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# Root moisture content influence on root tensile tests of herbaceous plants

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ABSTRACT

Root tensile strength controls root reinforcement, but a range of factors including root moisture and diameter have such a large impact that it is difficult to make predictions. In this study, we measured how variable root moisture content affects the relationship between root diameter and root tensile strength of herbaceous plants. Fresh roots of two herbaceous plants, *Heteropappus altaicus* and *Poa sphondylodes* were divided into four groups: (i) saturated in water, (ii) kept fresh, (iii) or dried for 6 h or (iv) 12 h in air. Root diameter and mechanical failure under tension before and after the moisture treatment were measured. Tensile strength and tensile force of both species decreased linearly while mean root diameter increased linearly with increasing root moisture content. Root moisture content has a large impact on the variability of root tensile strength. This emphasizes the need to avoid desiccation during testing. In field impacts of soil water potential on root strength requires further study. We recommend soaking roots in water before testing to decrease this source of error.

## 1. Introduction

Vegetation can protect slopes from shallow landslides by mechanical reinforcement effect of the root system underground (Gray and Sotir, 1996). The type, distribution, dimension and tensile strength of roots control reinforcement (Hales et al., 2009; Loades et al., 2010; Stokes et al., 2008), with seasonal differences resulting due to root age, desiccation and soil properties (Pollen, 2007; Wynn, 2004). From investigations of the failure of roots in landslides and by conducting direct shear tests on soil columns permeated with roots, several models of root reinforcement have been developed. These include the simultaneous breakage model of perpendicular or angled roots (Waldron, 1977; Waldron and Dakessian, 1981; Wu et al., 1979), or more recently the fibre bundle model (Pollen and Simon, 2005) and the root bundle model (Schwarz et al., 2010) where roots break successively from weakest to strongest. These models need only a few parameters, usually the root tensile strength and the roots distribution and their diameters. However, the models are limited by the quality of data, especially root tensile strength that is affected by a large number of factors (Hales et al., 2013).

There are many ways to measure root tensile strength. In the field, it is usually measured by spring scales or self-assembled devices (e.g., Bischetti et al., 2005; Tosi, 2007), and in the laboratory under more controlled conditions by universal testing machines (UTM) (e.g., Ji et al., 2012; Mickovski et al., 2009; Zhang et al., 2012). Although UTM measurements are more precise and spring scales are seen as unreliable as the test speed cannot be precisely controlled, similar tensile strengths have been measured using either of these different measuring tools (Hales et al., 2013). Test speed may not be very important for testing as speeds of 10 mm/min or even 400 mm/min have been found to have no significant effect on tensile strengths (Zhang et al., 2012). In field tests, roots are pulled with one end clamped by devices and one end in soil. This is more realistic of failure conditions that would occur during a landslide than tests with a UTM, as root failure can occur through either breakage or pull-out. Breaking roots are similar to roots in laboratory tests while pull-out may be weaker than roots in laboratory tests (Pollen and Simon, 2005). The strength of pulled out roots is controlled by the friction between the root segment in soil and the surrounding soil, which is affected by changes in soil moisture content (Pollen, 2007). Roots extract water from soil when the soil is wet and desiccate when the soil is too dry (Dodd et al., 2015).

A root system is a complex 3D network that varies between plant species by age, root type, orientation, branching patterns, interface properties with soil, and diameters. All of these factors cause a large variability in root tensile strength. For an individual species, diameter significantly affects root strength, prompting diameter vs strength relationships to be commonly used for parameterizing root reinforcement models. Smaller diameter roots are stronger than bigger roots, caused by the distribution of flaws with specimen size, the development of aerenchyma (Loades et al., 2013) and the chemical composition of the

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root tissues. Cellulose content (Genet et al., 2005) or lignin content (Zhang et al., 2014) are important to root strength and increase with decreasing root diameter. Root moisture content also affects the strength of tree roots (Turnmanina, 1965), with varying root moisture content with seasons driving changes in root strength, as dry roots are weaker than wet roots. Hales et al. (2013) and Yang et al. (2016) later also observed the phenomena that root tensile strength decreases with increasing root moisture content. However, the specific relationship between root tensile strength and root moisture content has not been characterized, particularly as affected by a decrease in diameter that may occur as a root desiccates. Moreover, studies to date have been limited to woody species. Diameter decreases would be expected to be greater in herbaceous species. Diameter is a key parameter in calculating root tensile strength from the tensile force and cross-sectional area. Many studies have explored how the moisture of wood affects its size. Moisture in wood takes two different forms: free water that is stored as liquid and vapour in cell cavities or vessels of the wood, and bound water that is held within the cell walls. When all free water has moved out of the cell, leaving only bound water saturating the cell walls, wood reaches what is called the fibre saturation point (FSP) (Smith, 1987). At and above the FSP, wood does not shrink or swell as it only has changes of free water. To our knowledge, there is no other research on the effects of root moisture content on root diameter of herbaceous species.

