Application of the ParSWMS Parallelized Code for Simulation of Three-Dimensional Water Flow and Solute Transport in Containerized Soilless Substrates

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Introduction

- **Simulation of three-dimensional water flow and solute transport in containerized variably saturated soilless substrates with complex hydraulic properties and boundary conditions necessitates high-resolution discretization of the spatial domain, which commonly leads to several million nodes requiring numerical evaluation. Even today's computational power of workstations is not adequate to tackle such problems within a reasonable timeframe. Hence, parallelization of the numerical code and utilization of supercomputers are required.**
- **We modified and applied the ParSWMS parallelized code that was developed for solving 3-Dwater and solute transport. The code was modified to accommodate nonlinear solute adsorption and to support multi-species solute simulations.**

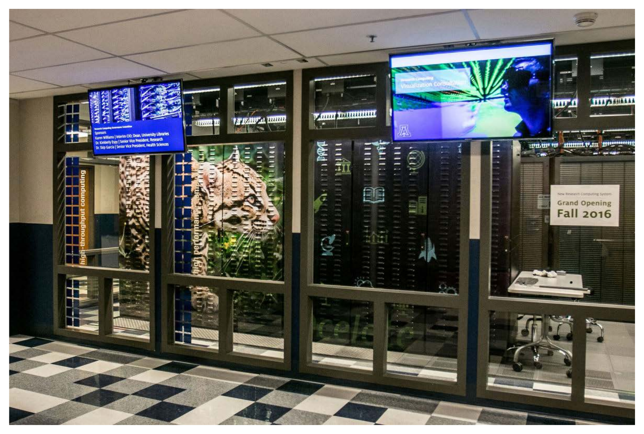

Figure 1. "Ocelote", the University of Arizona's high-performance computing cluster with Lenovo's NeXtScale M5 technology.

Materials and Methods

- **The current version of ParSWMS** (Hardelauf et al., 2007), **which is the parallelized version of SWMS-3D** (Simunek et al., 1995) **solves porous media water flow and solute transport equations considering one solute at a time and a linear adsorption isotherm. We have added support for a general adsorption isotherm of the form:**

$$s = \frac{k_s\, c^{\beta}}{1 + \eta\, c^{\beta}}$$

,where *s* is adsorbed concentration [M.M^{-1}], *c* is solution concentration [M.L^{-3}], *ks* [L$^{3\beta}$.M$^{-\beta}$], β [-] and *η* [L^3.M^{-1}] are empirical coefficients.

The addition of nonlinear solute adsorption behavior yields a nonlinear advection-dispersion equation (ADE), which may be solved with nonlinear numerical solvers or via Picard iteration. We implemented the latter approach in the modified ParSWMS version. Multi-species solute transport simulation support is another feature that has been added to the original ParSWMS code to increase computational efficiency for complex spatial domains.

- **The modified code was applied for simulating water flow and nutrient transport in a typical greenhouse growth container** (Fig 2) **filled with two types of soilless substrates; coconut coir and a coconut coir-tuff mixture. Five tomato plants were each irrigated with two angle arrow drippers with a combined discharge rate of 2 l.hr^{-1}.**
- **Two irrigation scenarios were considered: once a day (low frequency) and 12 times a day (high frequency), adding 10% to the actual evapotranspiration rate (i.e., 5.5 l.day^{-1}) for 21 days of simulation. Nutrients were dissolved in the irrigation water at 20, 80 and 20 mg.l^{-1} concentrations for NH_4^+-N, NO_3^--N and $H_2PO_4^-$-P, respectively. Batch laboratory experiments were conducted to determine the NH_4^+ and P adsorption isotherms.**

