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/RootS2025-24

Influence of vegetation on the hydrogeological behaviour of a slope in pyroclastic soils

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ABSTRACT: A multidisciplinary study involving experts from various fields (botany, geology, climatology, geotechnics, and hydrology) has recently begun to investigate the role of vegetation cover on the stability of sloping pyroclastic deposits in Campania, southern Italy, that are frequently affected by rapid, weather-induced shallow landslides. The research, conducted in an experimental field situated on a 32° steep slope in Salerno, primarily aims to identify the detected plant species and assess their impact on the slope's hydrogeological behavior. The first objective was addressed through an investigation conducted at both the landscape and microhabitat scales. The second goal was pursued by using high-resolution atmospheric data (rainfall height, temperature, and air relative humidity) and soil suction and moisture content data (collected at different locations and depths). The goal consists of comparing the response of a naturally forested plot to that of a deforested one where vegetation was mechanically removed, thus inhibiting rainfall interception and lowering the physiological processes of the woody plants.

Keywords: field monitoring; slope hydrogeological behaviour; pyroclastic cover; vascular flora; vegetation

1 INTRODUCTION

Shallow landslides represent one of the most pervasive geohazards in mountainous and hilly terrain worldwide, resulting in significant economic losses and posing an annual threat to human lives. The stability of shallow soil layers (typically 0.5-3.0 m thick) is fundamentally controlled by the complex interplay between hydrogeological processes, soil mechanical properties, and vegetation characteristics. Understanding the quantitative mechanisms by which vegetation influences soil stability has emerged as a critical research priority, particularly in the context of climate change, leading to an increasing frequency of extreme precipitation events.

The role of vegetation in slope stabilization operates through two primary mechanisms: (1) mechanical reinforcement provided by root systems, and (2) hydrological modulation through canopy interception, root water uptake, and altered infiltration patterns. However, despite four decades of research progress, significant knowledge gaps persist regarding the temporal evolution of these processes, particularly following disturbances to vegetation, such as coppicing and forest fires. This study is primarily dedicated to investigating rainfall interception by plant communities.

2 STUDY AREA

A pyroclastic slope located in Campania (southern Italy) was selected as a test site to investigate the influence of vegetation cover on slope hydrogeological behaviour (Pirone et al., 2025a). The site, situated within a limestone quarry owned by Italsud Srl in the municipality of Salerno (coordinates: 40° 41′ 51″ N, 14° 45′ 16″ E), on the eastern flank of the Lattari Mountains, exhibits a high level of plant biodiversity subjected to anthropogenic pressures, such as wildfires (Stinca et al., 2021). This area has a documented history of flow-like landslide events, including the significant Molina landslide of 1954.

