Quantifying soil reinforcement by fibrous roots

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Abstract

Reinforcement of soil by fibrous roots is crucial for preventing soil erosion and degradation, yet the underlying mechanisms are poorly understood. Without fully understanding root enmeshment within the soil matrix, and root biomechanical properties key for increasing soil shear strength, adoption in main stream civil engineering, understanding of natural systems and implications to agricultural soil management will be limited. Within this thesis the underlying processes that drive root reinforcement of soils were assessed through a variety of laboratory and field based experiments. This included recent advances in geotechnical engineering and model plant lines with specific root traits. Plant lines were barley (*Hordeum vulgare*) from a mapping population where differences in root hairs, tortuosity and lignin biosynthesis were previously identified by screening large numbers of mutants.

The initial hypothesis was that root numbers and area would control shear reinforcement, this was tested by altering planting density in both glasshouse and field experiments using one barley variety. After 5 weeks in the field, planting density was related to both reinforcement and root area ratio (RAR), with a 6.7 ±1.40 kPa, or 190%, increase in shear strength between 0 and 950/m^2. By 20 weeks in the field shear strength increased by only 29%. The glasshouse study showed an increase of 53%, with a positive correlation to planting density. Relationships between root number and shear strength were not, however, explicit highlighting further possible interactions between soil shear strength and root inclusions.

Various underlying processes were then investigated. Barley mutants, with differences in root hairs and tortuosity, were compared to parent lines. Hairless mutants had different root tensile strength characteristics, but experimental difficulties (malfunctioning logging hardware) prohibited detection of impacts on shear strength. A refined study was then

performed that also incorporated the influence of abiotic stress from compaction and water-logging. Barley with down-regulated lignin biosynthesis (Bowman 140) had increased nodal root tensile strength of 37% compared to the parent line (Bowman Line) under good growth conditions, but this changed to -31% for compacted and 26% for water-logged soil. In addition to abiotic stress, the age of the roots (measured as distance from root tip) type of root (seminal, nodal or lateral) had a large impact on biomechanical behaviour.

Orientation of roots and associated root movement during shear was assessed using Particle Image Velocimetry (PIV) techniques. PIV tracked movement of soil particles and roots at pixel resolution within a sequence of high definition digital images. Root deformation and strain were found to be dependant on root orientation to the shear force. A number of pre-failure changes in root form were also found and were dependant on orientation prior to ultimate failure, through roots either pulling out of the soil (pull-out) or breaking. Patterns of strain along root lengths were also shown to be influenced by orientation.

Conventional catastrophic failure mechanism models were compared to more recent fibre bundle models (FBMs) incorporating progressive failure. The earlier model significantly over predicted reinforcement in 75% of those modelled. Recently developed FBM models were shown to be more accurate, however, variability still existed. The strain based FBM over predicted reinforcement in 70% of the cores with the stress based FBM only over predicting in 46% of cores, highlighting increased model accuracy.

Publications

Loades, K. W, Bengough, A.G., Bransby, M.F. and Hallett, P.D. (2011), Fibrous root reinforcement of soils. American Society of Agronomy, Enhancing Understanding and Quantification of Soil-Root Growth Interactions (D. Tilman and L. Ahuja, Eds), under review.

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