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The influence of heterogeneous water and phosphorus supply on root growth in soil

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Phosphorus (P) and water are the two most limiting resources for plant growth in natural and agricultural ecosystems. Water and P distribution in soil varies over time and space and is heterogeneous on the scale of a root system. Temporal and spatial adaptation of root growth to these heterogeneities is crucial for nutrient and water uptake, plant fitness and plant production. Many plant species which are adapted to P-poor soil, develope root modifications like cluster roots to increase P uptake. Cluster roots are densely packed rootlets with increased organic acid exudation. P is considered to be the main factor determining cluster root production. The effect of water on cluster root production has not been elucidated yet. We conducted to growth chamber experiments using neutron radiography (NR) to investigate root and cluster root allocation patterns in soil with heterogeneous P and water distribution. We used the neutron imaging facility NEUTRA for thermal neutrons at PSI (Villigen).

In the first experiment, we supplied P fertilized soil to single root tips of Lupinus albus to investigate the effect of localized P supply on cluster root initiation. The roots were tracked in NR images on 20 day old root systems The soil around the root tips was thoroughly removed and replaced with unfertilized or fertilized soil (15, 40 or 100 mg P/ kg soil). We established six replicates. Ten days after soil replacement we washed the soil from the roots and counted the number of cluster roots produced on the treated root tips. Three root tips treated with 100 mg P/ kg soil, produced cluster roots. Only one tip treated with 40 or 15 mg P or the unfertilized control soil produced a cluster root. In the second experiment, we used L. albus to investigate root growth allocation in soil with heterogeneous water and P distribution. Therefore we established heterogeneous P and/or water distributions by implementing vertical bands of soil fertilized with P (30 mg kg-1) and/or with increased available water capacity (AWC). Treatments with homogeneous water and P distribution served as controls. The root system was imaged using NR on day 12, 19 and 35 after seeding. When water availability was limiting plant growth, cluster roots were preferentially allocated in the soil parts with lower water content (and lower AWC). Heterogeneous P distribution had no effect on cluster root allocation, neither at high, nor at low water availability.

Results demonstrate that heterogeneous water distribution is more important for cluster root allocation than heterogeneous P concentration in soil. Locally increased water availability hindered cluster root production, while locally increased P concentrations tended to promote cluster root production. This opposite effect of water and P is surprising because P diffusivity in soil and consequently P availability increases with water content. Results suggest that water content or other soil physical parameters influenced cluster root production independently from P availability.

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