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Exploiting the root phenome to increase tolerance to high strength soils

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Dry and compacted soils are major threats to global crop production, and their negative impact on yields will increase with climate change and agricultural intensification. Soil strength increases upon drying and compaction, resulting in decreased root elongation rates and higher energetic costs of root growth. As a result, the accessibility to water and nutrients is reduced and the carbon requirements for soil exploration increase, which eventually reduces crop productivity. Novel crop varieties that are adapted to high soil strength are essential to ensure agricultural productivity under drought and compaction. We investigated a diverse set of wheat genotypes (Triticum aestivum L.) to identify elemental root traits that increase root elongation and decrease the energy costs of root system expansion in soil with increased strength. A series of experiments with one- to two-day-old seedlings were employed to quantify genotypic diversity in root elongation rate, root tip shape, the energetic costs of root growth and root cortical cell size. The penetration stress exerted by growing roots was simulated as a function of root tip shape and soil mechanical impedance using cavity expansion theory. We show that a sharp root tip opening angle reduces the penetration stress exerted by growing roots, which in turn facilitates root elongation in soil with increased strength. The energetic costs of root growth were quantified in situ using isothermal calorimetry, with which heat dissipation resulting from metabolic activity is recorded continuously at μW precision. Calorimeter measurements were then combined with the assessment of root anatomical properties. We found that root cortical cell size is key to the energy requirements for root growth, especially under high soil strength. Large cortical cells resulted in reduced energetic costs of root growth due to decreased surface to volume and cytoplasm to vacuole ratios. Furthermore, high heritabilities were obtained for root tip opening angle as well as root cortical cell size. Given their physiological implication and high heritability, sharp root tip opening angle and large cortical cell size are suggested to be promising selection targets in order to increase the tolerance of crops to high soil strength. In the future, we are aiming to screen populations of several hundred genotypes to identify genetic markers and target genes associated with root tip shape and cortical cell diameter. Based on this information, crop breeding programs can be developed that will result in novel varieties with improved agronomic performance on dry and compacted soils.