Optimization of Soilless Greenhouse Substrates Based on Physicochemical Characterization and Numerical Simulations

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Optimization of Soilless Greenhouse Substrates Based on Physicochemical Characterization and Numerical Simulations

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Introduction

- The increase in human population, especially in underdeveloped arid and semiarid regions of the world, poses unprecedented challenges to production of an adequate and economically feasible food supply. As a response to these imminent challenges, soilless greenhouse production systems are regaining increased worldwide attention.
- Though there is considerable recent empirical and theoretical research devoted to specific issues related to control and management of soilless culture production systems, a comprehensive approach that quantitatively considers all relevant physicochemical processes within the growth substrates is lacking. To overcome these shortcomings, this project is aimed at thorough physicochemical characterization of commonly used greenhouse substrates in conjunction with state-of-the-art numerical modeling and greenhouse growth experiments (Fig. 1) to not only optimize management practices, but also to "engineer" optimal substrates by mixing inorganic with organic base substrates and modifying relevant parameters such as the particle size distribution.

Figure 1: Tomato growth experiment with different base substrates at the Ramat Negev Desert Agro Research Center in Israel.

Materials and Methods

- As a first step, transient moisture distributions in typical greenhouse growth containers (Fig. 2) were numerically simulated with HYDRUS 3D (Šimůnek et al., 2012) for different soilless substrates and irrigation management strategies.
- Each container is populated with 5 tomato plants, each irrigated with a 1.6 l/hr drip emitter. The irrigation water leaving the emitter is split up and supplied via 2 angle arrow drippers located in close vicinity of the plant stems (Fig. 2). The total amount of water supplied to the container per day is 12.5 liter either in 1 single dose (low frequency) or in 18 daily doses (high frequency).

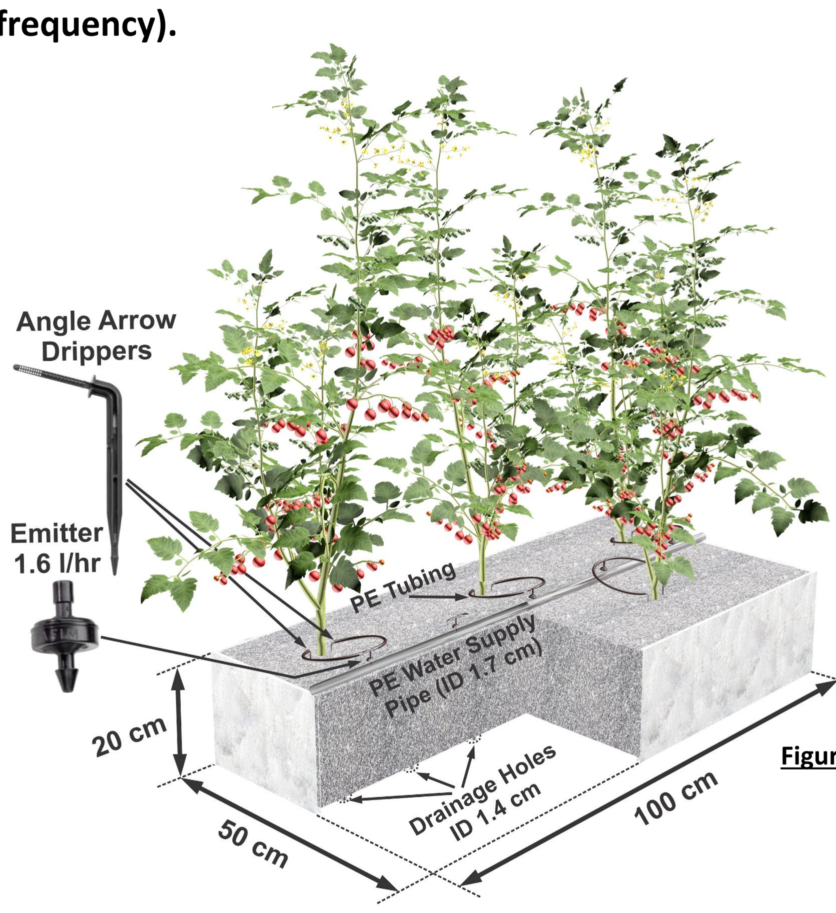

Figure 2: Sketch of a container used for tomato growth experiments at the Ramat Negev Desert Agro Research Center.