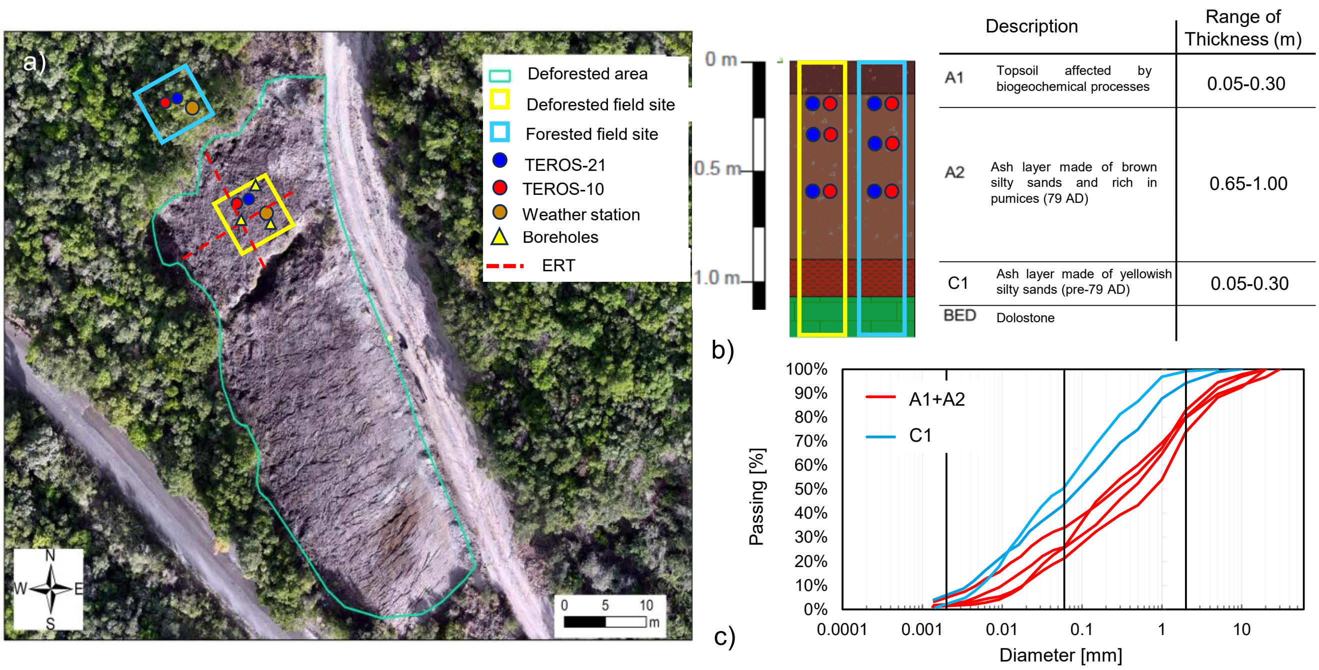

Figure 1. a) Map showing the location of boreholes, ERT survey lines, and instrumentation;b) mean stratigraphic profile showing soil layers and their thickness ranges and layout of instrumentation; c) soil grain size distributions

To assess the role of vegetation on slope stability, an area of approximately 700 m² was mechanically deforested in February 2024. Therefore, the study was conducted by comparing these two experimental conditions. The deforested area was subsequently selected for the development of the geological model (Fig. 1a). The slope inclination generally ranges from 25° to 30°, with localized areas exceeding 35° near the gully and the road cut. Geological and geophysical investigations revealed a pyroclastic cover approximately 1.3 m thick, overlying dolomitic bedrock. The stratigraphic sequence closely resembles that of another instrumented pyroclastic slope in the Lattari Mountains (Guglielmi et al., 2023; Pirone et al., 2025a,b). From top to bottom, the following soil layers were identified (Fig. 1b): A1, a biogeochemically active topsoil layer (5-30 cm thick); A2, a brown silty sand ash layer, rich in pumices from the 79 AD eruption (0.65-1.0 m thick); C1, a yellowish silty sand ash layer, predating the 79 AD eruption (15 cm thick on average), whose presence is discontinuous across the test site.

2.1 Soil properties

All layers consist of volcanic silty sands (Fig. 1c) and display geotechnical properties typical of pyroclastic soils in the Campania Region (Vitiello et al., 2025). All the soils are in particular featured by high porosity (n, 0.59–0.65) and low dry unit weight (γ_d, 9.05–10.80 kN/m³) (Table 1). Saturated hydraulic conductivity, determined through constant-head permeameter tests, ranges between $1.03 \cdot 10^{-6}$ and $8.03 \cdot 10^{-6}$ m/s. Layer A2 exhibits the highest saturated hydraulic conductivity, likely due to the abundant presence of pumice fragments within the soil matrix. The soils are characterized by a critical-state effective friction angle of 37°, which was determined through a direct soil shear test on undisturbed, saturated specimens (Vitiello et al., 2025). Such a value lies within the typical range reported for pyroclastic soils of the area (35°–39°).

Table 1. Mean soil physical, hydraulic, and mechanical parameters

Soil	Gs	n	γ_d (kN/m³)	K_{sat} (m/s)	φ' (°)
A1	2.67	0.65	9.30	1.03E-06	37.0
A2	2.69	0.59	10.80	8.03E-06	37.0
C1	2.74	0.64	9.05	4.14E-06	36.7

2.2 Vegetation analysis

Above-ground vegetation was analyzed through phytosociological and dendrometric surveys to detect species composition, structural characteristics, and related temporal variability. Below-ground vegetation was performed to evaluate the spatial distribution of roots along the soil profile at depths of 20, 40, and 60 cm.

Phytosociological surveys were conducted in both forested and deforested areas, with three plots of 5 meters in diameter randomly selected in each, using the Braun-Blanquet method (1932). Comparison of structural data between the two sites reveals significant differences for most measured parameters (Fig. 2). The forested area is characterized by four distinct vegetation layers: trees, shrubs, herbs, and litter. This area consists, in particular, of a plant community dominated, in both tree and shrub forms, by holm oak (*Quercus ilex*). The shrub layer is also associated with myrtle (*Myrtus communis*) and *Smilax aspera*. While the structure of the holm oak forest shows no appreciable evolution over time, the deforested area is undergoing a pioneering secondary recolonization phase, characterized by a straightforward dynamic process of vegetation recovery. Consistent with recolonization patterns, a significant increase in the herbaceous component over time is evident in that area, contributing to a substantial reduction in bare soil. The dominant species in the deforested area are the herbaceous *Galactites tomentosus, Dittrichia viscosa, and Bituminaria bituminosa*, usually growing in arid and disturbed environments.

