Proceedings RootS25
3rd International Workshop on Soil-Vegetation-Atmosphere Interaction
Boldrin D, Cecconi M, Cotecchia F, Leung A, Pedone G, Perrini P, Romero E, Tagarelli V, Zdravković L (eds)
ISSN: 3107-300X

doi: doi.org/10.53243/RootS2025-26

In-situ and laboratory mechanical tests for assessing the potential effect of vegetation cutting on shallow landslides in the source area of a debris flow

A. Lepri[1] , A. Fraccica[2] , M. Cecconi[1]

[1]*CIRIAF-Department of Engineering, University of Perugia, Perugia, Italy*
[2]*Department for the Geological Survey of Italy, ISPRA, Rome, Italy*

ABSTRACT: The paper presents the results of in-situ and laboratory tests aimed at evaluating the effects of tree cutting on shallow soil movements which are considered responsible for sediment recharge in a debris flow's source area. The study area (Central Apennines, Italy) was affected by debris flow events in 2012 and 2015, following intense rainfalls. The debris flow source area is close to parcels of beech tree cutting observed in the previous decade on the surrounding steep slopes. Experimental investigations were performed on the rooted and bare soil, to explore the differences in terms of soil shear strength, volumetric behaviour, and water retention properties. A large set of direct shear tests were performed at different hydraulic initial conditions. In the paper, only dry conditions are explored. Roots contributed to enhance the soil shear strength although inducing higher collapse and volumetric strains. In-situ corkscrew tests enabled the measurement of rooted-soil shear strength on the slopes close to the source area. Experimental results were mapped and interpreted within an effective stress formulation for partially saturated soils: even if preliminary, some trends of shear strength decrease were observed within the cut areas.

Keywords: vegetation's cutting effects; rooted soil's shear strength; lab. tests; in situ corkscrew tests

1 MOTIVATION OF THE STUDY

The southern portion of the Mounts Sibillini National Park, at the boundary between the Umbria and Marche regions in Central Italy, is the subject of ongoing experimental research (in situ and laboratory tests) aimed at evaluating the hydro-mechanical properties of rooted coarse-grained soils. The motivation of the study stems from the interest in understanding the potential effect of vegetation cutting on shallow landslides in the source area of debris flows which occurred in 2012 and 2015, upstream of the village of Nottoria, south of Norcia (Perugia), following heavy rainfall. The debris flow deposit covers a carbonate complex consisting mainly of dolomitic limestone and massive limestone formations. The whole territory of the Mounts Sibillini is rather heterogeneous: the landscape is characterised by limestone mountains, with peaks rising to over 2000 m, which alternate with karst plateaus.

The debris flow channel currently exhibits pronounced erosional features, with incised grooves reaching depths of up to 2 m. These morphological characteristics are the result of concentrated water runoff and subsequent material mobilization. The slopes adjacent to the debris flow source area are predominantly mantled by beech stands of varying ages.

The debris cover lying above the rocky substrate, in these zones, consists largely of coarse-grained deposits, derived from the weathering and reworking of limestone formations. Such lithological and geomorphological conditions provide a significant sediment supply, thereby contributing to the initiation and evolution of debris flow processes in the area.

In this paper, the shear strength properties of dry rooted and unrooted soils from the slopes surrounding the debris flow source area, are presented. The results of laboratory and in-situ tests are then compared, with the purpose to define a pattern of behaviour of the rooted soil and infer possible areas of instability.

Some outcomes of the study have already been published in Lepri et al. (2024, 2025) and Fraccica et al. (2025, a-b).

2 SOIL AND VEGETATION

The forest at the study site is predominantly composed of beeches (*Fagus sylvatica*), deciduous mountain trees found at altitudes of 1000-1800 m a.s.l. The intense and prolonged vegetation cutting in the past has led to forest fragmentation (Figure 1). From the available documentation, it is ascertained that the forest management in the Park is a coppice (Borfecchia et al., 2006); however, the adopted criteria for cutting applied in this region of the Park, which presumably occur every 20 years, are not yet known to the authors.

