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Root development under fluctuating soil physical stress – plastic and elastic responses

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Physical properties of soil such as penetration resistance and oxygen concentration of soil air strongly influence root system development in plants. Soils typically exhibit considerable spatial and temporal fluctuations in penetration resistance and oxygen concentration of soil air due to wetting-drying cycles, small-scale differences in soil compactness or hotspots of biological activity. Hence, roots of a single plant are exposed to different physical environments and thus physical stresses during their growth through the soil profile. Plants are known to adjust their root development to these spatiotemporal fluctuations in soil physical conditions. Such phenotypic adjustments include changes of root growth rate as well as alterations of root morphology and anatomy. However, these adjustments reduce accessibility of water and nutrients and may increase the carbon demand for soil exploration, which limits aboveground plant development. Until now, it is unclear whether such adjustments in root development are plastic (i.e. the phenotype is irreversibly changed even when roots re-enter zones with optimal growth conditions) or elastic (i.e. the phenotype is only temporarily changed and recovers again when roots re-enter zones with optimal growth conditions).

To investigate the plasticity and elasticity of root development, we designed customized microrhizotrons in which soil penetration resistance and the concentration of oxygen in soil air can be varied. Near-infrared (λ=830 nm) time-lapse imaging was applied to quantify root growth rates, and combined with measurements of root morphology and anatomy. A series of experiments was conducted using different crop species with contrasting root system properties (fibrous vs. taproot system, thin vs. thick roots). After an establishment period of three days under optimal growth conditions, roots were exposed for 24 hours to increased penetration resistance, hypoxia and the combination of both stresses. Following this, the stress was released, and plants continued to grow for 24 hours at optimal conditions, before a second stress was applied for another 24 hours. Generally, root development responded to changes in soil physical conditions across all species. However, depending on the species, the adjustments in root development were found to be constant or temporary, i.e. plastic or elastic. This difference between species was particularly pronounced for root growth rate. Root growth rate in pea recovered after soil physical stress was released, while root growth rate in wheat remained low after stress release. The obtained findings will be discussed with respect to the tolerance of different plants to soil physical stress as well as the effects of root growth on soil structure dynamics.