- The simulation boundary conditions (B.C.) were established to closely match the actual greenhouse growth experiment. While a variable flux B.C. was applied at locations where water enters the container via the angle arrow drippers, an atmospheric B.C. with an evapotranspirative flux equivalent to 12.5 liter per was established for the remaining top surface. For the 7 drainage openings at the bottom a free drainage B.C. was used.

Materials and Methods - Continued

- Three soilless substrates, a mixture of Growstone® (foamed glass) aggregates and coconut coir (Growstone LLC, USA), horticultural perlite (Therm-O-Rock West Inc., USA), and rockwool (Delta™, Grodan®, The Netherlands) with hydraulic properties depicted in Fig. 3 were considered for the preliminary simulations.

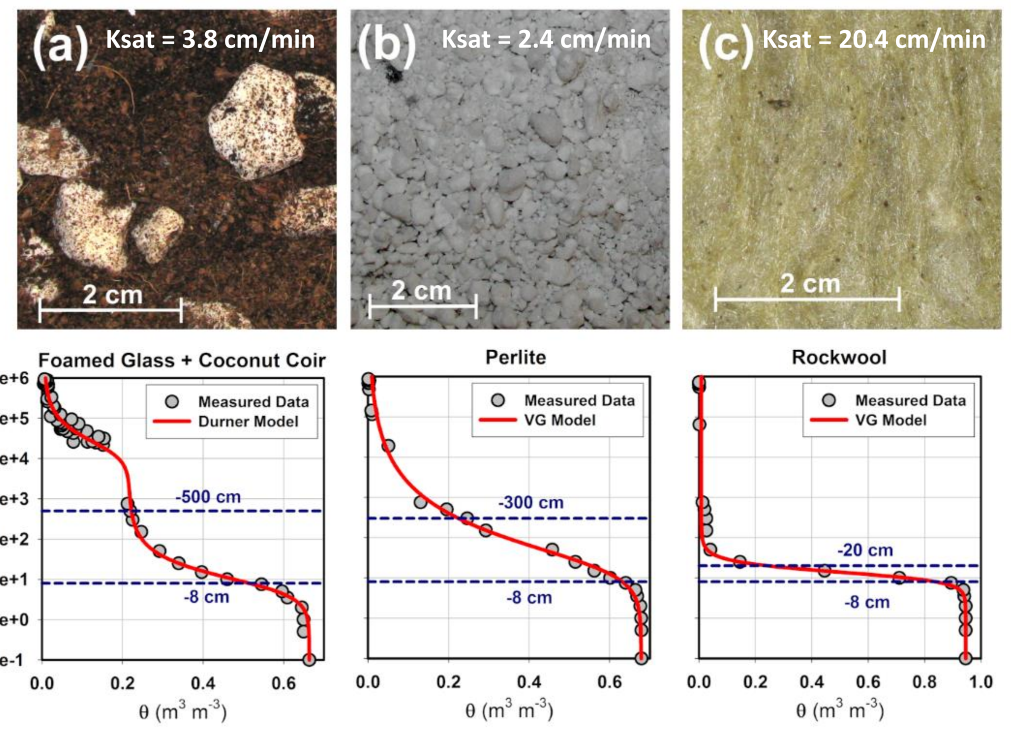

Figure 3: Hydraulic properties of considered soilless substrates (horizontal dashed lines in the soil water characteristic graphs mark the water availability stress limits).

- To evaluate substrate performance for low and high frequency irrigation, two criteria were considered; the Critical Window of Diffusivity (CWD) derived from gas diffusivity and porosity (Chamindu Deepagoda et al., 2012) to account for aeration, and Water Availability (WA) with stress limits (Fig. 3) defined based on tomato plant physiology (Thompson et al., 2007) and irrigation management constraints (Lieth and Oki, 2008).

Preliminary Results

- Figure 4 depicts snapshots of simulated spatial moisture distributions within the growth substrates short after water application for high-frequency (18 applications per day) irrigation management. Color coding identifies regions that fall within the CDW and WA limits. Visual inspection of Fig. 4 reveals that for these particular snapshots the Growstone® coconut coir mixture seems to perform best, followed by perlite and rockwool.

