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Water uptake efficiency of a maize plant - A simulation case study

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Water uptake by plant roots is a complex mechanism controlled by biological and physical properties of the soil-plant-atmosphere system and affects a major component of the water cycle, transpiration. This uptake of water by plants is one of the major factors of plant development. Since water uptake occurs at the roots, root architecture and hydraulic properties both play a crucial role in plant productivity. A fundamental understanding of the main processes of water uptake will enable better breeding of drought resistant plants and the improvement of irrigation strategies. In this work we analyzed the differences of root water uptake between idealized genotypes of a plant using mathematical modelling

The numerical simulations were performed by the R-SWMS software (Javaux et al., 2008). The model describes 3-D water movement in soil by solving Richard's equation with a sink term representing root uptake. Water flow within the root xylem network and between soil and root is modelled based on water pressure gradients and calculated according to Doussan's model. The sink term is calculated by integration of local uptakes within rooted representative elementary volumes of soil. The plant water demand is described by a boundary condition at the base of the shoot.

We compare the water uptake efficiency of three types of root system architectures of a maize plant. Two are actual architectures from genotypes showing significant differences regarding the internodal distance, the root growth rate and the insertion angle of their primary roots. The third one is an ideotype according to Lynch of the maize plant designed to perform better in one dry environment. We generated with RootBox five repetitions of these three root systems with the same total root volume and simulated two drought scenarios at the flowering stage (lack of water at the top or at the bottom of the soil domain). We did these simulations for two distinct distributions of local conductivities of root segments based on literature values.

This numerical experiment shows significantly different behaviors of the root systems in terms of dynamics of the water uptake, duration of the water stress or cumulative transpiration. The ranking of the maize architectures varied according to the considered drought scenario. The performance of a root system depends on the environment and on its hydraulic architecture suggesting that we always need to take the genotype-environment interaction into account for recommending breeding options. This study also shows that an ideotype must be built for one specific environment: the one we created experienced difficulties to transpire when placed in different conditions it has been designed for. By mathematical simulation we increased the understanding of the most important underlying processes governing water uptake in a root system.