

New insight on the role of root radial conductivity on the overall uptake dynamics

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1 Introduction

Water transport along the soil-plant-atmosphere continuum is thought to be regulated by a handful of key features (on the plant side): the opening of stomata (leaf radial resistance), the axial resistance of the xylem pipes and the radial resistance of the root. While the regulation of the stomatal resistance was extensively studied both in natural and artificial conditions, and the axial resistance is thought to be negligible (at least for annual crop plants), little is known about the importance and regulation of the root radial resistance of plants growing in soil.

Root radial resistance is primarily determined by the development of apoplastic barriers [Enstone et al., 2003] and the presence of aquaporins [Chaumont et al., 2001]. These two components are themselves regulated by endogenous (e.i. abscissic acid concentration, age) and exogenous factors (e.i. salinity, water potential, pH). Therefore, root radial conductivity varies between root types but also along the roots.

As most crop plants grow in soil, the overall resistance to the flow of water entering the plant encompass the hydraulic resistance of both the roots and the soil directly surrounding them. The latter will change with the soil type but, more importantly, will decrease with the soil water content. In particular, while the soil is drying around the roots, it can become the limiting factor in the overall water uptake process. In other words, even a thin dry layer around a root can limit this root uptake, even if the bulk soil around it is well watered [Draye et al., 2010]. It is therefore important to look at the soil-root system with a fine resolution to analyse its water dynamics. Local phenomena might otherwise be hidden from observation.

This research aimed at (1) develop new analysis tools to observe local water dynamics in the soil-root system and (2) observe its implication at the root system scale.

2 Material and methods

Our experiments are based on the light transmission imaging (LTI) technique developed by Garrigues *et al.* (2006). This method generates pictures of the soil water content distribution in thin rhizotrons based on the quantity of light transmitted through the substrate.

2.1 Plant growth

Our experimental setup was made of 24 transparent acrylic rhizotron (500 x 500 x 4 mm) filled with a mix of white sand (Flamingo Siberia) and clay (Bentone HC, Necarbo) (respectively 98.5% and 1.5%). This substrate was saturated with a modified Hoagland solution.

We used two maize lines having contrasted root radial hydraulic conductivities (Lr^+ and Lr^-). Seed were germinated in petri dishes and transplanted into the rhizotrons when the hypocotyl was 1 cm long. During two weeks, plants were grown with a constant supply of nutrient solution in order to avoid drought or nutrient stress. Shoot and root growth were observed every two days.

2.2 Water shortage episode

When the plants were at stage six visible leaves, the nutrient solution supply was stopped during three days. Pictures of the soil water content distribution were taken at regular interval (7AM, 11AM, 3PM, 7PM) using the LTI technique. We therefore generated, for each plant, a sequence of twelve water content pictures. At the same time root growth and plant transpiration were monitored.

2.3 Root system digitising

At the end of the experiment, shoot and root systems were split at the collar level and scanned separately. A specific scanning procedure was developed for the root system in order to reduce root overlaps. First order roots were scanned individually in the same position as they were in the rhizotrons (based on *in situ* drawings). We obtained with this technique a stack of ca. ten images for each root system. Each of these images were digitised using SmartRoot [Lobet et al., 2011] and exported to a database for further analysis.

2.4 Data analysis

The approach used to analyse our data was to cross the root system information with the variations in soil water content. For each pixel in every soil water content image, we localised the closest root, based on the information contained in the database. We therefore linked the water depleted pixels to individual root segments and their characteristics (diameter, order, distance to the collar, etc).

3 Results

The figure 1 shows the comparison of average local uptake (at the root segment level) for both genotypes (in % of the Lr^- genotype). It appears that the amount of water uptaken is higher for the Lr^+ plants. This finding is consistent with the expectation that these plants have a higher root radial conductance, hence a higher capacity to take up water at the root segment level.

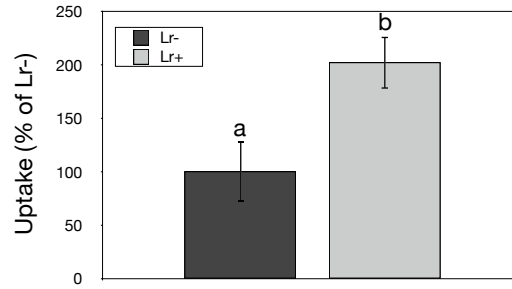


Figure 1: Average, at the root segment level, of the amount of water up taken by the whole root systems during the third day of experiment (in % of the Lr^- genotype). Statistical significance of difference is indicated by different letters ($P < 0.05$)

The figure 2 shows the mean distance between the root segments and their corresponding water depleted pixels (in % of Lr^-). Interestingly, even if the uptake is higher for the Lr^+ plants, the corresponding distance is smaller. One way to interpret this result is to assume that more water is taken close to the root segments, which we can see on the figure 3.