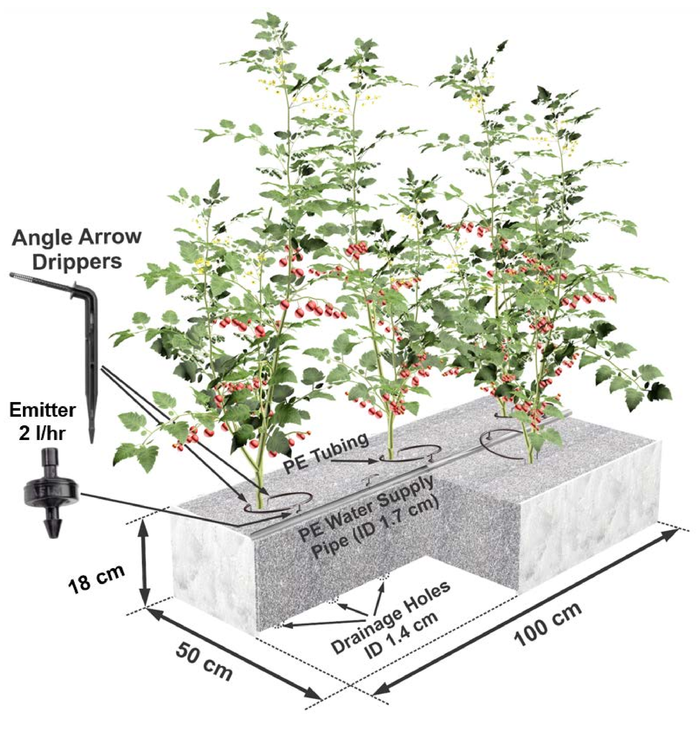

Figure 2. Sketch of the container used for the tomato growth experiments at the Ramat Negev Desert Agro Research Center.

Materials and Methods - Continued

- **Parameters of the van Genuchten hydraulic model as well as the Langmuir adsorption isotherm model (LAIM) for coconut coir and the coconut coir-tuff mixture are shown in Table 1** (β=1 when the LAIM is considered).

Table 1. van Genuchten and Langmuir isotherm parameters.

Substrate	θ_r	θ_s	α	n	K_s $[cm.hr^{-1}]$	Solute	k_s $[cm^3.g^{-1}]$	η [cm^3.mmol^{-1}]
Coconut coir	0.010	0.874	0.044	1.334	54.79	NH_4^+	51.12	2.57
						$H2PO_4^-$	9.83	79.85
Tuff - Coir	0.014	0.549	0.185	1.339	72.14	NH_4^+	43.08	5.95
						$H2PO_4^-$	10.25	9.99

- **The Feddes water stress response function was employed with parameters reported in** *van Dam et al. (1997)* **in which h_{3max} and h_{3min} were adjusted based on water content stress threshold values reported for tomato plants. h_{3max} and h_{3min} are -640 and -1200 cm for coconut coir and -520 and -1000 cm for coconut coir-tuff, respectively.**

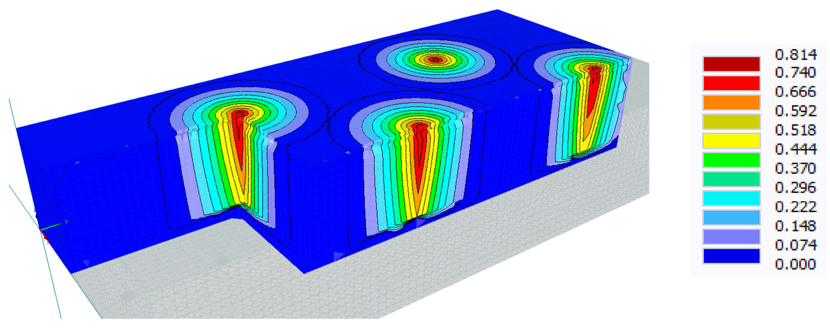

Figure 3. Normalized root distributions of tomato plants in the container.

