases for this case. The irrigation frequency has no obvious effect on nutrient uptake by roots, but if water is applied in a single daily dose the evaporative water loss is lower than for higher frequency irrigation (results not shown).

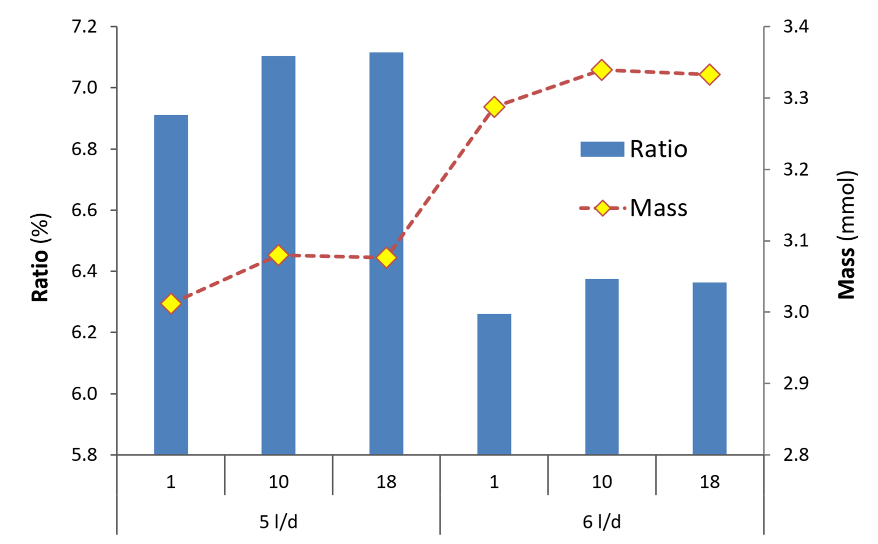

Figure 6: The ratio of phosphorus uptake and the total applied amount and the total adsorbed mass.

Ongoing and Future Work

- We are currently running simulations for other substrates including tuff, perlite and their mixtures with coconut coir to find the most efficient soilless substrate.

- Other parameters such as the denitrification rate, which plays an important role for the nitrogen balance will be estimated from greenhouse experiments that are currently in progress and will be implemented in future simulations.

References

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Acknowledgements

The authors gratefully acknowledge support from Binational Agricultural Research & Development Fund BARD under grant # US-4764-14-R.