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Root reinforcement effect of different grass species: A comparison between experimental and models results

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ABSTRACT

Root systems effects along the slopes are widely investigated with the aim to quantify the contribution to prevent soil erosion. Previous studies and methodologies have been carried out to estimate the additional cohesion provided by roots to the soil. In this research five grass species were tested, two of them (*Festuca pratensis* and *Lolium perenne*) belonging to the Poaceae family, while *Trifolium pratense*, *Lotus corniculatus* and *Medicago sativa* are three species of the Fabaceae family. We realized in situ tests in order to quantify the contribution of the root system to the soil shear strength, and laboratory tests estimated the root tensile strength of the different species. Laboratory data and root area ratio (RAR) values, measured during the field tests, were used to implement the models of Wu et al. [Wu, T.H., Mckinnell, W.P., Swanston, D.N., 1979. Strength of tree roots and landslides on Prince Of Wales Island, Alaska. Can. Geotech. J. 16, 19–33], and of Pollen and Simon [Pollen, N., Simon, A., 2005. Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model. Water Resour. Res. 41]. These models are widely used in the literature to simulate the roots behavior in soil during a shallow landslide phenomenon. The in situ measured shear strength values were compared with the models outcomes, verifying if the models describe well the natural behavior of the five tested species. The experimental tests provided a measured value about the effective increase (in percentage) of soil shear strength at 10 cm depth, due to the presence of root systems (i.e. the percentage increase given by *T. pratense* is 515%). Some discrepancies between the experimental tests and the models results became visible. The applied models do not account for some complex factors involved in the soil reinforcement. The root–soil matrix should thus be characterized by mechanisms not fully captured by the W&W and FBM models.

1. Introduction

The contribution of vegetation to the stability of slopes has been widely investigated and discussed. Starting in the 1960s, several researchers have studied soil reinforcement given by the presence of root systems (Megahan and Kidd, 1972; O'Laughlin, 1974; Greenway, 1987). The stabilizing effect of vegetation is essential in preventing shallow landslides (Abe, 1997; Gray, 1995; Genet et al., 2008), in the control of water erosion (De Baets et al., 2007) and in remediation works based on soil bioengineering techniques, to such an extent that vegetation is considered as a building material (Schiechtl, 1980).

Plant roots reinforcement in soil affecting both mechanical and hydrological properties. The mechanical reinforcement effect (increase of soil shear strength) is studied by modelling roots as fibers inclusion within the soil matrix. The mechanical properties of the root–soil system are regulated by a combination of soil strength, single root strength, the interface strength between soil and roots (Waldron and Dakessian, 1981; Waldron, 1977) and the morphological characteristics of the root systems (Di Iorio et al., 2005, 2008; Chiatante et al., 2003; Dupuy et al., 2005). The hydrological effects are studied investigating the relationship between soil water and root profile (Coppin and Richards, 1990; Gray and Sotir, 1996; Normaniza and Barakban, 2006), and the root water uptake (Doussan et al., 1998; Fatahi et al., 2009).

Several studies have documented the relationship between mechanical and hydrological factors: Fan and Su (2008) and Pollen (2007) studied the effect of soil moisture content on the shear strength of root-reinforced soils; Normaniza et al. (2008) showed the connections between root reinforcement and water absorption capacity; Normaniza and Barakban (2006) suggested that both the soil moisture content and the root length density (RLD) could be used as indicators of slope stability.

The present research deals with the study of the effect of root reinforcement of grass species in terms of the additional shear strength provided by roots in rooted soils (mechanical root effect).