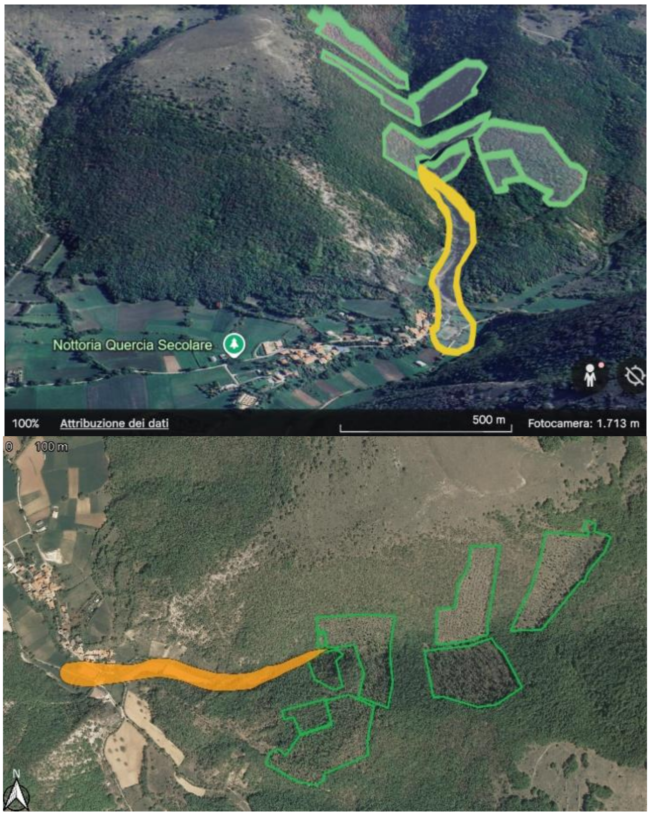

Figure 1. Google Earth (3D oblique view at top) and plan (at bottom) views of the study site with green polygons showing the cut areas and the orange polygon representing the debris flow area from the IFFI's database.

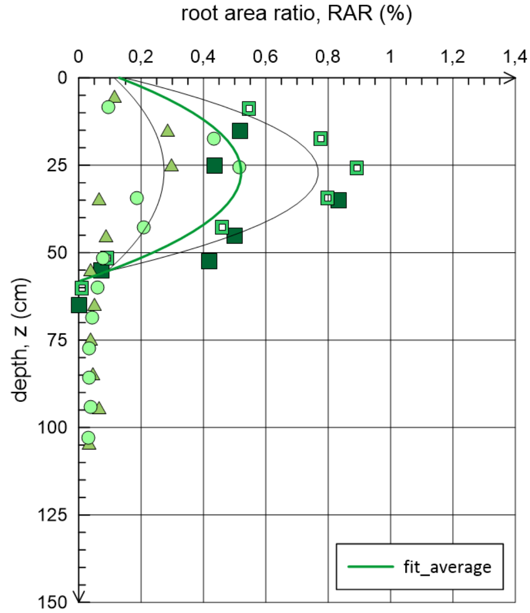

Figure 2. Assumed RAR profile for beech tree roots' type (following Bischetti et al. 2009, adapted from Fraccica et al., 2025a)

Root architecture is commonly described in the literature through the root area ratio, varying with depth, defined as the ratio between the total root cross-sectional area (A_r) and the soil area considered (A_s), RAR(z) = A_r/A_s. This parameter is usually determined in trenches dug into the ground. The total root area A_r is the sum of all the section areas of the roots crossing the horizontal soil area (A_s) at the bottom of the trench. For the root types detected in situ, the assumed RAR profile is plotted in Figure 2 (following Bischetti et al. 2009). From this profile, it is possible to calculate the mechanical reinforcement of soil by roots in terms of "conventional" soil cohesion increase (e.g.: Mao, 2022; Wu, 2013), by using the following equation:

$$\Delta c_{roots}(z) = \Delta\tau_{roots}(z) = k\,\mathrm{RAR}(z) t_r \qquad (1)$$

whereas coefficient k = 0.265 is calculated based on in situ corkscrew measurements, while an average root tensile strength t_r = 33 MPa is assumed based on the mean root diameter (roots diameter between 1.0 and 4.5 mm, see Fraccica et al., 2025a, Brigante et al., 2025). A cautious range of values for $\Delta\tau \cong 10 - 20$ kPa is calculated for the considered rooted topsoil.

