Federal Ministry of Education and Research (BMBF), Germany

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Joint German-Israeli Water Technology Research Program
FINAL REPORT

German Project Number 02WIL1489 Israeli Project Number ID13 3-14907

Title of German: Bodentrocknung und Versalzung unter Tropfbewässerung: Wirkung der hydraulischen Eigenschaften von Wurzel und Rhizosphäre auf das Blattwasserpotential

Title of Israeli Project Soil drying and salinity stresses in crops under drip irrigation: effect of root and rhizosphere hydraulic properties on leaf water potential

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Signatures of–

Israeli Principal Investigator(s): Date: 15.02.2022

German Principal Investigator(s): Date: 15.02.2022

Section 1: JOINT SUMMARY

Joint summary of results from all research groups involved in the project (max. 800 words, max. 2 Figures).

At University of Bayreuth, we addressed how root traits impact stomatal regulation for different soil water and salinity stress. First of all, we have addressed the fundamental question on what drives transpiration losses. We have demonstrated that soil is the primary limit to transpiration and stomata close well before xylem cavitation (trapped gas emboli in the xylem). We used a root pressure chamber to measure transpiration rate (E) and leaf xylem water potential ($\psi_{leaf\text{-}x}$) during soil drying in intact tomato shoots grafted onto two contrasting rootstocks, a long and a short one. A soil-plant hydraulic model was used to reproduce the measurements. We hypothesize that stomata close when the relation between transpiration and leaf water potential becomes nonlinear and that nonlinearity occurs at higher soil water contents and lower transpiration rates in short-rooted plants. The E ($\psi_{leaf\text{-}x}$) relation was linear in wet conditions and became nonlinear as the soil dried. Plants with shorter root systems required larger gradients in soil water potential to sustain the same transpiration rate and exhibited an earlier nonlinearity and stomatal closure (Fig1a,b). We conclude that the soil was the primary hydraulic limitation to transpiration and stomata closed when the soil hydraulic conductivity drops around roots. These results prove that stomatal regulation is controlled by root-soil hydraulics. We have also demonstrated that there is no unique relation between stomatal conductance and leaf water potential and that such relation depends on root properties in a predictable way. In terms of applications, this indicates that irrigation schedule should depend on root and soil hydraulic properties.

In further experimentations, we investigated the combined effect of salinity and soil drying on plant hydraulics, leaf water potential and transpiration rate. We treated tomato plants with 100 mM NaCl, and measured transpiration (E) and leaf xylem water potential ($\psi_{leaf\text{-}x}$). Control plants showed linear relation of $E(\psi_{leaf\text{-}x})$ in wet soil and nonlinear in relatively dry soils. Under saline conditions nonlinearity occurred in wetter soils and was more severe as soil progressively dried (Fig. 1c,d). An offset in leaf water potential occurred upon NaCl treatment. Our findings suggest that salinity increased the radial resistance to water fluxes due to its accumulation near or inside roots. Increment in soil-root hydraulic resistance limits high transpiration rates, which is pertinent to growth reduction in saline and dry soils.

At the Hebrew University, we compared the drought response of different tomato rootstock. We constructed an innovative measurement system and operate it at a semi-field condition. We performed three cycles of experiment, where in each cycle we measure a suite of parameters allowing us to compare the drought response of the different rootstocks. Using electrical resistivity tomography (a non-invasive geophysical method), we compare between the spatial distribution of root water uptake between three rootstock varieties. We also monitored transpiration and xylem water potential using psychrometer. We found that the depth of maximum water adsorption increases with the progression of the drought period, and that in the first growing cycles variety B adsorbed water from the deepest layers of soil (see Fig. XXX). In the third growing cycle, variety C adsorbed from the deepest layers, possibly due to seasonality effects. In the first two cycles, the transpiration of plant B was the highest and in the third cycle, similar relatively high transpiration was observed for plant B and C. It is interesting to note that during the first two cycles, the soot to root ratio was highest for plant B. These results suggest that during drought, plant B and C adsorbed water from deeper soil layers and therefore were able to perform better under drought conditions. Interestingly, root biomass distribution was not found to be a good predictor to the root water uptake distribution.

In addition to the experiments at the semi-field scale, we also tested the response of the different rootstock to drought and salinity in a controlled greenhouse environment with six replicates from each variety. The results from this experiment confirm that in comparison to plant B and C, the performance (transpiration and plant weight) of plant A is the worst. Similar results were also obtained under salinity conditions. Interestingly, no correlation between the shoot to root ratio and the transpiration and total plant biomass was found.

Overall, our results demonstrate that root water uptake distribution is more compatible with the hydraulic properties of the soil-root root interface rather than the root distribution in the soil. We showed that with the progression of drought the plants that can extract water from deeper soil layer perform better, and that this ability is mainly related to the soil-root hydraulic properties. We also conclude that the ERT can provide valuable information about root water uptake distribution in a non-invasive fashion.