Therefore, this study aims to (1) find the relationship between root moisture and root tensile strength of two herbaceous plants, *Heteropappus altaicus* and *Poa sphondylodes*, in Northern China, (2) investigate whether root moisture affects root diameter, tensile force, and their relationship and (3) discuss how to account for variable root tensile strength under different root moisture content conditions. The research can provide a basis for understanding how soil moisture variability in time and space may affect root reinforcement of slopes in addition to developing testing approaches with fewer artefacts. Although slopes are less likely to fail when soils are dry, delayed root hydration during intense rainfall on a dry slope could diminish overall root reinforcement.

## 2. Materials and methods

### 2.1. Root sampling

Roots were collected from two typical herbaceous plants, *Heteropappus altaicus* and *Poa sphondylodes*, on the mountains of western Taiyuan City (37° 84′ N, 112° 46′ E), Shanxi Province, China (in the Loess Plateau where serious soil erosion is happening), in May with temperatures between 10 °C and 25 °C. The plants were established to control severe soil erosion in this area and are native species. The area has a typical warm and humid subtropical monsoon climate with an annual rainfall of 468 mm and an annual mean temperature of 9.5 °C. The soil in this area is mainly classified as Semi-Luvisols (CRGCST (Cooperative Research Group on Chinese Soil Taxonomy), 2001).

Roots were placed with its original soil in insulated boxes above ice and taken quickly to the laboratory to keep roots fresh. In the laboratory, roots were selected from the soil carefully. Intact and straight roots were cut with scissors to 50 mm length, put in plastic bags, and then refrigerated at 4 °C. Roots were selected to cover a broad range of diameters from 0.10 to 2.22 mm (*Heteropappus altaicus*) and from 0.05 to 0.23 mm (*Poa sphondylodes*), with a total of 400 roots sampled from each of the plant species. Tests on roots were finished within 7 days of sampling. To detect water content background of soil where roots sampled, soil water content by weight was measured after drying at 105 °C in an oven and weighing.

### 2.2. Root treatments

To achieve different root moisture contents, fresh roots of the two species with a length of 50 mm were divided into four groups to be treated. The first group of roots was soaked in water to saturation (Saturation). When roots were soaked and weighed at half an hour intervals until no additional weight increase was observed, roots were regarded as saturated, which took 6 h. The second group was kept fresh (Fresh) and stored for 6 h before testing. The third group was air-dried for 6 h (Dried 6 h) at approximate 20 °C and 30% relative humidity in a laboratory. The last group was air-dried for 12 h (Dried 12 h) in the same laboratory. Root moisture content (*RMC*) of each group was measured after drying at 105 °C in an oven and weighing. Relative root moisture content (*RRMC*) was defined here as the proportion of *RMC* of roots to *RMC* of water saturated roots ($RRMC = RMC_{act}/RMC_{sat}$).

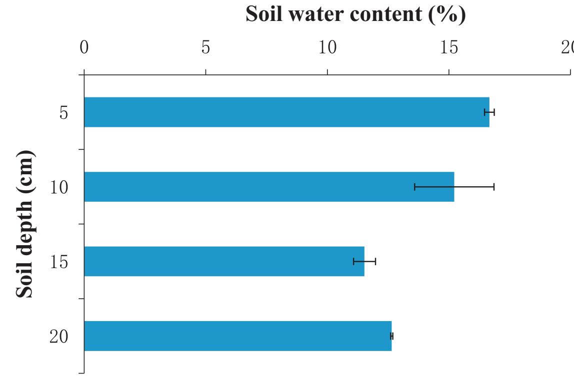


**Fig. 1.** Soil gravimetric water content at the time of sampling roots from the field. Vertical bars represent standard error of the means (SE).

### 2.3. Root diameter measurement tests

Root diameter (*D*; 84 *Heteropappus altaicus* samples, 45 *Poa sphondylodes* samples) was measured using a digital vernier calliper with an accuracy of 0.01 mm. Digital callipers were used instead of microscopes as it is quicker to conduct and results are similar to microscopes so unlikely to produce systematic differences in measuring root diameter (Hales et al., 2013). Each 50 mm length root section was measured repeatedly at three positions: two points at a distance of 10 mm from the two ends and the middle point. The mean value of the three duplicates was considered as the *D*. To observe the variation of root diameter under different root moisture contents, the broad range of root diameters sampled from the field were measured at the same positions of the roots under fresh status ($D_F$) and treated status ($D_T$).

### 2.4. Root tensile tests

Root tensile tests were conducted using a spring dynamometer with an accuracy of 0.1 N and some auxiliary equipment including a stand and top and bottom grips. The top and bottom grips were connected to the stand and moved in direct line with each other to allow for accurate tensile displacement of the root specimen. The grip separation was set to 50 mm. Before conducting root tensile tests, root diameter was measured ($D_{observed}$) as described above. Roots breaking in 20 mm distance from the centre position were considered valid tests, because root failure near the clamps could be due to damage. The tensile strength (*T*) was calculated by dividing the maximal force required for failure (*F*) by the root cross-sectional area. From the initial batch of 400 root samples for each species and moisture treatment, between 31.5% (126 *Heteropappus altaicus* samples) and 32.0% (128 *Poa sphondylodes* samples) successful tensile tests resulted.

### 2.5. Data analysis

We introduced relative root diameter (*RRD*) to identify the

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