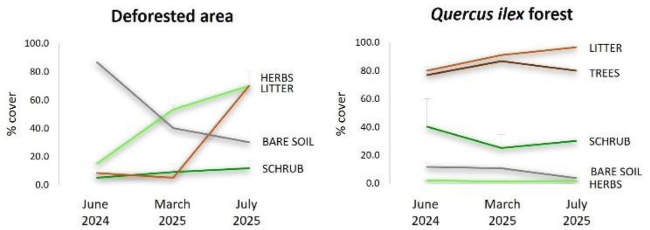

Figure 2. Pattern of structural parameters of the study stand

Dendrometric analysis of the holm oak forest structure (Tab. 2) highlighted a moderate density of stems per sampling area, well-differentiated vertical stratification, and canopy depth, parameters responsible for rainfall interception.

Table 2. Mean±st.dev. values of dendrometric parameters in Quercus ilex forest

Parameter	Trees layer	Shrub layer
no. of stems	13±2	13±8
total height [m]	7.7±1.1	3.5±0.8
stem diameter [cm]	7.3±1.1	2.0±0.3
height crown insertion [m]	2.1±0	1.0±0.2
crown depth [m]	5.6±1.1	2.5±0.9

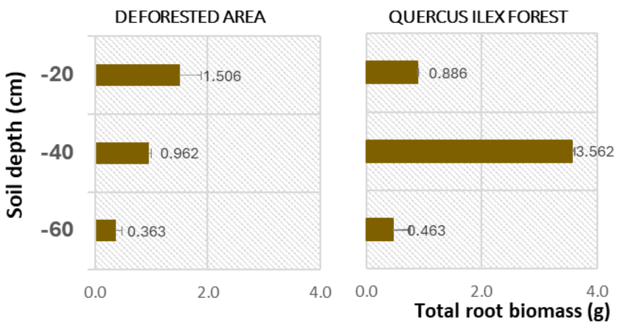

Figure 3. Mean + st. dev. dry weight values of total root biomass along the soil profile.

Root spatial distribution was detected using soil samples of 360.8 cm³ in volume, which were dehydrated and sieved through different mesh sizes ranging from 0.25 to 2 mm. The total root amount (Fig. 3) indicates that the distribution of root biomass along the profile differed significantly between the two study sites. In particular, the classic so-called heart-shaped distribution was observed in the forest profile, with a greater presence of root biomass at a depth of 40 cm. In the deforested area, the greater biomass was recorded in the 20 cm layer. This is due to both the alteration of the soil horizons caused by the removal of tree cover and the presence of herbaceous species with shallow fasciculate root systems.

2.3 Monitoring station

Within the study area, two monitoring stations were installed to investigate the slope hydrogeological behaviour for both the deforested and forested sites (Fig. 1c). Specifically, a total of six pairs of TEROS-10 and TEROS-21 sensors (METER Group) were installed on 31 January 2025 to measure soil moisture content and suction respectively at the depth of 15, 30 and 60 cm in the deforested test site, and of 15, 35 and 60 cm depth in the wooded test site (Fig. 1b). All the sensors were calibrated on the volcanic soils of the Campania Region through experiments conducted over the past decades. All measurements are acquired every 5' by a datalogger powered by a solar panel and equipped with a GSM telemetry device that sends the data to an online repository every 60'. Rainfall data are also registered by a rain gauge installed in the deforested site. Moreover, air temperature and relative humidity are measured at two pairs of sensors installed at both investigated sites, starting from 17 March 2025.

3 FIELD MONITORING DATA

Figure 4 shows field measurements from January 31, 2025, to May 15, 2025. Figure 4a highlights that vegetative cover acts as a thermal attenuator, reducing the hourly air temperature in the wooded area by approximately 5°C on average. At the same time, the hourly air relative humidity in the forest is on average 2% higher than in the deforested site. Figure 4b primarily points out that the short-term rainfall-induced increases in soil moisture content are consistently higher in the deforested area. Considering the surface runoff amounts not relevant in both plots due to the presence of the shallow herbaceous component, this result clearly indicates that the multi-layer vegetation system covering the wooded area intercepts part of the rainfall, thereby reducing the corresponding infiltrating amount. Additionally, the presence of vegetation slows down the infiltration process, as indicated by the delayed response in the forest. The two effects are consistently observed at all three depths.

The sudden increase in matric suction observed in May at both sites (Fig. 4c), particularly sharp at the depth of 15 cm, was due to several factors: the absence of significant rainfall events, higher temperatures, and higher solar radiation. The not correspondingly high soil moisture reduction can be associated to quite flat flow paths in the water retention plane.