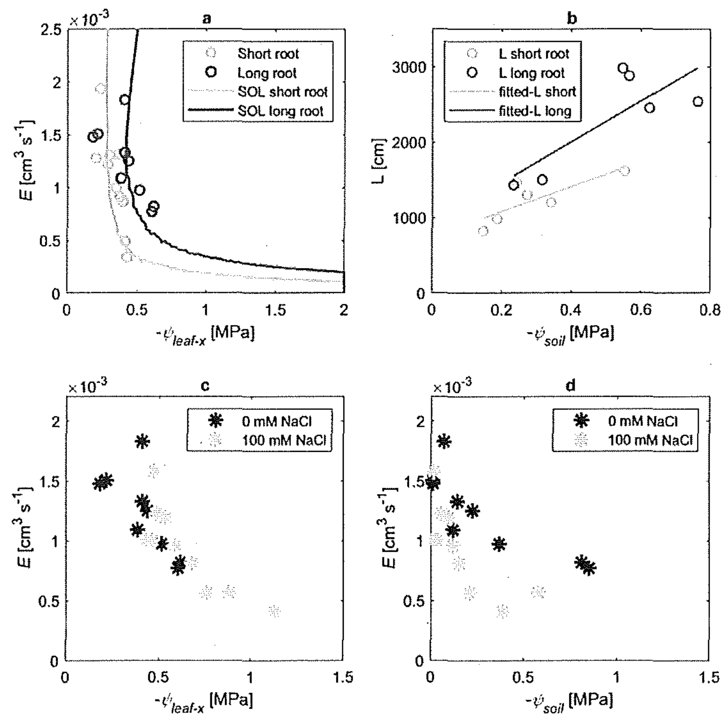

Figure 1: (a) Relation between transpiration rate (*E*) and leaf xylem water potential ($\psi_{leaf\text{-}x}$) for varying root systems. The measurements (o) were well reproduced by the model (—). The reduction in transpiration of long and short rooted plants are significantly different (*p-value* < 0.001; Fig. S2), with the shorter root system reducing transpiration at less negative leaf water potentials. **(b)** Active root length (*L*) as a function of soil water potential (ψ_{soil}) for the short-rooted (orange open symbols) and long-rooted plants (blue open symbols). **(c)** Relation between transpiration (*E*) and leaf xylem potential ($\psi_{leaf\text{-}x}$) during soil drying. With NaCl treatment, leaf watr potential is more negative **(c)** and transpiration declines at less negative soil water potentials ψ_{soil} **(d)**.