Preliminary Results

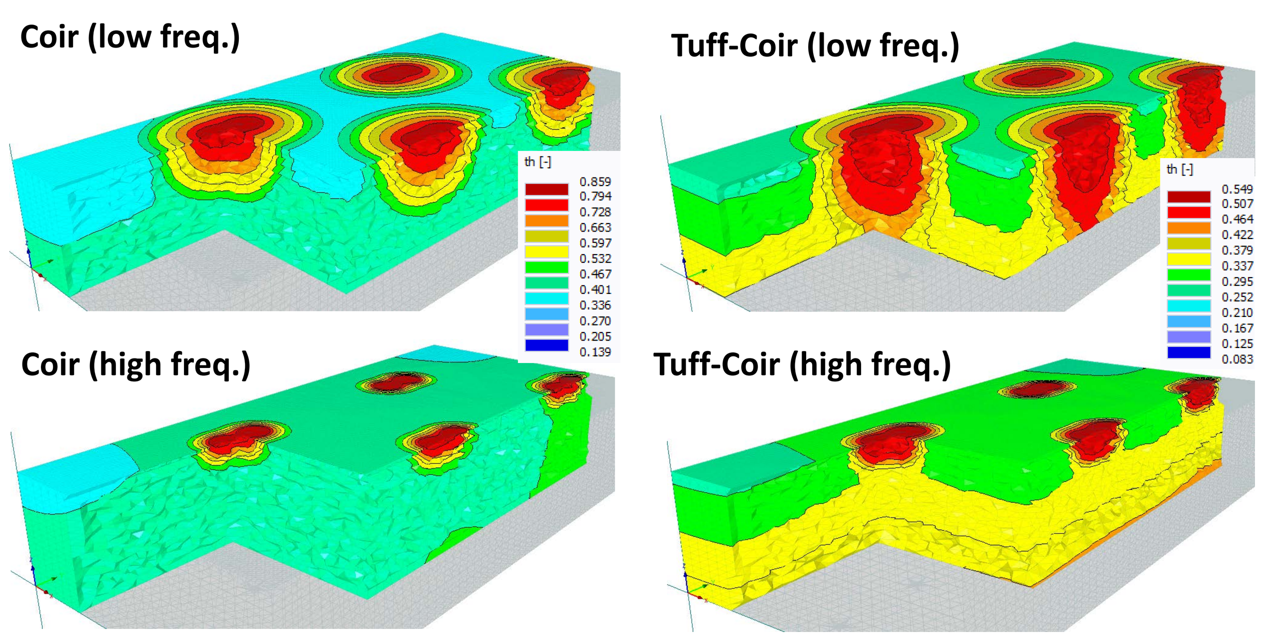

Figure 4. Water content distribution after low and high irrigation frequencies for coconut coir (left), and for the tuff-coconut coir mixture (right).