The figure 3 represents the water depletion directly at the root-soil interface (in % of Lr^-). We defined the root-soil interface as the soil points at a distance from the root segment smaller than 0.1 cm. We can clearly see that the depletion is more important in the case of the Lr^+ plant. According to soil physics, an important decrease in the soil water content implies a parallel decrease of the soil water conductivity which can ultimately lead to a local conductivity drop and hydraulic separation between the root segment and the bulk soil.

If such hydraulic isolation appears, the water uptake area would be forced to move down in the root profile. The figure 4 shows that this occurred in our experiment. We can see that the uptake area is moving downward faster for the the Lr^+ plants. This implies that the amount of root localized in a dry zone increase more quickly for these plant or, in other word, that the amount of roots able to uptake water decrease more quickly which can, on the long term have a negative influence on the whole plant development.

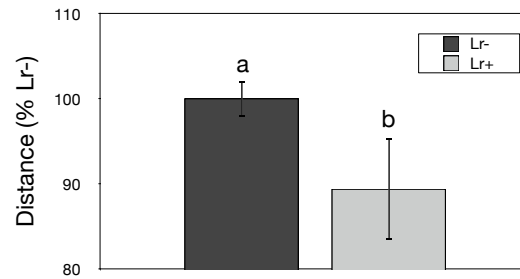


Figure 2: Average of the distance between the root segments and their corresponding water depleted pixels during the third day of experiment (in % of the Lr⁻ genotype). Statistical significance of difference is indicated by different letters (P<0.05)

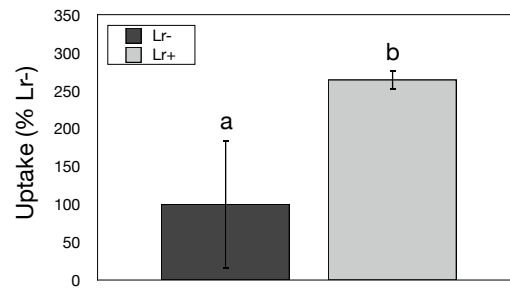


Figure 3: Average, at the root segment level, of the water potential depletion at the soil-root interface (soil points at a distance from the root segment smaller than 0.1 cm) during the third day of experiment (in % of the Lr⁻ genotype). Statistical significance of difference is indicated by different letters (P<0.05)

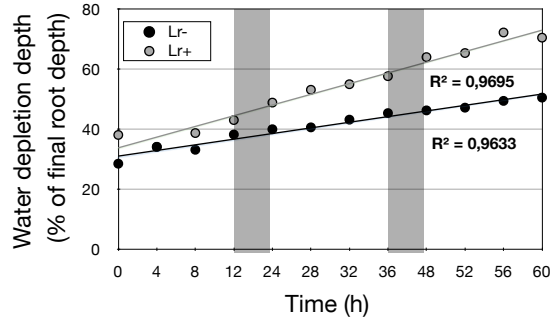


Figure 4: Depth of the water depletion front, in percentage of the total root system depth

4 Conclusion

In our experiment, we monitored the water uptake of plants having contrasted root radial conductivity. The first results show different uptake rates at the root segment level, leading to a quick drying of the surrounding soil which, in return force the water uptake to take place more deeply in the profile. A local variation of the plant hydraulic characteristics, coupled with a strong response of the soil, can then lead to a global change in the whole water uptake dynamics and an important redistribution of the water uptake sites.

These water uptake dynamics changes might be of importance on the overall plant life cycle. Isolating some part of the root system from the bulk soil might indeed be damaging for the plant on the long term as these regions might not be re-watered again (if not by rainfall). In this situation, drought stress might occur while the bulk soil is still well watered, which can lead, for crop plants, to yield decrease.

In, other cases, the presence of roots in dry areas might trigger long distance signaling stress signal (e.g. abscissic acid or hydraulic changes), leading to a stomata closure [Sobeih et al., 2004]. In this case, the hydraulic isolation of part of the root system might lead to water saving response at the plant scale.

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