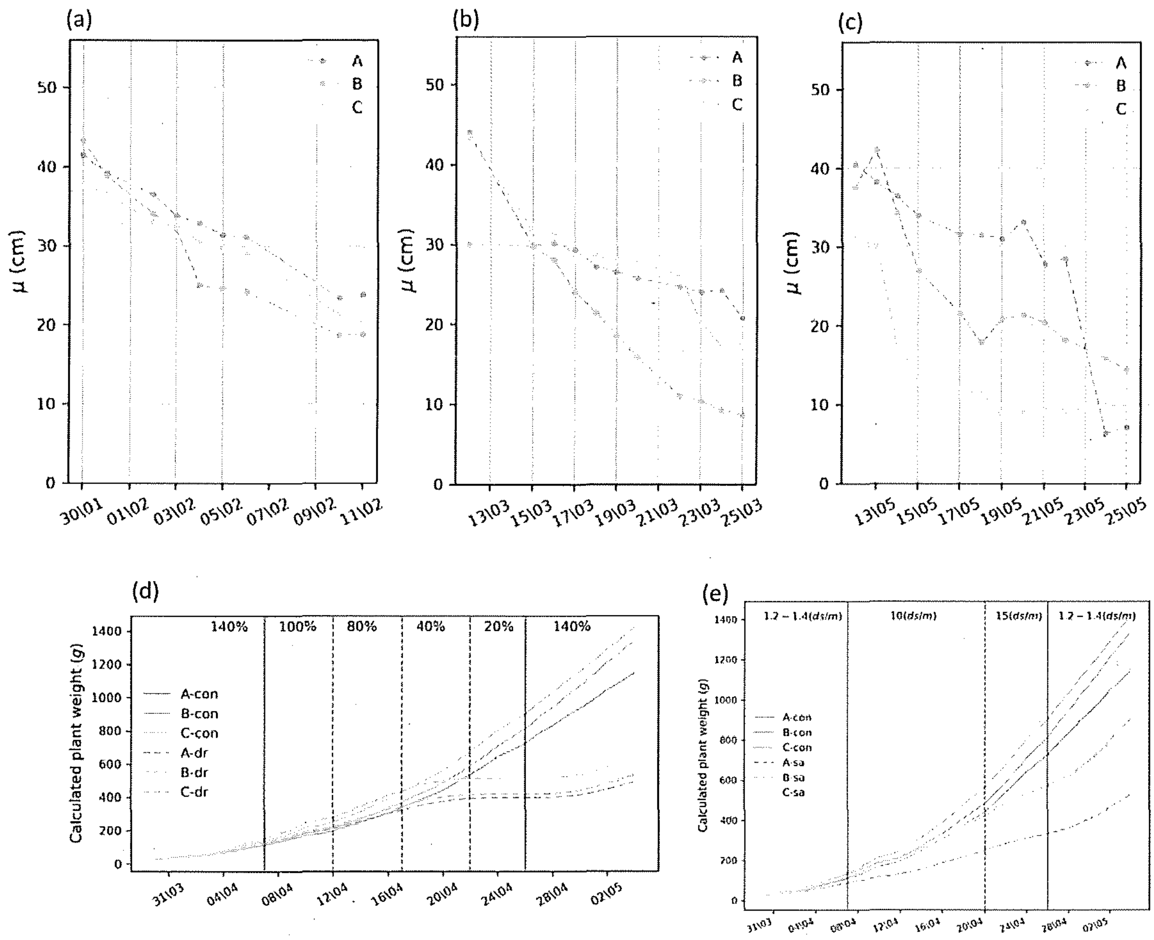

Figure 2: The height of root water maximum uptake for varieties A, B, and C for the first (a), second (b) and third (c) growing cycle. Note the deepening of water uptake with the progression of drought. The cumulative plant weight for the controlled conditions (full irrigation) and for water and salinity stress are shown in panel (d) and (e), respectively. Note the different shape of the drought and water stress.

Section 2: INDIVIDUAL SCIENTIFIC OR TECHNICAL RESULTS AND OTHER RELEVANT EVENTS

Scientific or technical results of each Israeli research group:

Please briefly fill the following table:

Milestone in the research proposal	Accomplished/not accomplished	Comments
Set up and test of the field experiment	Accomplished	- ERT was found to be great tool to assess water uptake distribution. - psychrometers were found to be extremely fragile.
Construction of the macroscopic model	Partial Accomplishment	- Transport of salt was added to the flow model by including advection dispersion equation module. The new module was tested and performed well. coupling between the flow model under salinity stress and root water uptake model didn't converge.
Exaction of the field experiment	Accomplishment	- All three planned repletion on the three rootstock varieties were conducted.
Analysis of the field experiment	Accomplishment	- Main technical achievement is the translation of ERT data into uptake distribution.
Running macroscopic model with the experiment parameters and construction of decision support system.	Not Accomplished	- Due to the lack of convergence between the developed 3D transport model and the root water uptake model we couldn't accomplished this task.

Scientific or technical results of each German research group:

Please briefly fill the following table:

Milestone in the research proposal	Accomplished/not accomplished	Comments
Explanation of the mechanisms controlling stomatal closure	Accomplished	- Scientific article published
Understanding the effect of root traits (root hydraulic conductivity and root length) on water use by crops.	Accomplished	-Scientific article under review
Understanding the effect of salinity on leaf water potential and water use.	Accomplished	-Scientific article in preparation
Recommendation to breeders.	In progress	-On going discussion with Israeli-partner. Publication planned.

Section 3: COLLABORATION BETWEEN THE GERMAN-ISRAELI GROUPS

Due to the current COVID-19 pandemic we could not physically meet and the students could not perform the planned joint experiments. However, we had regular remote meetings to coordinate experiments and compare the results. This helped the success of the project.

Section 4: PUBLICATIONS, PATENTS, INVENTIONS

- *Stomatal closure during water deficit is controlled by below-ground hydraulics.* M Abdalla, MA Ahmed, G Cai, Wankmüller F, Schwartz N, Litig O, Javaux M, **Carminati A**. *Annals of botany*. 2022 Feb 1;129(2):161-70.
- *Soil textures rather than root hairs dominate water uptake and soil–plant hydraulics under drought.* Cai G, Carminati A, Abdalla M, Ahmed MA. *Plant Physiology*. 2021 Oct;187(2):858-72.
- *Stomatal closure of tomato under drought is driven by an increase in soil-root hydraulic resistance*. M Abdalla, **A Carminati**, G Cai, M Javaux, MA Ahmed *Plant, Cell and Environment*; 44 (2), 425-431. (DOI: 10.1111/pce.13939)
- *Declining soil-root hydraulic conductance drives stomatal closure of tomato under drough.* M Abdalla, **A Carminati**, G Cai, M Javaux, MA Ahmed. Conference paper at European Geoscience Union (EGU) General Assembly, 19–30 April 2021. (https://doi.org/10.5194/egusphere-egu21-4192)
- *Comparing the drought resilience of different tomato rootstocks using ERT.* **N. Schwartz**, O. Litig, G. Cai, Abdalla, M., and **A. Carminati.** Invited talk at the Dryland, Desert & desertification virtual conference.
- *Monitoring the response of plants with different root system to drought stress.* **O. Litig**. Master Thesis, The Hebrew University of Jerusalem.
- *A finite element method numerical solution package to solve the advection dispersion equation in 3D*. R. Ben-Zvi and N. Schwartz. https://github.com/SoilHydrology/ADE3D