A specific focus of the ongoing research concerns the evaluation of the roots' system architecture (geometric features) such as the roots' diameter, length, and root volume ratio $R_v = V_{roots}/V_{tot}$ since all these quantities may affect the rooted-soil hydraulic behaviour (e.g. Cecconi et al., 2025; Capobianco et al., 2025; Fraccica et al., 2024, 2019; Leung et al., 2023; Tagarelli et al., 2024). As an example, for the first measuring depth in a trench, R_v is the sum of the volumes of all the roots that were found above that depth in the trench, normalised by the bulk volume of material excavated until that depth. Due to the complexity of measuring the RAR, it is planned to characterize the Root Volume Ratio R_v in-situ. For consistency, the R_v is determined for laboratory tests, too.

With this goal in mind, an original photogrammetry-based method (still in progess) is proposed in a companion paper to this Workshop (Brigante et al., 2025).

In the investigated area, the topsoil constituting the surrounding slopes delimiting the debris flow granular deposit is made of well graded medium dense gravels and sands (from GW to SW, according to USCS classification), with very angular grains (see Fraccica et al., 2025a).

3 SHEAR STRENGTH PROPERTIES OF DRY ROOTED SOILS

Conventional direct shear tests were performed on remoulded bare and rooted soil samples, prepared in dry conditions (oven-dried samples) at initial target void ratios $e_0 \cong 1$ (Fraccica et al., 2025b), inside a circular shear box (dia. = 50 mm).

Tests were performed at vertical effective stress of 50, 100, 200 kPa. For both bare and rooted samples, the observed behaviour was ductile: generally contractant for the rooted soil and moderately dilatant for the bare

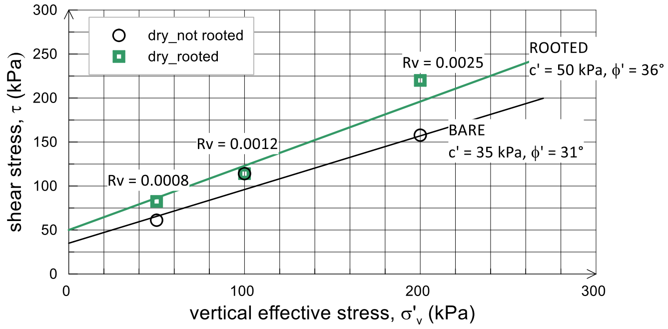

Figure 3. Failure envelopes for bare and rooted samples (from conventional direct shear tests)

samples, especially at the lower applied stress levels, as expected.

The adopted Mohr-Coulomb failure envelope is shown in Figure 3, which shows the clear beneficial effect of roots on the shear strength parameters. In the figure, for each failure point the value of the root volume ratio R_v is plotted (see previous §2); the slightly smaller value of τ_{max} for the rooted sample tested at $\sigma'_v = 50$ kPa could be reasonably attributed to the lowest value of $R_v = 0.8\times10^{-3}$. The induced roots cohesion increase $\Delta c_{roots} = 15$ kPa (from bare to rooted samples) reasonably falls in the range of values deriving from Equation (1).

4 IN-SITU CORKSCREW TESTS

Specialised in-situ equipment was required to measure the shear strength of the soil–root system. To this end, an investigation was carried out with corkscrew tests, in-situ measurement of water content and suction. The corkscrew test evaluates the resistance of rooted soil by screwing a corkscrew into the ground and, subsequently, pulling it out.