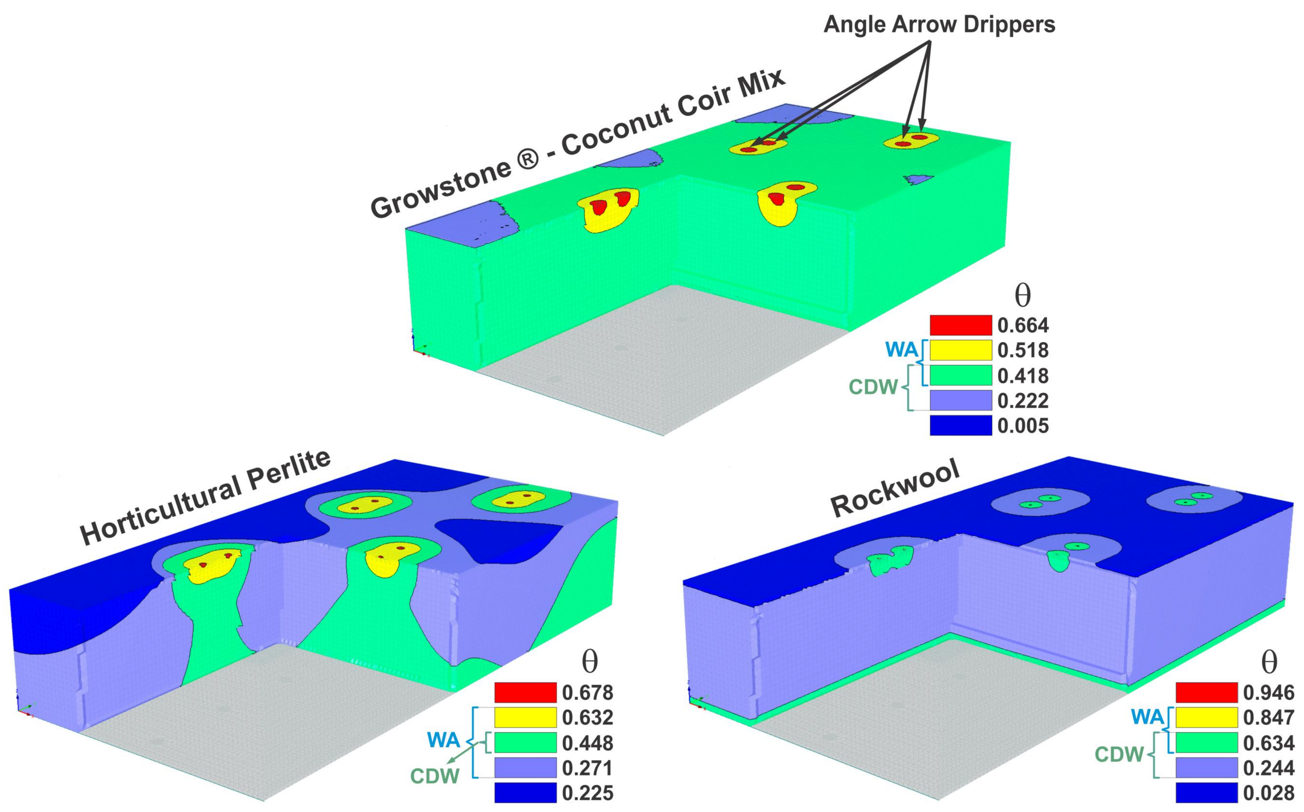

Figure 4: Snapshots of simulated spatial volumetric water content distributions within investigated substrates short after water application for high-frequency irrigation management.

- Figure 5 shows the temporal change in substrate/container volume (%) that satisfies both the CDW and WA criteria over several irrigation cycles for low frequency (1 application per day) irrigation management. While a high percentage of the Growstone® coconut coir mixture volume provides seemingly good growth conditions in terms of aeration and water availability, large portions of the perlite and rockwool substrates rapidly desaturate after water application. Most of the rockwool volume never reaches a state that satisfies both the CDW and WA criteria. Obtained simulation results can be potentially used to inform geometrical container design and to optimize irrigation management.

