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State of the knowledge of vegetation impact on soil strength and trafficability

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ABSTRACT

Researchers in a variety of fields have studied using vegetation to alter or reinforce soils. However, using vegetation for soil preservation in long-term land management of military training areas used for off-road vehicle maneuvers is more recent. Much of the work reported in the literature deals with trees and larger shrubs, appropriate for slope and bank stabilization. Other research efforts are for agricultural or forestry applications and involve crops, and again, large trees. This review discusses the issue of vegetation and its effect on a variety of soil strength parameters. It also reviews work regarding the effect of vehicle operations on vegetation and conversely the effect of vegetation on vehicle performance, or trafficability. The reviewed test methods and proposed soil strength models, based on a variety of soil properties, provide a basis for continuing work on models to evaluate areas used for off road military vehicle operations.

Contents

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1. Introduction

Researchers in a variety of fields have studied the use of vegetation to alter, stabilize or reinforce soil surfaces or soil masses. Slope and stream-bank stabilization, erosion control, and agricultural crop yield are areas of significant work. Other researchers have looked at the effects of a variety of tracked and wheeled vehicles on vegetation. However, investigating vegetation with regard to impacting soil strength, and therefore improving off road vehicle mobility and performance, while maintaining the ground surface integrity, is more limited.

This review discusses several vegetation applications and their effect on a variety of soil-strength parameters. It discusses the main study areas found in the literature; testing procedures used to evaluate soils, roots, and root–soil composites; and the specific issues of vehicle impacts on soils and vegetation, and finally vehicle/terrain interactions.

2. Slope stabilization

Stabilizing slopes to minimize landslips is a common use of vegetation as soil reinforcement. Because most soils have very low strength in tension, the roots of surface vegetation act as a fiber network and provide tensile strength to the soils analogous to the reinforcing steel in concrete. This is especially helpful in saturated soils that are even less likely to have strength in tension. Schmidt et al. (2001) investigated slope stabilization of forested areas with the intent of looking at the age and type of vegetation as a variable in the effectiveness of the slope stabilization. The vegetation studied included coniferous and deciduous trees with significant understory and also replanted areas that had previously been clear-cut. They found that reinforcement could not only be predicted by age of the vegetation but also that it is strongly affected by the vegetation mix, especially when comparing natural forests to those previously cut. Terwilliger and Waldron (1991) found that both small and large slips were more likely on slopes with evenly distributed, low magnitude reinforcement, such as under grasslands, than on hillsides with scarce but relatively large root reinforcements, such as under chaparral dominated by native chamise (*Adenostoma fasciculatum* H. & A.). The chaparral offered randomly spaced but relatively high magnitude reinforcement of the soil surface. The magnitude of the root reinforcement depends on a number of factors, including the total number of roots, the area of the thickest root, and the ratio of the cross-sectional area covered by roots to the total cross-sectional area of the soil-shearing surface.

Preti and Giadrossich (2009) looked at Spanish Broom (*Spartium junceum* L.), a shrub used for slope bioengineering stabilization through root reinforcement. Their investigation included laboratory testing of root tensile strength; measurement and calculation of mean root number, mean root diameter, root area ratio (RAR); and calculation of root cohesion and the factor of safety for the slope. The RAR is the ratio between the cross-sectional area occupied by roots and the cross-sectional area of the rooted soil. RAR varies with species, location, and depth, and is also strongly influenced by genetics, local soil and climate and by forest or other land management practices (Bischetti et al., 2005).

Using their tensile-strength testing data and models by others (see Section 5.1), Preti and Giadrossich (2009) found that planting a steep slope with Spanish Broom provides a considerable increase in cohesion of the surface soil layers. However, their more thorough look at the Wu (1976) and Waldron (1977) root–soil model for soil cohesion indicated a tendency to overestimate the root cohesion. Section 5.1 will discuss this further.

Ali (2010) looked more closely at the mechanical properties of roots for slope stabilization. He investigated both the tensile strength of roots and the pullout strength of the plant. He worked with three species of plants (*Leucaena leucocephala*, *Acacia mangium* and *Melastoma malabathricum*) and found the following: (1) Pullout capacity exhibited two peaks, the first indicating the failure of the lateral roots, the second the failure of the taproot. (2) Root tensile strength decreases with increasing root diameter, as Section 7 will discuss.

Abdullah et al. (2011) conducted field-shear box tests on three plants, two trees (*Acacia mangium* and *Leucaena leucocephala*) and a shrub (*Dillenia suffruticosa*), commonly used for slope stabilization in Malaysia. The soil type of the test area was not identified. They noted that plants with heart root systems, where both large and smaller roots descend diagonally from the stem or trunk, provide a greater increase in soil cohesion compared to taproot systems, where a strong main root descends vertically from the underside of the stem or trunk. Heart root systems also contribute more root coverage for a wider area of the topsoil, reducing shallow landslides. Their results indicated that the shear strength of most root–reinforced soil samples increased gradually with increasing plant stem diameter.

Hu et al. (2013) investigated using direct shear and triaxial tests for both rooted and unrooted soils by using five shrub types while analyzing strategies for reducing shallow landslide activity. They also directly tested roots in single tensile and shear tests and found that the internal friction angles of both the root-soil composite systems and the soil without roots were similar. However, the cohesion forces of the root-soil composite were notably higher than the soil without roots, increasing by 29.4–394.6%. Their preliminary findings indicated the greater the percentage of secondary phloem (bast fiber) and xylem (wood fiber) in the root cross section, the higher the root strength (single tensile resistance and tensile strength).

3. Erosion control

Using vegetation to preventing surface erosion, without intent to provide any additional surface strength, has also been widely studied. Brown et al. (2010) looked at the root depths of 16 native and five amenity grasses used as roadside plantings. Using test soil columns containing four plants, with n indicating the number of replicate columns, they found a variety of root depths as shown in Fig. 1. Also, visually estimating the percent of vegetation cover, they observed a significant difference in the survival rate of the different grasses planted at a roadside location (Fig. 2). They concluded that the ability to establish and maintain a sodded surface is a significant consideration, as grasses that do not survive cannot provide benefits, and that grasses with shallower root depth tend to produce sod that sloughs under heavy rain conditions.

Gyssels et al. (2005) completed a review of the impact of plant roots on the resistance of soil to water erosion. They found that vegetation cover is the most important parameter for splash or interrill erosion, whereas for rill and ephemeral gully erosion, the plant roots are at least as important as the vegetation cover. From a hydrological point of view, plants reduce soil erosion rates by intercepting raindrops, enhancing infiltration, transpiring soil water, providing additional surface roughness, and adding organic matterial to the soil. Their comparison of previous studies showed a large discrepancy between data gathered in the field and data obtained from laboratory experiments. They attribute this discrepancy to thigmomorphogenesis, the change in morphology and the mechanical properties of a plant due to the contact disturbances such as friction with neighboring plants or passing animals, wind, rain, changes in soil pressure, and other factors. Plants grown in natural conditions will be shorter, and stockier with more supportive features, and therefore stronger than plants grown in