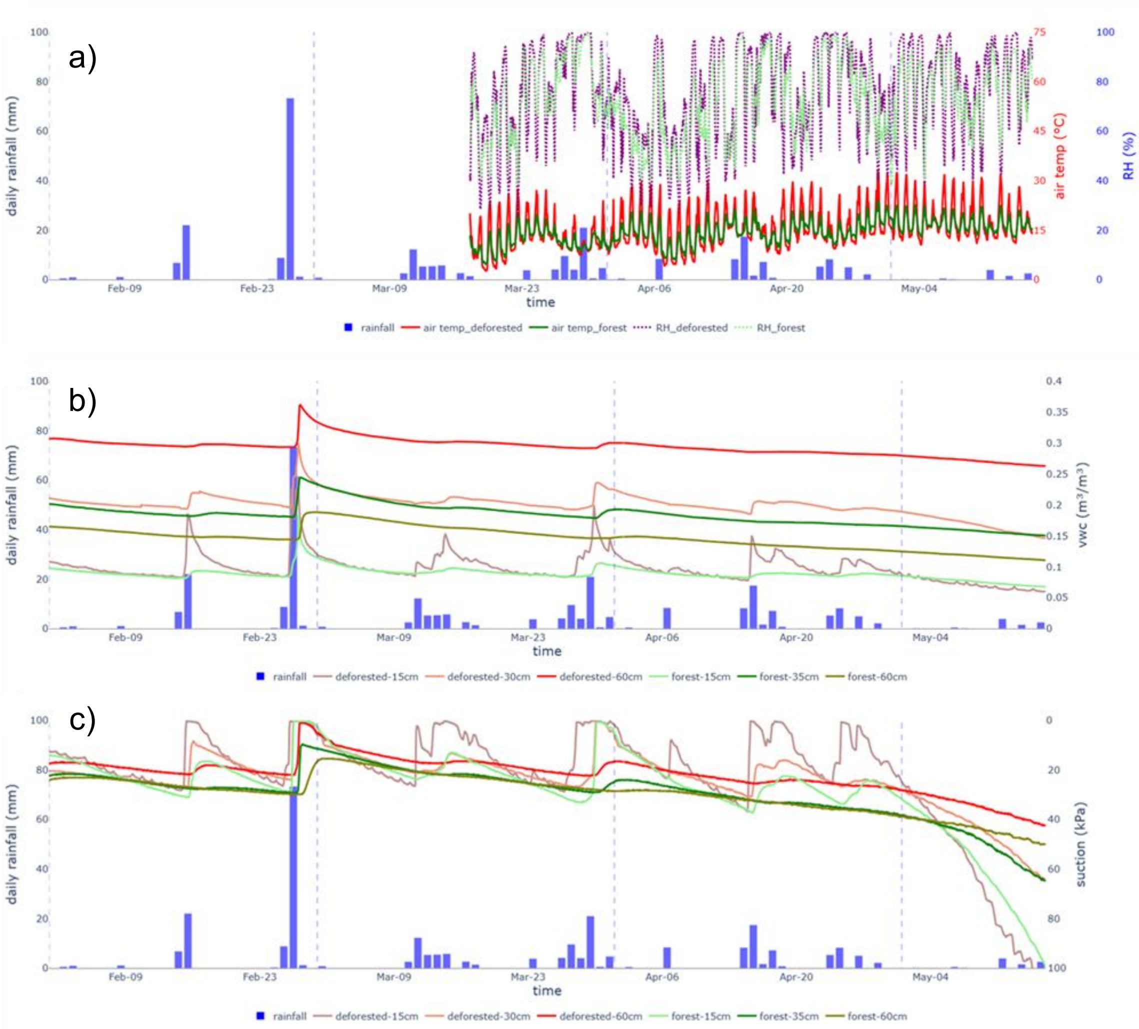

Figure 4. Field measurements of volumetric water content (a), suction (b), air temperature, and relative humidity (c) compared to the daily rainfall registered by the rain gauge from 31 January 2025 to 15 May 2025

4 CONCLUSIONS

An experimental field was established to investigate the influence of vegetation on the hydrogeological behaviour of a pyroclastic slope. Field monitoring clearly demonstrated the contrasting responses of forested and deforested plots. The forested area showed reduced and delayed increases in soil moisture due to rainfall interception by the canopy. In contrast, the deforested site exhibited faster and larger variations in suction and water content. These results confirm the key role of vegetation in modulating rainfall infiltration, which may affect the stability of pyroclastic slopes.

5 ACKNOWLEDGEMENTS

This research has been supported by MUR PRIN 2022 PNRR Program (prot. P20223WY2L).

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