The pull-out force of the screw–soil interface is measured using a load cell and soil-root shear strength is derived according to Meijer et al. (2018). Three testing depth intervals were chosen on this site (0–125 mm, 125–250 mm, and 250–375 mm). For consistency, the corkscrews were installed vertically rather than perpendicular to the slope, since slope inclination varied across the study site (30-40°). Tests at higher depths were not carried out due to large friction development at the soil-corkscrew interface, which made its advancement impossible. Figure 4 presents the results obtained in proximity to cut and uncut trees. In particular, uncut trees show higher scattering since both young and old trees were tested (trunk diameters between 0.10 m and 0.60 m), whereas regions with cut trees, where trunk diameters were more consistent (i.e. 0.30 m, on average), showed less scattered results. As a consequence, soil shear strength around cut trees show a clear trend whereas uncut trees show higher shear strength peaks as well as larger scattering. Testing in the vicinity of

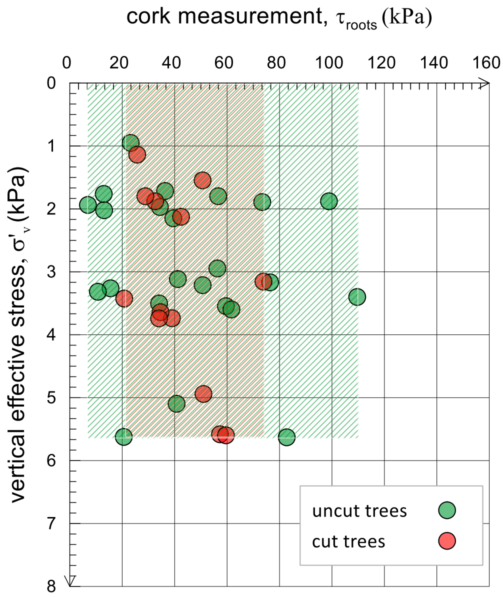

Figure 4. Corkscrew results vs. effective vertical stress for partially saturated soils

younger trees showed lower shear strength (i.e. below 20 kPa) due to poor root development. The results are presented as function of the vertical effective stress. For the latter stress, a Bishop's formulation for partially saturated soils was adopted, with degree of saturation S_r being equal to the Bishop's χ factor

$$\sigma'_v = \sigma_v - u_a + S_r s \quad (2)$$

with σ_v total vertical stress, u_a pore relative atmospheric pressure, S_r and s the degree of saturation and matric suction corresponding to each corkscrew test. Degrees of saturation were evaluated considering an in-situ void ratio $e = 1.52$ (see Fraccica et al., 2025a for more details).

Finally, Figure 5 presents the vegetated soil shear strength measurements on the map, within the cut and uncut areas: higher shear strength peaks were observed within the latter area. Additional measurements will be taken in both areas to improve the comparison.

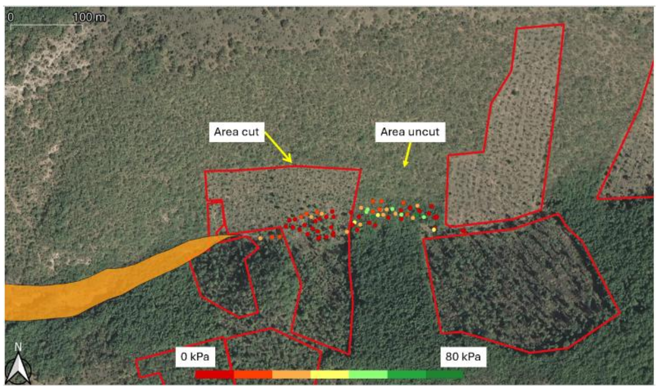

Figure 5. Corkscrew points at 0-12.5 cm depth with "τ_{roots}" colour scale

5 CONCLUSIONS

The paper presents some mechanical in-situ and laboratory tests which are part of a study on the potential effect of extended forest tree cutting on the triggering of shallow landslides close to the source area of a debris flow. Direct shear tests on remoulded soil with and without vegetation showed marked differences: an increase of soil shear strength and a more contractant behaviour due to root presence.

In-situ corkscrew tests gave some insights on the effects of tree cutting on soil shear strength. Soil in proximity to uncut old trees and within the uncut study area exhibited higher shear strengths, comparing points at similar effective vertical stresses formulated for partially saturated soils.

The study will progress with more laboratory and in-situ tests with the aim of correlating vegetation morphological and mechanical features to soil hydro-mechanical behaviour and to infer areas of possible instabilities.

6 ACKNOWLEDGEMENTS

This study has been funded through a project under the Italian National Recovery and Resilience Plan (NRRP).