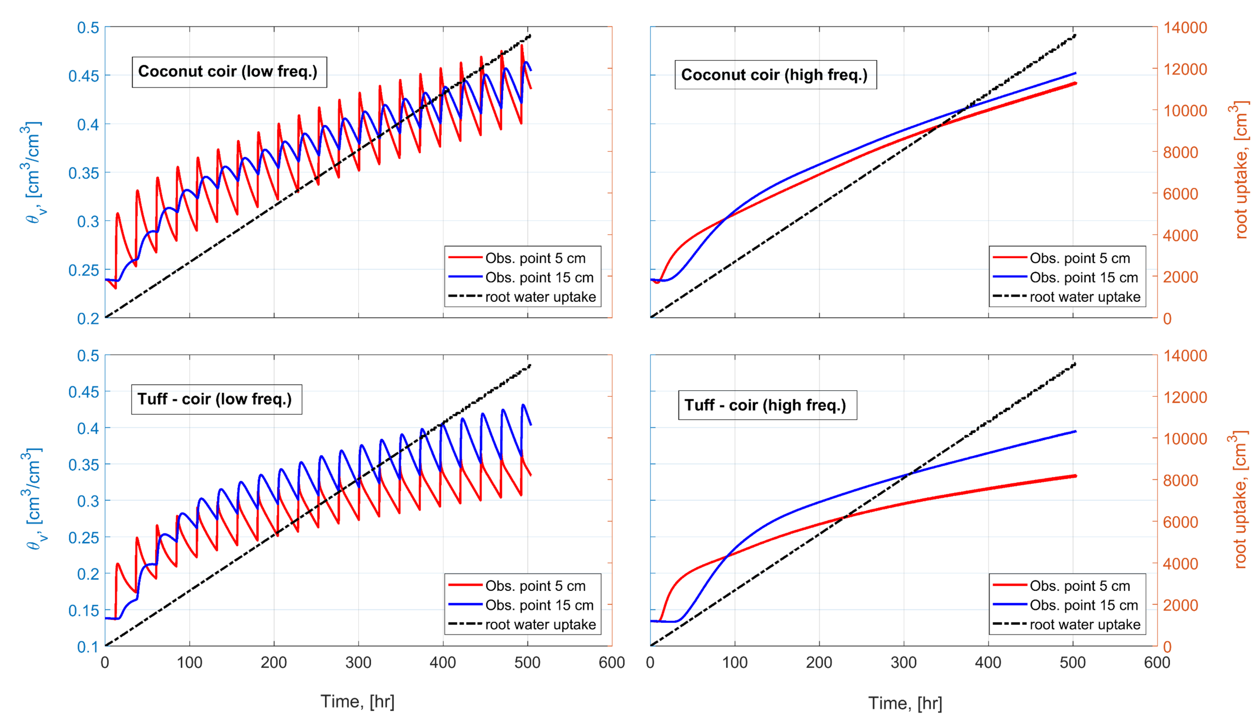

Figure 5. Left axis: volumetric water content at two observation points in the center of the container at 5 and 15 cm depths from the soilless substrate surface; Right axis: cumulative root water uptake for both substrates and two irrigation frequencies.

Preliminary Results - Continued

- **Figure 6 depicts the proportion of applied nutrients utilized by plants. Even though the irrigation frequency up to this simulation time had no significant effect on nutrient adsorption, tomato plants took up more ammonium and phosphorus in coconut coir when compared to the tuff-coir substrate.**

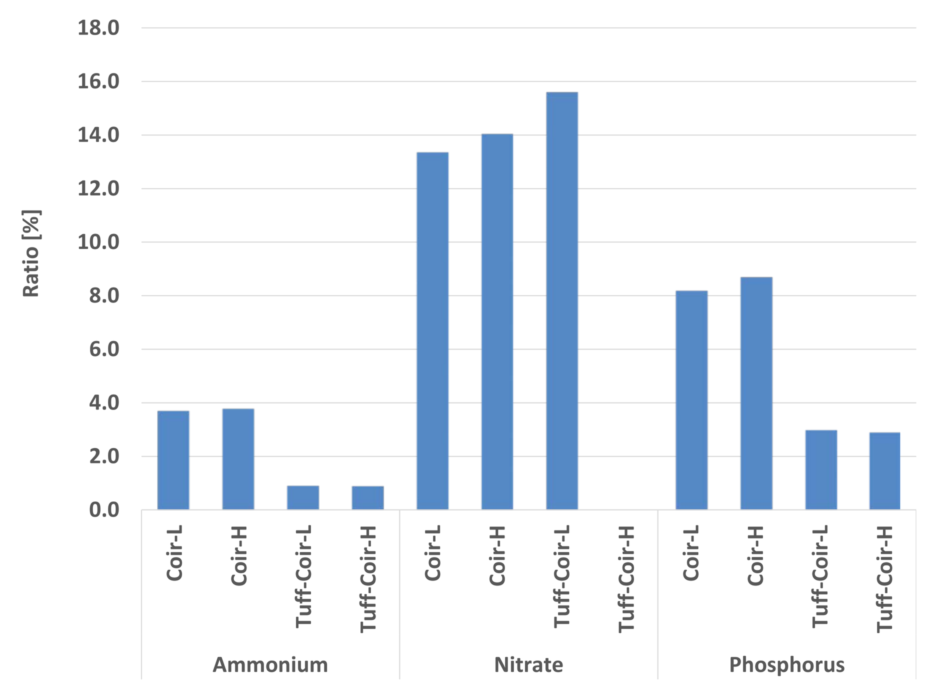

Figure 6. Proportion of ammonium, nitrate, and phosphorus which is adsorbed by plant roots.

- **Greenhouse experiments at the ARO Volcani Center revealed that tuff-coir is the most sensitive material to the irrigation frequency, which is pronounced about three months after planting tomatoes. Low and high irrigation frequencies in this material lead to low and high yields, respectively with a difference of about 5 kg.m^{-2}. This was also true in the case of coconut coir but with less total yield reduction, which was 2 kg.m^{-2}.**
- **As Figs. 4 and 5 suggest, the water content distribution over container space and time is more uniform when irrigating at higher frequency for both the coconut coir and tuff-coir mixture, which may be the reason why at later times when the water demand of plants increases, the containers are more productive.**

Ongoing and Future Work

- **We are still modifying the ParSWMS code to further increase computational efficiency.**
- **Once ParSWMS performs satisfactorily, we will run a large number of simulations with different irrigation and nutrient management strategies for various soilless substrates to develop best management practices for greenhouse tomatoes and to design optimal growth modules.**

References

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