Preliminary Results - Continued

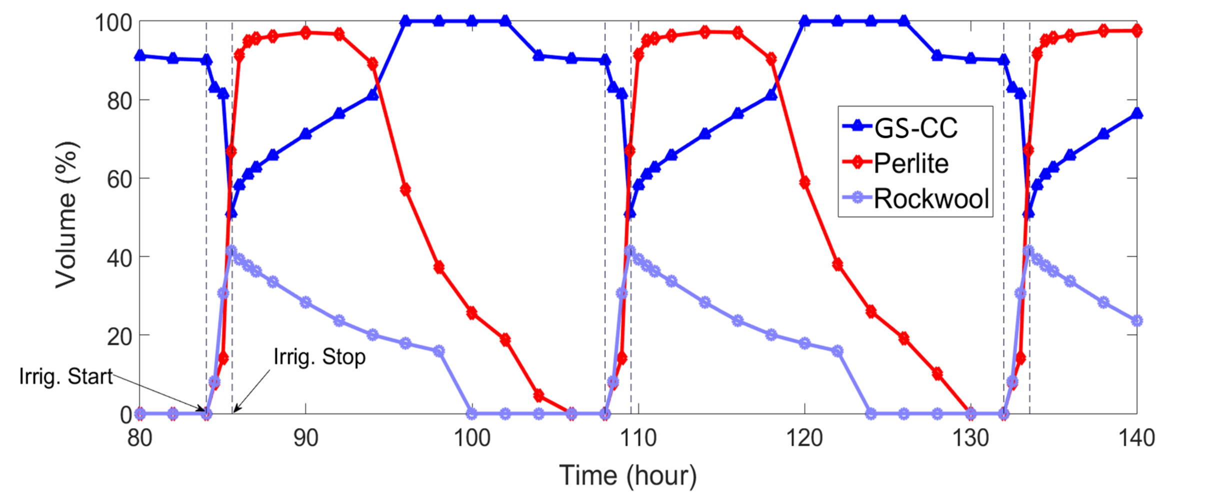

Figure 5: Temporal change in substrate volume (%) that satisfies both the CDW and WA criteria over several cycles of low frequency irrigation.

- Figure 6 summarizes preliminary simulation results and compares average substrate volumes (%) satisfying the CWD and WA criteria for low- and high-frequency irrigation. Based on performed simulations it seems that the Growstone® - coconut coir mixture provides a better growth environment than perlite and rockwool.

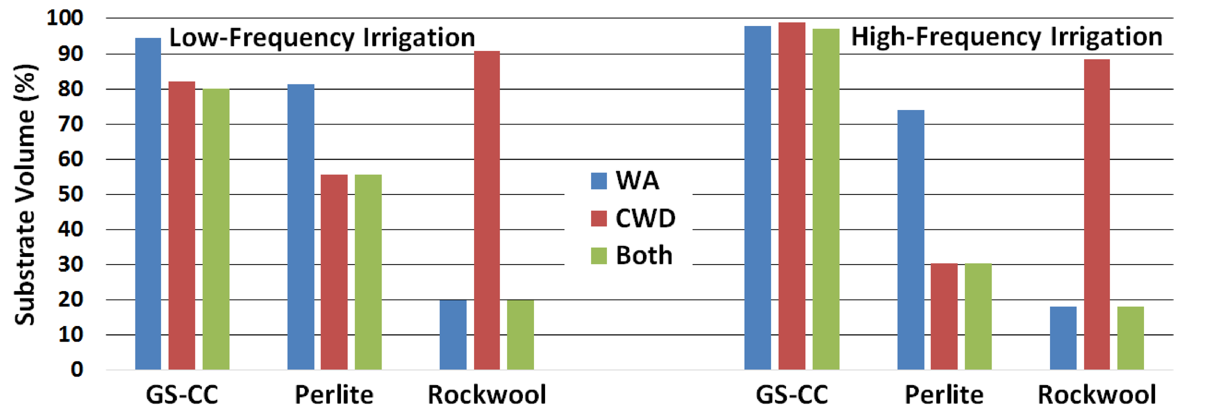

Figure 6: average substrate volumes (%) satisfying the CWD and WA criteria for low- and high-frequency irrigation.

Ongoing and Future Work

- Implement a realistic root water uptake model based on feedback from the greenhouse growth experiments at the Ramat Negev Desert Agro Research Center and consider modifications of substrate hydraulic properties during the growth season due to root growth to provide recommendations for a dynamic adaptation of irrigation management.
- Simulate non-equilibrium solute transport considering first-order decay reactions to predict NH_4^+, NO_3^-, and H_3PO_4 transport within the growth substrates including NH_4^+ adsorption and transformation to NO_3^-, as well as dissociation of H_3PO_4 to H_2PO_4, HPO_4 and PO_4 to provide feedback for fertigation management.
- The ultimate project goal is to apply simulation results in conjunction with knowledge gained from growth experiments to "engineer" optimal substrates for specific crops and management strategies by mixing organic and inorganic base materials and modifying relevant parameters such as the particle (aggregate) size distribution.

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