7 REFERENCES

Bischetti, G. B., Chiaradia, E. A., Epis, T., Morlotti, E. 2009. Root cohesion of forest species in the Italian Alps, *Plant and Soil* **324**, 71-89.

Borfecchia, F., Ciucci L., Dibari C., Fermanelli A., Iannetta M., Pedrotti F., Schino G., Terranova C. 2006. *Il Parco visto dallo Spazio (EOBEM),* Quaderno n. 11, Parco Nazionale Monti Sibillini, in Italian.

Brigante, R., Marconi, L., Lepri, A., Fraccica A., Cecconi, M. 2025. A 3D Imaging Method for in-situ non-destructive roots monitoring, submitted to the present *RootS25 - 3rd Int. Workshop on Soil-Vegetation–Atmosphere Interaction*, Bari.

Capobianco V., Fraccica, A., Anselmucci, F., Tagarelli, V. 2025. Nature-and bio-based solutions for ecosystem restoration, landslide hazard mitigation, and ground improvement: Research and application novelties, *Ecological Engineering*, 107710.

Cecconi, M., Tagarelli, V., Cotecchia, F., Pane, V., Anselmucci, F., Bertolini, I., Biondi, G., Boldrin, D., Capobianco, V., Cardile, G., Cuomo, S., De Vita, P., Fraccica, A., Meijer, G., Pagano, L., Pirone, M., Schwarz, M., Tarantino, A., Vaunat, J., Yildiz A. 2025. Soil-vegetation-atmosphere interaction for engineering applications: Recent multi-scale and multi-disciplinary insights, *Geomechanics for Energy and the Environment* **43**, 2025,100723

Fraccica, A., Romero Morales, E.E., Fourcaud, T. 2019. Multi-scale effects on the hydraulic behaviour of a root-permeated and compacted soil. *IS-Glasgow 2019–7th International Symposium on Deformation Characteristics of Geomaterials*, 1-5. EDP Sciences.

Fraccica, A., Romero, E., Fourcaud, T. 2024. Effects of vegetation growth on soil microstructure and hydro-mechanical behaviour, *Géotechnique* **75**(3), 293-307.

Fraccica, A., Lepri, A., Papini, N., Cecconi, M. 2025a. On the measurement of in situ unsaturated shear strength of a beech-rooted soils, *E3S Web Conf., 5th European Conference on Unsaturated Soils and Biotechnology applied to Geotechnical Engineering* **642**, 2025.

Fraccica, A., Cecconi, M., Lepri, A., Tagarelli V. 2025b. On the measurement of laboratory and field retention states of a loose coarse and vegetated topsoil, submitted for the *21st International Conference on Soil Mechanics and Geotechnical Engineering, Vienna 2026.*

Lepri, A., Fraccica, A., Cencetti, C., Cecconi, M. 2024. A preliminary study on the possible effect of deforestation in debris flows deposits, *EGU24-15726*, Vienna, Austria.

Leung, A. K., Liu, J., Jiang, Z. 2023. When nature meets technology: AI-informed discovery of soil–water–root physical interaction. *In E3s web of conferences (ed. Bardanis)* **382**, 21001. Les Ulis, Paris, France: EDP Sciences.

Leung, A. K., Liu, J., Jiang, Z. 2023. When nature meets technology: AI-informed discovery of soil–water–root physical interaction. In E3s web of conferences (ed. Bardanis), **382**, article 21001. Les Ulis, EDP Sciences, Paris, France.

Mao, Z. 2022. Root reinforcement models: classification, criticism and perspectives. Plant Soil **472**, 17–28 (2022).

Meijer G.J., Bengough A.G., Knappett J.A., Loades K.W, Nicoll, B.C. 2018. In situ measurement of root-reinforcement using the corkscrew extraction method, *Canadian Geotech. J.* **55**(10), 1372–1390.

Tagarelli, V., Stasi, N., Cotecchia, F., Cafaro, F. 2024. Root-induced changes in the hydraulic properties of a fine slope cover. *E3S web of conferences* **544**, 16002. EDP Sciences.

Wu, T.H. 2013. Root reinforcement of soil: review of analytical models, test results, and applications to design. *Canadian Geotech J.* **50**, 259–274.