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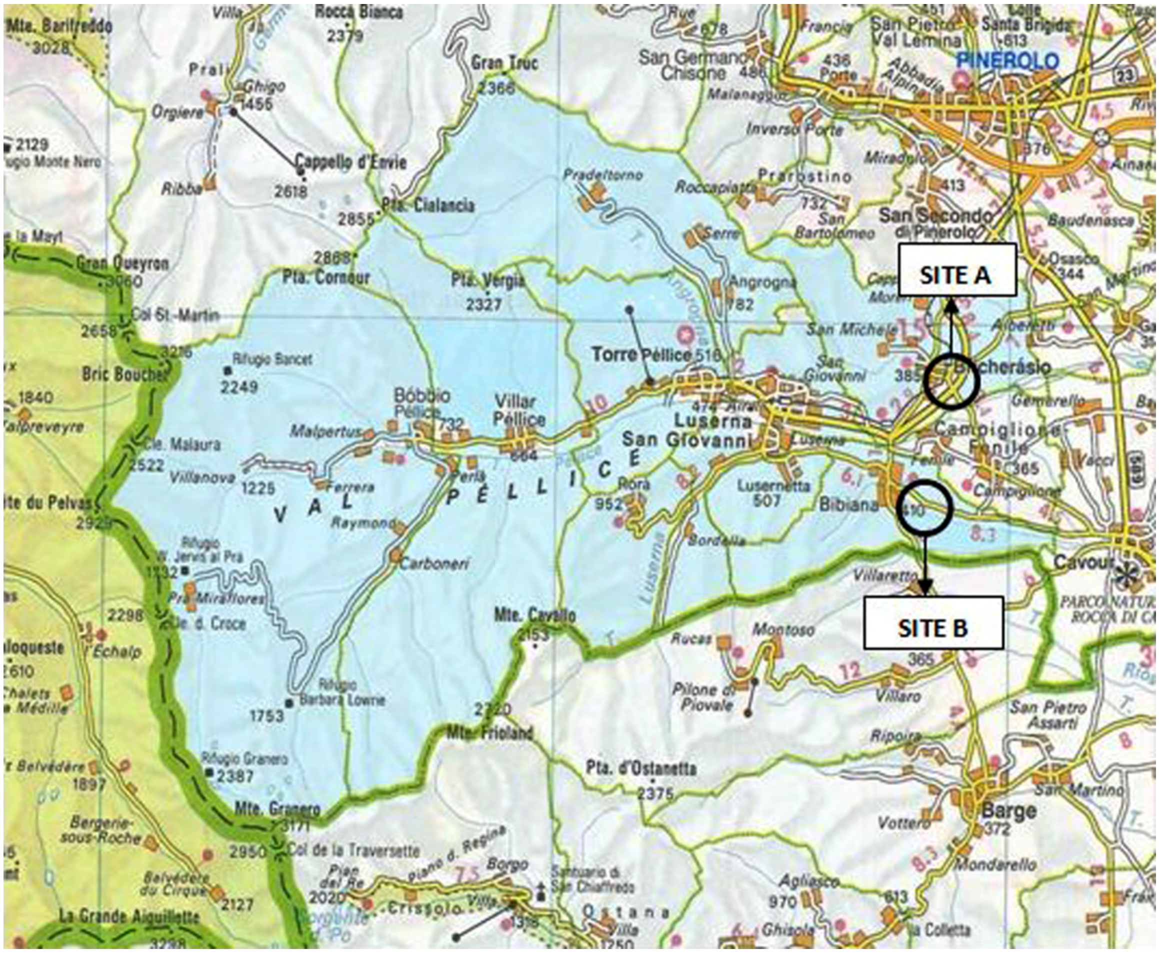

Fig. 1. Map showing the location of the sites where the field tests were carried out.

Laboratory shear tests (Loades et al., 2009) and in situ shear tests (Fan and Su, 2008) on root-reinforced soil blocks have been conducted by several researchers, in order to quantify the root reinforcement effect. In addition, analytical models for soil–root interactions have been developed. The first model considered the root contribution as a cohesion term added to the Mohr–Coulomb equation for soil strength (Waldron, 1977; Wu et al., 1979). It models roots as fibers crossing perpendicularly the shear plane and failing all at the same time, with the soil heavily reliant on the root area ratio (Loades et al., 2009). A recent model (known as the *Fiber Bundle Model*), developed by Pollen and Simon (2005), considers roots as fibers bearing load with load redistributed as fibers break (Daniels, 1945), with progressive failures.

In this research five grass species were tested with the purpose to estimate the root contribution to the soil reinforcement. Grass species belonging to the Poaceae (*Festuca pratensis* and *Lolium perenne*) and Fabaceae (*Lotus corniculatus*, *Medicago sativa* and *Trifolium pratense*) families grew up in field and were tested in situ with an experimental equipment (Comino and Druetta, 2009) to measure the clods shear strength. In this way it was possible to obtain a mean value that characterized the soil reinforcement arising from each species. Laboratory tests were also carried out in order to evaluate the tensile strength of single root specimen.

The field data were compared with the models output values. The latter were obtained by the elaboration of the laboratory data implemented using two different models (Wu et al., 1979 and the Fiber Bundle Model: Pollen and Simon, 2005). In this way we tried to evaluate the reliability of the models to describe the field data set. According to Loades et al. (2009) the considered models are limited in their predictions because they involve only part of the main parameters that rule the root–soil interactions.

2. Materials and methods

2.1. Sites description

The in situ tests were conducted in two different sites, Ghiaie (*site A*) (380 m a.s.l.) and Bibiana (*site B*) (400 m a.s.l.) (Fig. 1). Both sites are located in an Italian Alpine environment, the Pellice Valley in the West part of the Piedmont region (Comino and Druetta, 2009). *Site A* (Ghiaie) is characterized by alluvial deposits (Oleocene), gravel and sand of different grain sizes. *Site B* (Bibiana) is characterized by ancient alluvial deposits with a considerable percentage of clay and silt. The grain size analysis sampled soil at 30 cm for both sites, while the in situ tests involved only 10–15 cm of depth. Pluviometric monitoring (placed in the Luserna San Giovanni station) realized by the Regional Environmental Protection Agency (ARPA Piedmont, 2005) during last twenty years, measured a mean annual precipitation of 1092.3 mm. Snowfall events are frequent in the upper part of the valley in the period between November and April, while rainfall events are more common in the spring and autumn with peaks in May and September.

2.2. Grass species

Five different grass species were tested. Three of them are part of the *Fabaceae* family: *M. sativa*, *T. pratense* and *L. corniculatus*. These species have common characteristics typical of their family,